NORGES VASSDRAGS- OG ELEKTRISITETSVESEN

SELECTION OF NORWEGIAN GLACIER MAPS

Distributed at the

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on Glacier Mapping and Surveying

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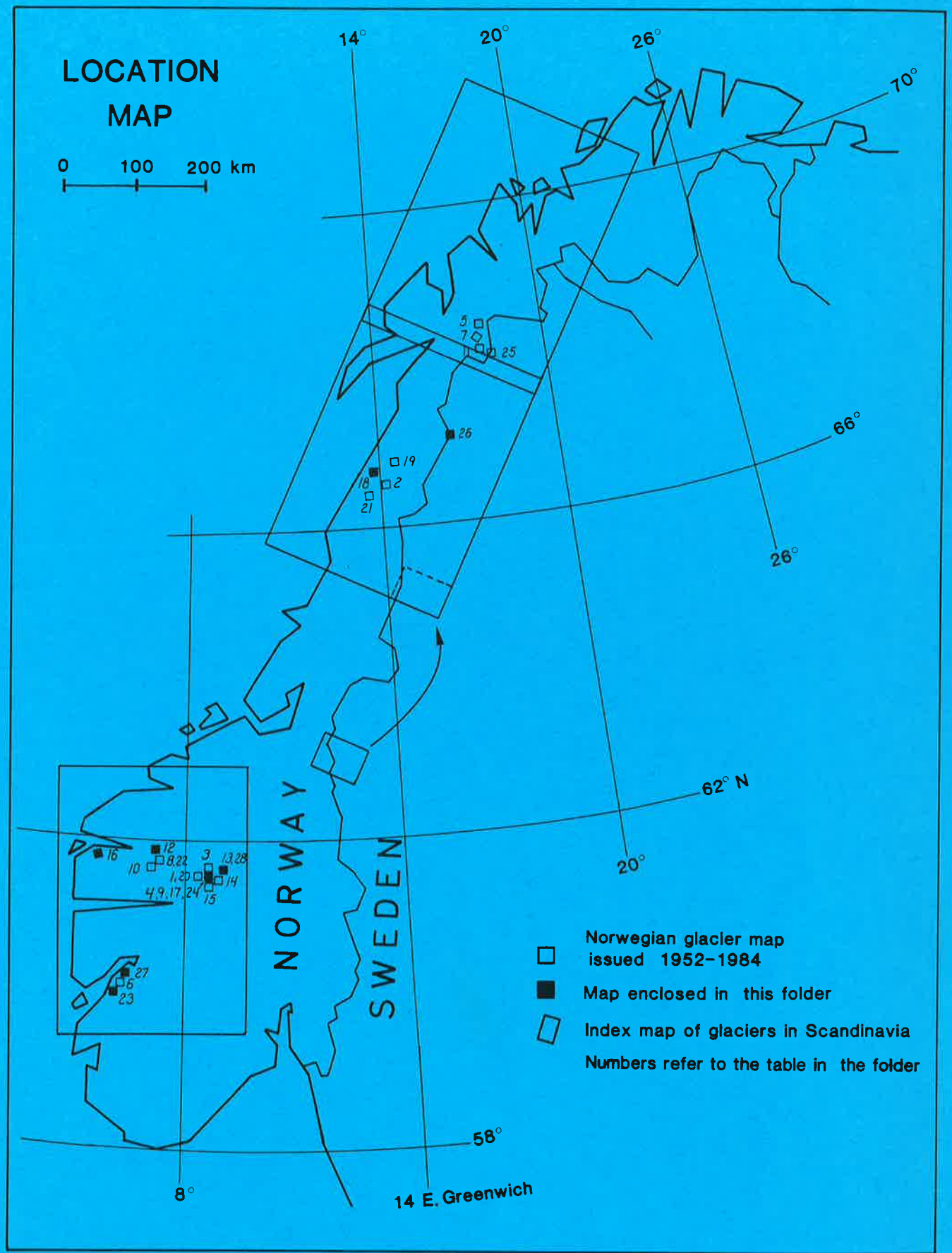

LOCATION MAP
0 100 200 km
14°
20°
26°
70°
66°
26°
62° N
20°
58°
8°
14 E. Greenwich
NORWAY
SWEDEN
Norwegian glacier map issued 1952-1984
Map enclosed in this folder
Index map of glaciers in Scandinavia
Numbers refer to the table in the folder

BONDHUSBREEN

PART OF FOLGEFONNI
SOUTHERN NORWAY

1 : 10 000

0 — 1 km

Contour interval 10m on glacier, 20 m elsewhere

LEGEND

- Triangulation point (NGO)
- Triangulation point (NVE)
- 1431 Spot elevation
- Forest
- Moraine ridge
- Morainic debris
- Water divide
- Crevasses
- Large rock
- Discharge station
- Diversion dam
- Cabin or house

COORDINATE SYSTEM: Geographical Coordinates (Greenwich) and UTM zone 32 (in outer frame)

Air photography by Fjellanger Widerøe A/S, 11 August 1979,
(flying height 6100 m a.s.l. Contract No. 6095).
For a small shadowed area below the glacier, older photos
were used: Widerøes Flyveselskap A/S, 10 August 1959
(flying height 6300 m a.s.l. Contract No. 1061).
Plotted by B. S. Haga, Fjellanger Widerøe A/S.
Drafted by B. Hansson, Dept. of Physical Geography, Univ. of Stockholm

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
1979

Trykk: Sekkelsten & Sønn a.s

BRIEF COMMENTS ON THE MAP

The compilation of this glacier map, covering a part of the Folgefonni icecap in southwestern Norway, was based upon air photographs taken for this purpose on August 11, 1979, by Fjellanger Widerøe A/S. The photography was planned to cover the entire drainage basin of the river discharging into the Lake Bondhusvatn and this intention was completely fulfilled. However, it proved difficult to perform stereo compilation in a small area below the ice tongue due to insufficient illumination. This shadowed area was, however, clearly shown on a photo coverage from 1959, so a stereo-pair from this older photography was used for contour compilation in this particular area.

The plotting of the map was made solely for the purpose of making a glacier map. Consequently, certain features could be emphasized already at the compilation stage. All larger crevasses are directly depicted on the map as thin lines, whereas wide, deep openings are marked by a heavier line or a lense-formed area indicating the size and shape of these holes in the glacier surface. Note, however, that all the plotted crevasses may change their size and position from time to time. Extremely heavily crevassed areas on the tongue were given a particular pattern, as single crevasses could not be marked individually. All triangulation points, which are used for glaciological field work, were plotted as well as large and/or predominant rocks. The border line between ice-free areas and the glacier (or snow patches) was plotted with a minimum of generalization. A brown colour was used to indicate areas of «bare ground» at the time of photography.

The scale of 1 : 10 000, which was recommended for glacier maps at the International Symposium on Glacier Mapping held in Ottawa, Canada, in 1965, and the recommended contour interval 10 m, could be used. The Universal Transversal Mercator grid net, Zone 32, is marked in the outer frame, whereas Geographical coordinates are shown on the map as tick-marks.

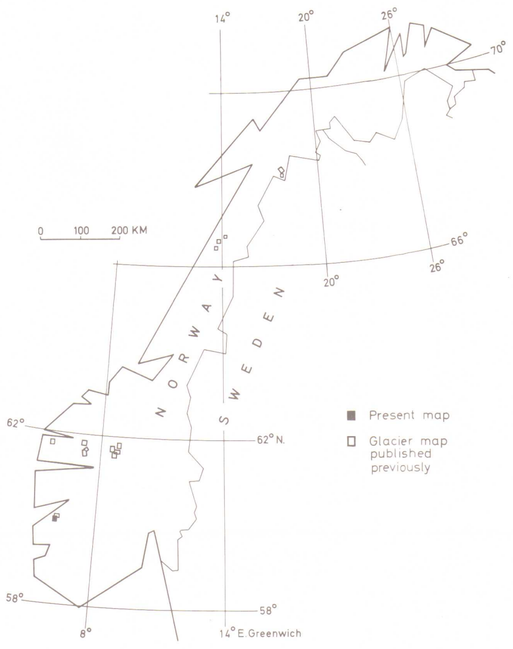
A number of triangulation points were used in the construction of this glacier map. Some of them are established by the Norwegian Geographical Survey (NGO) and some are established and surveyed by NVE. These well-marked survey points on the ground were used for orientation of the stereo-models in the B-8 plotter. However, it was desirable to improve ground support for the models in the upper part of the glacier, i.e. in areas where no bedrock is visible, and, consequently, where no survey points are established. To overcome this problem it was decided to mark selected points on the glacier surface (some of the main ablation stake positions were used for this purpose). These marks were kept visible throughout the summer by a thin layer of powdered dye until the air photography was completed. The accurate position of them was repeatedly surveyed and it is assumed that their coordinates at the time of photography were accurate within a fraction of a metre. All these marks could be easily identified on the verticals, see examples shown below. They proved to be an important aid for the stereo-operator, but they were not plotted in the final map.

It is assumed that the plotting accuracy of this map is better than 3 m in both horizontal and vertical direction. For single points, e.g. rocks etc. the accuracy is better. The relative accuracy (between points within the map area) is better than 2 m.

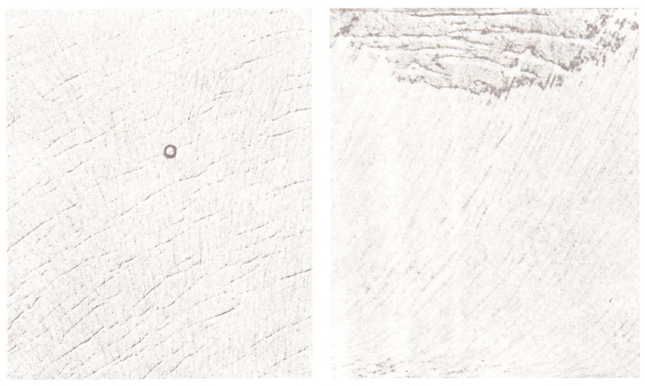
A topographic map of Folgefonni and its immediate surroundings was produced by Norges Vassdrags- og Elektrisitetsvesen (NVE) in 1959. A part of this map was enlarged to the scale of 1 : 10 000 and it formed a base for glacier studies during the years 1963 to 1968. For the location of this map and previously published glacier maps in Norway, see the location map below.

The production of this map was organized through the Hydrology Division within the Norwegian Water Resources and Electricity Board (NVE). The Western Norway Hydroelectric Power Plants (NVE-Vestlandsverkene) and the Building Division of the State Power System contributed financially, whereas the final drafting was made at the Department of Physical Geography, University of Stockholm.

G. Østrem



Location map showing areas covered by detailed glacier maps produced and published by NVE. More complete maps of all existing glaciers are found in the glacier inventory publications: Østrem & Ziegler (1969) and Østrem, Haakensen & Melander (1973).



Left
One of the temporary survey points in the upper firn basin, as seen on an air photograph. The mark was made by dusting a 0.5 m wide ring, 6 m in diameter, on the snow surface.

Note the crevasses and the melt features on the snow surface. These slightly darker stripes are always running at a right angle to the contours.

Right
The special melt features on the snow surface are well detectable on most of the verticals. They always indicate the slope direction, and may be an aid in determining local «water divides» on the glacier surface. Note, however, that such features do not necessarily coincide with subglacial drainage patterns.

The small settlement Sundal (at Mauranger Fjord, an arm of the Hardanger Fjord) and the valley Bondhusdalen. The icecap Folgefonni and the outlet glacier Bondhusbreen in the background. A recently uncovered area (since 1940) can be clearly identified. (Photo Fjellanger Widerøe 42939).

GLACIER VARIATIONS DURING RECENT YEARS

It has been assumed that Norwegian glaciers in general had their greatest extent about 1750 and that no greater advance has occurred since then. However, for parts of the icecap Folgefonni this does not seem to be the case. In several places signs are found, indicating that the largest extent was reached in the last part of the 19th century. The southern part of the icecap has now a size and areal extent which seems to coincide with the maximum extent during historical time (Tvede & Liestøl, 1977). The following information is, in general, taken from Tvede (1972), whereas data from the front variations have been supplied by Norsk Polarinstitutt.

In the case of Bondhusbreen it has been assumed that a large amount of big rocks resting just outside the moraine ridges marked on the map must have been deposited by the glacier during the 1750 advance (Rekstad, 1905). However, Tvede (1972) proposes that these rocks are possible remnants from an old rock fall originating on the east side of the valley, possibly influenced by a postglacial, relatively large Bondhusbre.

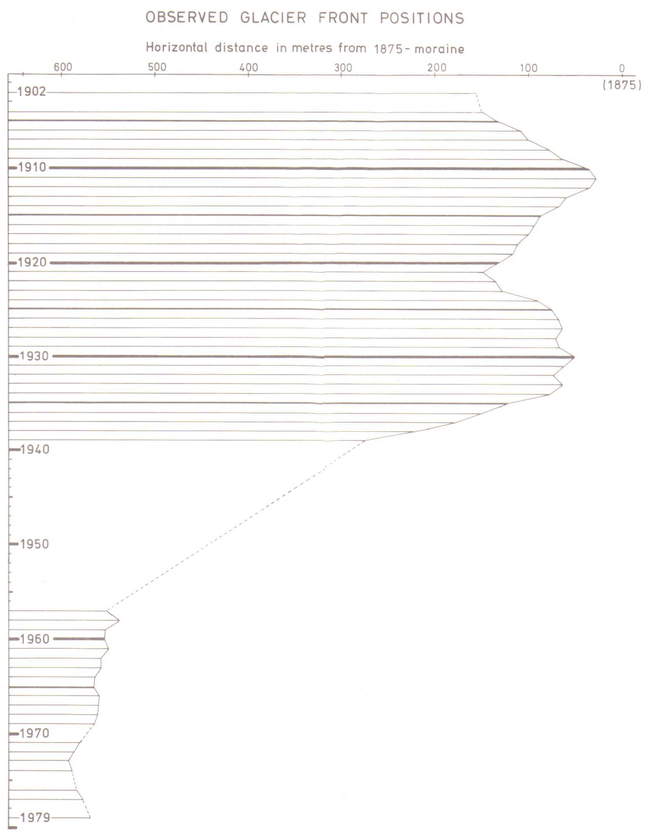
A local inhabitant in the area, Lars K. Bondhus, has told (Tvede, 1972) that his grand-grand-father could remember that threes were growing on the plain in front of the glacier until the ice pushed forward and covered the plain.

An early written description of the glacier was given by Sexe (1864) who visited the area about 1860. He does not describe details which can be used to locate the front position at that time, but he made a sketch which indicates that the ice front covered most of the plain mentioned above. Rekstad (1905) says that the outermost of the 3—4 arch-formed moraines was a result of a glacier advance between the years 1865 and 1875. Some other moraine ridges which are situated very close to the outermost one must have been formed in the 1880-ies and 1890-ies. (These ridges are not shown on the map due to scale limitations). He also says that a photograph taken by K. Knudsen (probably in 1891, see below) shows a greater glacier extent than on a photograph taken in 1869. On Knudsen's photograph it is quite clear that the ice front is situated just at the outermost ridge.

Rekstad made some measurements of the ice front and he says that it had retreated about 150 m from the 1875 moraine (the outermost one) in the year 1904. Since then, routine observations have been made of the front position and the data are plotted in the diagram shown below. From this diagram it is obvious that the glacier has advanced markedly during two main periods, with maxima in 1911 and 1930. These two advances may have formed the two innermost end moraine ridges.

A period of very rapid retreat occurred during the 1930-ies and the 1940-ies. Unfortunately no measurements were taken during the 1940-ies due to practical difficulties. Then the glacier retreated up a very steep hill so that any measurements would have been uncertain and even dangerous to perform.

The lower part of Bondhusbreen has been photographed from almost the same point by various photographers: K. Knutsen 1891, J. Rekstad 1904, and O. Liestøl 1971. Comments on the glacier variations are given in the text.



Glacier front observations have been made by various institutions and individuals, and different bench-marks have been used. Norsk Polarinstitutt has collected all available information in this respect, and this diagram was then constructed at the Glaciology Section within NVE. The connection between observations made in various periods proved difficult, but the inaccuracy in joining these observation series is regarded less than about 20 metres.

VARIOUS INFORMATION ON FOLGEFONNI

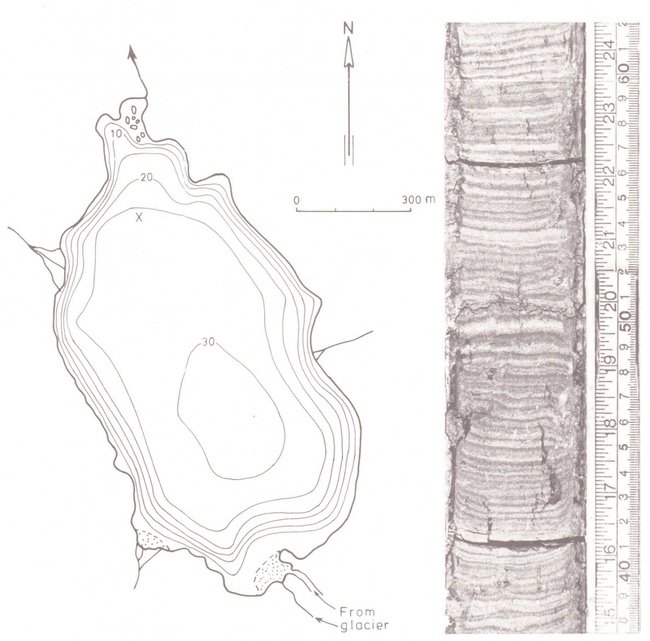
In historic time it has been reported that local people quite often walked across the icecap Folgefonni to visit people and the church on the other side. (Hoel & Werenskiold, 1962, p. 82—85).

From the beginning of the 19th century the first tourists started to cross the glacier. The number of tourists increased steadily and culminated about 1860—1890. To serve the present day requirements, the Bergen Tourist Association has built a small, self-service tourist cabin (Fonnabu) in the area.

Not only the tourist traffic gave the local people some income. Ice from Bondhusbreen was also sold abroad — the first ship loaded with glacier ice travelled to Scotland in 1822. To facilitate the transportation from the glacier down to the fjord, a small road was constructed between Lake Bondhusvatn and Sundal (Hoel & Werenskiold, 1962 p. 99—104).

Further, from Bondhusvatn a track was made to facilitate the tourist traffic up to the glacier — it was in fact possible to travel on horseback onto the glacier and further over to the other side. The construction of this track was financed from Germany, it is told that the German Emperor Wilhelm II was the main donator.

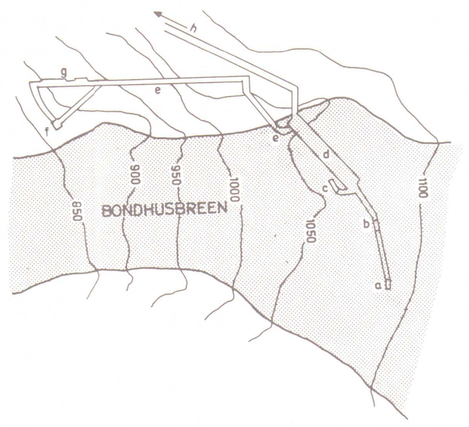
The economic importance of the glacier is even more pronounced today because the glacier provides water for a large hydro-electric power installation at Mauranger. Water from various parts of the icecap is diverted and collected in reservoirs through a system of tunnels and shafts. A gallery (an almost horizontal tunnel) has been constructed to collect water subglacially from the intake shafts in the bedrock under Bondhusbreen (just under the ice fall at 1100 m where the glacier is 150—170 m thick). This project has been very successfull and is of great interest both for engineers and scientists. Before, under, and after the construction period it has been possible to perform many scientific studies under the glacier, as well as at the front and on the ice surface. The ice velocity just above the intake is in the order of 30 cm per day whereas the movement along the bottom is less than 15 cm/day. Various observations could be made in the ice caves which were melted at the ice/rock interface to find the best places for intake shafts. Studies were made also of the sediment carried by the glacier stream, see below. Several other glaciological and hydrological investigations will be carried out in the future — the production of this map is a part of this work. A review of investigations made so far is given in Wold & Østrem (1979 a, 1979 b). A bibliography of older litterature is given in Hoel & Norvik (1962).



In the planning stage of the hydro-electric power station at Mauranger, various technical and scientific investigations were made.

One problem was to determine the annual sediment transport in the glacier stream without taking numerous water samples from the stream during a series of years. Only two melt seasons were available for sampling, so these seasons' result must be compared with previous years' sediment discharges into the Lake Bondhusvatn. The annual sediment discharge is more or less related to the thickness of annual varves on the lake bottom.

Several undisturbed bottom samples were taken by a Kullenberg piston corer, a section of one of these samples is shown above — the sampling location for it is plotted (x) on the map. Annual deposits back to about 1895 were identified in most of the cores, and a good statistic was obtained for variations in sediment discharge into the lake. On an average some 6000—7000 metric tons of suspended sediment are carried annually by the glacier stream. Note that depths are shown in metres on the map above.



Sketch showing the main subglacial tunnel system: *a, b* and *c* are intake shafts, *d* is the sedimentation chamber, *e* the unloading tunnel, *f* the helicopter landing platform, *g* workshop, *h* the diverting tunnel leading water to the main reservoir.

Photograph taken in one of the artificial ice caves along the glacier bottom. The rocks are resting on bedrock. Note, however, a large embedded rock in the roof. The «walls» consist of clear glacier ice.

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MIDTRE FOLGEFONNI

South Norway

Scale 1:10 000

0 1 km

Contour interval 10 m on glacier and 100 m elsewhere

COORDINATE SYSTEM: UTM, Zone 32

Heights in metres above sea level

Air photography by Fjellanger-Widerøe A/S, 8 August 1981
(Flying height 5300 m a.s.l., Contract No. 7016)

Plotted by B. Fagerlund. Drafted by S. Bergfeldt.

LEGEND

Glacier outline

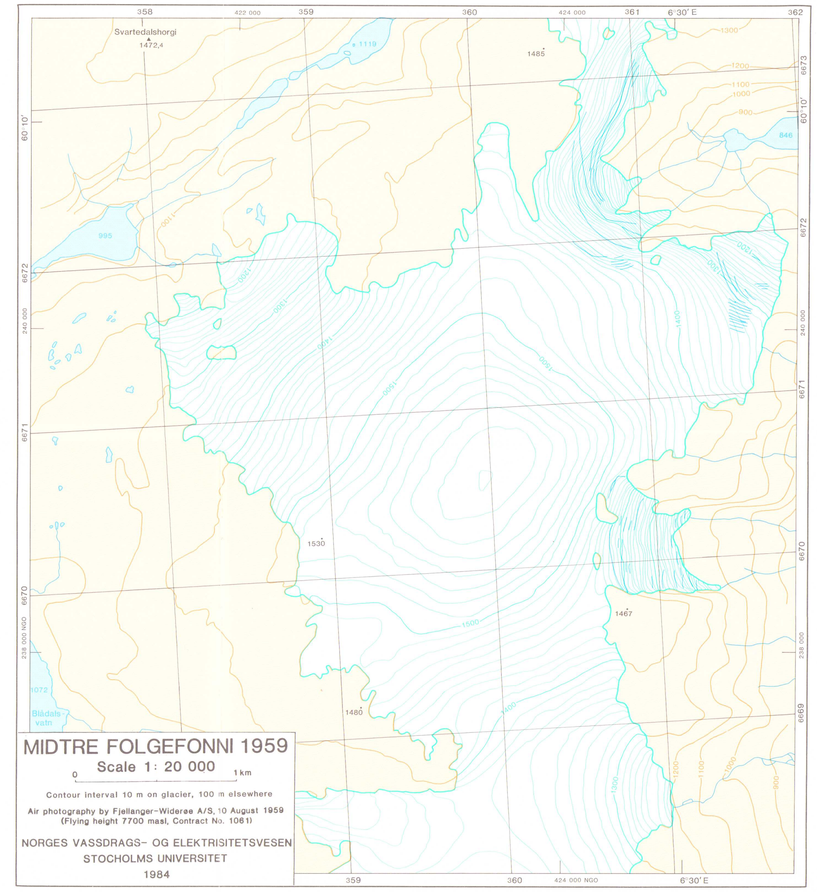
Crevasses

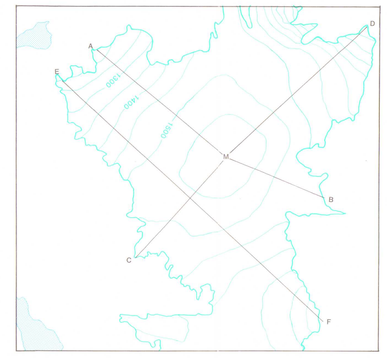
▲1472,4 Triangulation point, with height

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN

STOCKHOLMS UNIVERSITET

1984

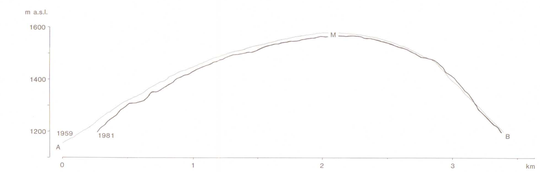


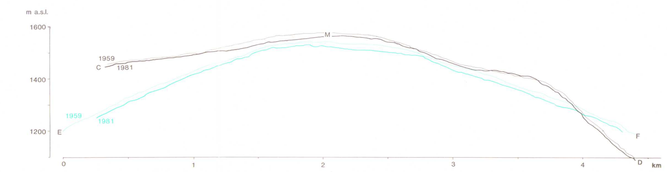


The illustration to the left shows the glacier outline in 1959 and some profiles which have been drawn on both maps to find the vertical displacement of the glacier surface between 1959 and 1981. For practical reasons it was decided to draw some of the profiles from the highest point of the icecap down to the termini of glacier tongues draining in various directions. Some of these profiles are plotted below to visualize the general lowering of the glacier surface. It can be seen that the outlet glaciers draining towards NE and E has not undergone the same general mass loss as the rest of the glacier, compare further comments on the reverse.

The average vertical mass loss for the selected part of Midtre Folgefonni amounts to 9,6 m water equivalent from 1959 to 1981. In total, $85 \cdot 10^6 m^3$ "extra" water has been delivered to adjacent rivers by this general negative mass balance. Expressed in specific figures this corresponds to 14 l/s km^2 extra water given to the streams draining from the icecap. The general specific discharge in the area is in the order of 120-140 l/s km^2. This means that the glacier has added about 10% extra water to the normal annual water yield during these 22 years. A more detailed analysis of the mass balance of Midtre Folgefonni is given on the reverse.

Some details concerning the map constructions etc., as well as location map and other relevant data are also given on the reverse.





LOCATION MAP

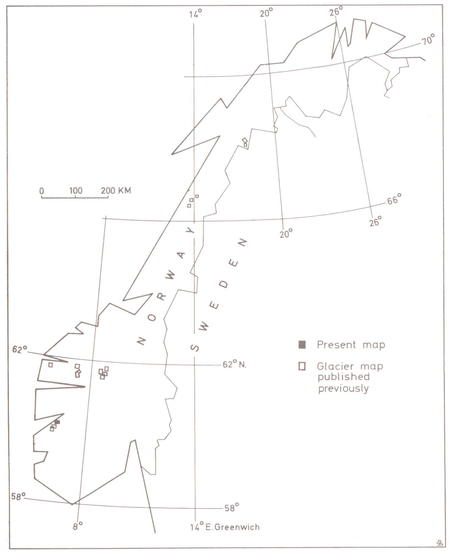


Fig. 1 Location map showing the areas covered by detailed glacier maps produced and published by NVE since 1962.

BRIEF COMMENTS ON THE MAPS

The two glacier maps, printed in four colours, are a result of a cooperation between the Department of Physical Geography at the University of Stockholm and the Norwegian Water Resources and Electricity Board (NVE).

Already in the 1950-ies plans were made to construct a hydroelectric power producing system near the icecap Folgefonni in southwestern Norway. For the planning of this power scheme it proved necessary to take air photographs of the icecap and adjacent areas to construct detailed maps. These maps were later used in the engineering work connected to dam sites, diverting tunnels, etc. All the three separate icecaps having the common name «Folgefonni» was also mapped at this occasion. The 1959-map of the glacier, printed on the front side of this publication, is a redrawn version of that map. Note, however, that the present map comprises only the middle part of Folgefonni (named Midtre Folgefonni).

The total surface area of the three separate icecaps is 212 km^2 whereas Midtre Folgefonni covers only about 13 km^2. However, for the study of the hydrological consequences of glacier variations in this area it is thought that conditions found at this small icecap is fairly representative for the entire drainage basin to the hydro-power scheme named Folgefonnverkene.

In 1981 another air photography was made in this part of the country and it was decided to construct a new glacier map at the same scale and with the same contour intervals as the 1959-map to make possible a calculation of the net glacier changes within the intervening 22 years (1959-1981).

The glacier has been photographed at many more occasions and at various scales, but for the construction of this glacier map we selected the 1981-verticals which covered the entire Midtre Folgefonni. Further, the photographs were of high quality and suitable for map construction of the glacier surface. This means that the surface must be identifiable on the photographs which, in turn, means that most of the last winter's snow should have melted away or have become «dirty» by dust etc. Then the operator working at the stereo-plotter will be able to draw contour lines with a reasonable accuracy.

The photographs taken in 1959 were, in this respect, very well suited for map construction (negative scale 1 : 40 000) because they were taken in August after a fairly hot summer so that much of the icecap was almost snowfree. The photographs taken in August 1981 were also of a high quality (negative scale 1 : 30 000) with the glacier surface clearly shown. However, in contrast to conditions in 1959 nearly all of the glacier surface was still snow covered in 1981, but the snow surface consisted of old snow with some ablation rills, small exposed ice surfaces, etc. Therefore, it was possible to find sufficient «micro-topography» in the snow-covered areas and, hence, the glacier surface was well defined on the photographs used for construction of the map.

In several places cracks, crevasses and foliation patterns are visible on the glacier surface. This applies particularly to the 1959-photographs, see the reproduction in the lower right corner.

The compilation of the 1981-map was made for the sole purpose of determining the change in ice volume since 1959. Great care was therefore taken to adjust the stereo model to obtain identical heights for spot elevations within the map area. In both cases a Wild B-8 stereo-plotter was used. In the first case the map construction was made by the Widerøe Flyveselskap A/S in Norway (on contract from the Norwegian State Power Board) whereas the 1981-map was constructed at the Department of Physical Geography at the University of Stockholm. The accuracy in *relative* height within the model is thought to be better than one meter for both map constructions. The horizontal plotting accuracy for single points is thought to be 1-2 m in both cases.

The *absolute* height determinations are thought to be slightly less accurate due to lack of a dense triangulation network. However, as mentioned above, the second map construction was adjusted so that the terrain outside the glacier should be shown as identical as possible on both maps. Consequently, the variations in glacier thickness could be measured as a difference between surface elevations shown on the two maps.

The border lines between glacier areas and snow fields in 1981 was difficult to determine in some areas. To decide where this border line should be drawn, it was necessary also to use information from field trips and vertical photographs from other years.

The first International Symposium on Glacier Mapping, held in 1965 in Ottawa, Canada, recommended the scale of 1 : 10 000 and a contour interval of 10 m for glacier maps. The present maps were constructed accordingly but, for practical reasons, the 1959-map was reduced to the scale of 1 : 20 000. The contour interval is, however, 10 m on both maps. It has also been recommended to use the Universal Transverse Mercator grid net on glacier maps. Consequently, this net is drawn on both maps (Zone 32). However, for practical reasons, the local Norwegian rectangular net used by the Norwegian Geographical Survey (NGO, Zone 1), is marked in the frame by X and Y coordinates for each km, whereas geographical coordinates for 6° 30' East Greenwich and 60° 10' North latitude are shown by tick marks in the frame.

The final drafting of the maps was made at the Department of Physical Geography at the University of Stockholm but financial support for the printing was given by NVE. Without the close cooperation between these two institutions it would have been impossible to produce this publication.

For the location of the map area and for previously published glacier maps, see the location map in the upper left corner. Note: Some of the older glacier maps are no more available or very difficult to obtain.

Gunnar Østrem

GLACIER VARIATIONS, MASS BALANCE AND SNOW DISTRIBUTION ON MIDTRE FOLGEFONNI

Midtre (the Middle) Folgefonni is the smallest of the three Folgefonni icecaps. The total area of Midtre Folgefonni is 12,6 km^2, measured from the maps constructed from the 1959 air photographs, whereas Søndre (Southern) Folgefonni is 172 km^2 and Nordre (Northern) Folgefonni is 27 km^2. A summary of the recent glacier variations of Folgefonni in general together with various information on Folgefonni are given on the reverse of the glacier map «Bondhusbreen», published in 1979. References to some of the most relevant works on Folgefonni are given in the literature list below.

The main part of Midtre Folgefonni, shown on the maps on the front side, forms a regular dome-shaped icecap with four small tongues draining in separate directions. The drainage areas are roughly equal for the southfacing, the northwestfacing and the northeastfacing tongues, whereas the eastfacing tongue is draining a smaller area. The total glacier area of these four tongues was 8,7 km^2 in 1959, the rest of Midtre Folgefonni are «ice aprons» to the north and south of the icecap.

Mass balance measurements were carried out on Midtre Folgefonni for the two balance years 1969-70 and 1970-71 as part of a thesis in Geography at the University of Oslo (Tvede, 1972). The mass balance measurements were done by the traditional methods. The winter balance was calculated from 460 snow depth soundings evenly distributed over the glacier surface and the summer balance was measured on 14 stakes. The winter balance distribution for 1971 is presented in Fig. 5. The snow distribution is rather uneven and reflects the influence caused by wind transport of snow combined with the topography of the glacier.

This snow distribution pattern was analysed more closely by Tvede (1973). The overall pattern was the same both winters, but the snow was more unevenly distributed in 1970 than in 1971. This was explained by the fact that most of the snowfalls during the winter 1969-70 came before January. The wind distribution processes continued for the rest of the winter with only small supplies of new snow. During the winter of 1970-71 the snowfalls came more regular through the whole winter season and some mild spells formed ice layers on the snow surface and this prevented some of the wind drifting.

The two balance years were climatically rather different. The year 1969-70 had a dry winter and a warm summer and hence the net balance was negative. In 1970-71 the winter was wet and the summer was cold, the result was a positive net balance. However, the mean climatic values for these two balance years came out very close to the average values for the 1931-60 period with regards to winter precipitation and summer temperature. It is therefore belived that also the mean mass balance values for these years were close to the «normal» values. In the table below these values are presented, both individually for the four drainage areas and for the icecap as a whole. The mass balance measurements indicates an average annual precipitation of 3700 mm on Midtre Folgefonni, but runoff measurements give values as high as 4400 mm per year.

Midtre Folgefonni. Mean balance values for 1969-71.
Spesific balance values in metres of water equivalent.

	Southern	North-western	North-eastern	Eastern	Whole icecap
Winter balance	2,13	2,11	2,31	2,38	2,20
Summer balance	2,43	2,37	2,14	2,32	2,33
Net balance	-0,30	-0,26	0,17	0,06	-0,13
Height of equilibrium line m a.s.l.	1580	1475	1425	1355	1460

Taking into consideration the uncertainties involved in the mass balance measurements, it may be correct to say that the icecap as a whole was close to an equilibrium state in 1969-71. Looking at the individual drainage areas does however reveal some differences. The southfacing and the northwestfacing areas had negative net balance while the northeastfacing and eastfacing areas had positive net balances. The height of the equilibrium line was higher than the highest point for the southfacing area, but as low as 1355 m for the eastfacing area. As an average the equilibrium line was 1460 m a.s.l., which means that exactly half of the glacier area was above and the other half below this line.

The volume changes from 1959 to 1981 are calculated from the contour lines on the two maps. The calculations are based on four profiles drawn across the icecap, three of these profiles are presented on the front side. The vertical displacement of the glacier surface is measured for every 50 meter along these profiles and the corresponding water equivalent is calculated. This was made by taking into consideration, at every single point, whether the glacier surface was ice or firn. In this way the net balance from 1959 to 1981 was calculated for 325 points. Based on these individual points, isolines for net balance values were drawn as shown in Fig. 2. This map was planimetrated and the net balance for each of the four areas and for the whole icecap calculated. The results are presented in the table below.

Net balance values and area changes 1959-81.
Specific balance values in metres of water equivalent.

	Southern	North-western	North-eastern	Eastern	Whole icecap
Net balance	-10,3	-15,2	-4,9	-0,9	-9,6
Mean value m/year	-0,47	-0,69	-0,22	-0,04	-0,44
Mean value in l/s·km^2	-15,0	-22,0	-7,0	-1,0	-14,0
Areal change in km^2	-0,07	-0,35	-0,04	-0,03	-0,49

The results indicates surprisingly large differences in net balance values between the four draining areas. The Southern and particularly the Northwestern areas have suffered large losses while the Northeastern and the Eastern areas have had only a small negative net balance. Measured in volume, 51 % of the mass loss and as much as 71 % of the area loss, were suffered by the Northwestern area. Why have the loss of glacier mass been so unevenly distributed? There is no obvious answer to this question. It is, however, interesting to note that the net balance distribution from 1959 to 1981 have some similarities to the net balance distribution measured in 1969-71. For these two years the measurements indicate a net mass loss from the Southern and the Northwestern areas whereas the Northeastern and Eastern areas had a slight mass gain. The top point of the icecap also seems to have moved about 100 m to the northeast. An explanation may be that some changes have occurred in the dominating wind conditions, producing an increased wind drifting of snow out from the Southern and Northwestern areas. This can, in turn, be followed by an earlier exposition of the old glacier surface and hence lead to an increasing melting rate due to lower albedo.

In order to verify if such changes in the wind conditions really have occured, we have analysed wind data from two standard climate stations and from one radiosonde station. The radiosonde station is at Sola Airport and we have used the data from the 850 mb-level which corresponds fairly well with the altitude of Midtre Folgefonni. The two periods 1951-59 and 1960-79 are analysed. This is done to see if there has been some changes in the average wind directions from the first to the second period. We have calculated the frequency of winds from the Eastern and from the Western sector for all the observations with wind force ⩾ 4 Beaufort. Only the months with snow accumulation on the glacier is used (November-April). The data indicates that the total frequency of wind from the Western sector has increased circa 13 % from 1951-59 to 1960-79. Also at the standard climate stations (Hellisøy fyr and Utsira fyr) we find an increase in the frequency of wind from the Western sector for the same periods. The increase is, however, less significant than at the radiosonde station. Hence, these wind records indicates an increasing frequency of western winds for the period after 1959. This may in turn have increased the amount of snow drifting out from the Southern and Northwestern areas on Midtre Folgefonni.

Arve M. Tvede

VERTICAL SURFACE DISPLACEMENT FROM 1959 TO 1981

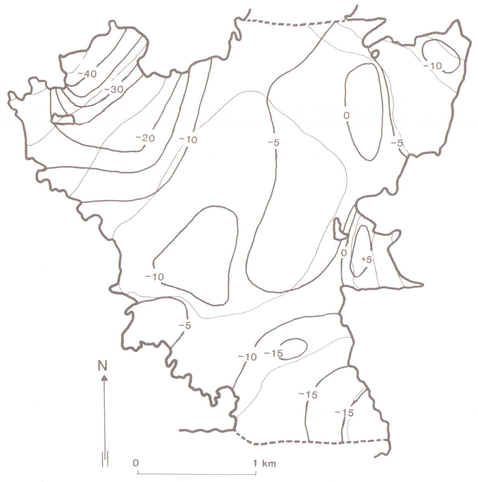


Fig. 2 The vertical displacement of the glacier surface for the period 1959-81 is shown as isolines for metres of water equivalent. The map is mainly based on the profiles shown on the front side. Comments on the net balance distribution are given in the text, see upper right.

Fig. 3 The Northwestern drainage area on Midtre Folgefonni was photographed on 10 September 1971 by Olav Liestøl, Norsk Polarinstitutt. Due to a cold summer most of the glacier surface was then still snow covered. This part of the glacier has undergone much larger mass losses in the period 1959-81 than other areas.

Fig. 4 The Southern, the Eastern and the Northeastern drainage areas of Midtre Folgefonni were photographed on 30 August 1969 by Olav Liestøl, Norsk Polarinstitutt. In contrast to the snow conditions on Fig. 3, nearly all the snow had melted in 1969 and the glacier surface consisted of exposed glacier ice or old firn.

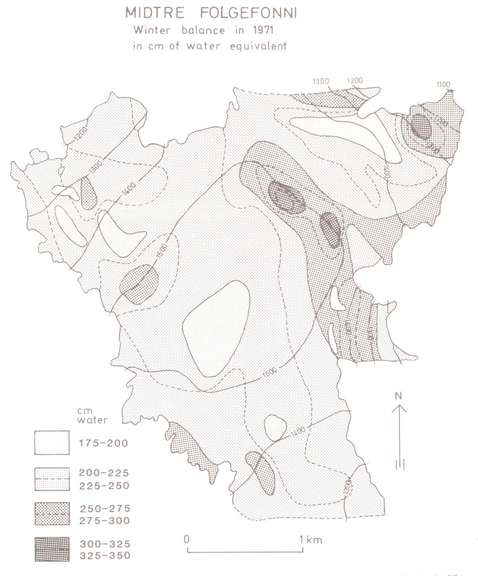


Fig. 5 The distribution of last winter's snow on Midtre Folgefonni as measured in April 1971. The snow depth is expressed in cm of water equivalent.

Trykk: Per Larsen & Co. -84
Repro: Kays Platekopi a.s

Fig. 6 Vertical air photograph taken on 10 August 1959 (Widerøe, Contract no. 1061, frame 88). The border lines between snow, firn and ice are clearly seen. The areas still covered by snow correspond well with areas where the heaviest winter snow accumulation is found, compare Fig. 5.

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ÅLFOTBREEN
(Nordfjord, Norway)

1:10 000

0 — ½ — 1 KM

Contour interval 10m

LEGEND

- △978,9 Triangulation point
- ·1096 Spot elevation
- Observation hut
- Limnigraph
- Moraine ridge
- Outwash
- Crevasses
- Snow-bank

COORDINATE SYSTEM: UTM ZONE 32

Magnetic north points 4° west of grid net on map in 1974

Air photography by Wideröes Flyveselskap A/S August 1968
Flying height 6200 m a.s.l.
Plotted in Wild B-8 by P. Vold in 1969

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
HYDROLOGISK AVD.
1969

STORE ÅSKÅRA

NEDRE BREVATN

323 000m. 322 000m. 324 325 326 5°40' E Greenwich

6853 6852 6851 6850 000m. 6854

61° 45'

Sekkelsten & Sønn - VI. 69

BRIEF COMMENTS ON THE MAP

The compilation of the glacier map of Ålfotbreen was based upon air photographs taken on 5th August 1969 from an altitude of 6200 m a.s.l. (Widerøe's Flyveselskap, contract No 3210, pictures F 10 — F 13).

The photography was originally done for the Norwegian Geographical Survey to form a base for a new, modern topographic map series (1 : 50.000) of this part of Southern Norway. The plotting, however, was made independently for the purpose of making a glacier map. This is contrary to what has been the case for many of the earlier glacier maps in the series. Consequently, particular glaciological features could be emphasized in the plotting procedure.

Crevassed areas are marked separately. Although the exact form and size of each crevasse is not depicted in detail, an attempt was made to plot the predominant directions of the crevasses. This is done by light green lines. There are generally not many crevasses visible on this glacier as the ice movement is relatively slow. At the end of summers with great ablation, crevasses may be found higher up on the glacier but in an average year crevasses are generally found only in the areas that are indicated on the map.

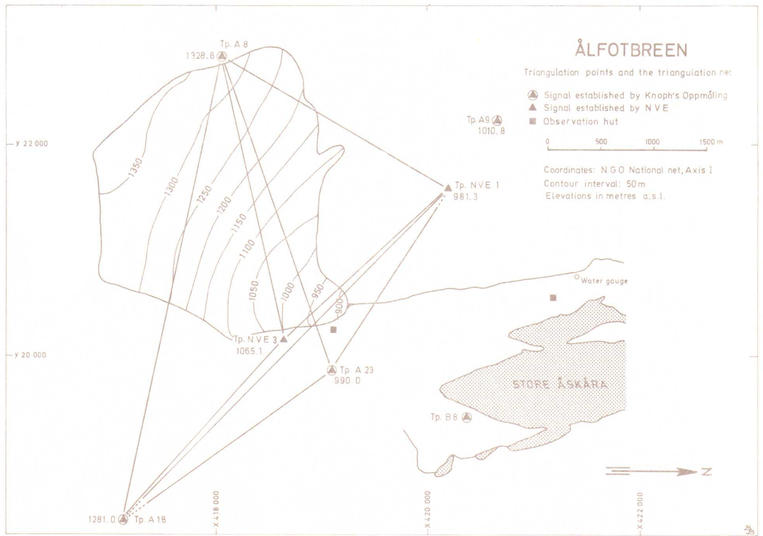
The border between ice free areas and the glacier or the snow patches were plotted with a minimum of generalization. To emphasize the ice free areas a brown colour was chosen to indicate «bare ground» as of the date of photography. Melt water streams were also plotted in great detail even in cases when they were very small. A number of predominant points on the ground as well as triangulation points in the local network were plotted on the map and their elevation given. This was made to facilitate navigation and triangulation work for movement studies etc. on the glacier.

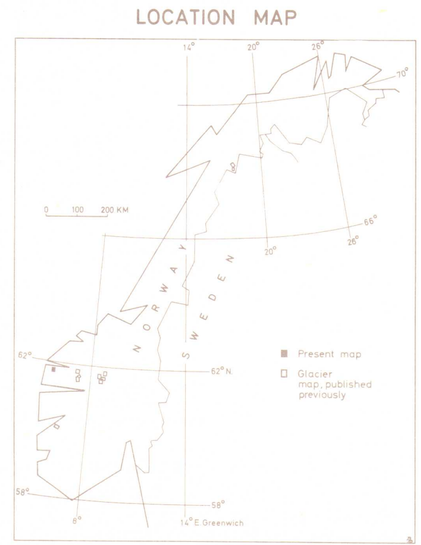
The accuracy is estimated to be better than 2 metres in relative height determination, better than 5 metres in absolute height determination. For spot elevations of single points it is better than 2 metres. The maximum error in horizontal determination is less than 5 m.

Note: The river discharge station was moved 350 m due south after that the map was constructed. The symbol for «Limnigraph» (plotted near the upper map frame) should therefore be moved accordingly.

The Universal Transversal Mercator grid net, Zone 32, is marked in the map frame for each 1000 metres. Geographical coordinates are plotted for one latitude (61° 45' N.) and one longitude (5° 40' E. Greenwich) on each map sheet. The location of all recent glacier maps in Norway is given on the index map.

For detailed triangulation work in the area it is recommended to calculate point coordinates in the Norwegian National Net (NGO Axis I) as the geodetic source material permits a higher degree of accuracy for the local triangulation net. For various technical reasons the UTM coordinates could not be given with the same degree of accuracy. The local triangulation net is shown on a sketch and the point coordinates are given in a separate table.





ÅLFOTBREEN

Point	Coordinates, national net NGO, Axis I		UTM coordinates Zone 32		Elev.	Height of Signal	X, Y og Z refer to:
	X	Y	X	Y	Z		
Tp. A 8	418 098.14	-22 809.76	6 851 500.13	321 663.59	1328.60	2.30	Centre of top of bolt under signal and cairn
Tp. A 8	420 708.45	-22 235.28	6 854 081.69	322 355.86	1010.80	2.00	"
Tp. A18	417 155.88	-18 449.92	6 850 363.75	325 972.70	1281.00	2.00	"
Tp. A23	419 118.09	-19 893.88	6 852 387.89	324 622.63	990.00	1.96	"
Tp. B 8	420 402.41	-19 459.01	6 853.650.25	325 115.15		2.00	"
NVE 1	420 217.35	-21 626.21	6 853 564.06	322 938.40	978.86	2.00	Centre of top of bolt under stake
NVE 3	418 601.94	-20 152.34	6 851 887.09	324 341.21	1063.53	2.00	"

GRÅSUBREEN

Jotunheimen, Norway

1 : 10 000

0 ½ 1

Contour interval 10m, with 5m contours on the endmoraine system.

LEGEND

- △ 1940,9 Triangulation point
- · 2000 Spot elevation
- ■ Observation hut
- Crevasses
- • Large rock

COORDINATE SYSTEM: UTM ZONE 32

Magnetic north points 4° west of grid net on map in 1974

Air photography by Wideröes Flyveselskap A/S August 1968:
Flying height 4300 m a.s.l.
Plotted in Wild B-8 by P. Vold in 1968

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
HYDROLOGISK AVD.
1968.

Ö GROTBRE

8°35' 478 479 480

477000m.

6838 6837 6836 6835000m

61° 40'

T1 △ 1986,4 · 2022 · 1973 · 1986 · 2044 · 1947 · 1937 · T2 △ 1940,9 · 1948 · 1854 · 1886 · 1761 · 1778 · 1752 · 1699 · 1728 · 1722 · 1743 · 1968 · 2006 · 2018 · T3 △ 2261,9 · 2222 · 2223 · 2259 · 2209 · 2182,0

1900 1950 2000 2050 2100 2150 2200 2250 2300 1450 1500 1550 1600 1650 1700 1750 1800 1850

477000m 478 479 480 481

8°35' aust Greenwich meridian

TRYKT I NORGES GEOGRAFISKE OPPMÅLING 12–68

BRIEF COMMENTS ON THE MAP

The compilation of this glacier map was based upon air photographs taken on 27th August 1968 from an altitude of 4300 m a.s.l. (Widerøe's Flyveselskap, contract No 3207, pictures D 3 - D 6.

The photography was specially ordered for the construction of the present glacier map. This enabled particular glaciological features to be emphasized in the plotting procedure.

On the Gråsubreen glacier crevasses are almost non-existent. These can only be recognized by ground inspection or from photographs taken at very low altitudes. Hence, no crevasses could be marked on the map except in the upper part of the firn area. Here, the Bergschrund is marked by light green lines as is also the case for the crevasses in a small "ice fall" between the upper part of Gråsubreen and Østre Grotbre. Movement studies have shown that the annual ice movement on Gråsubreen is in the order of 0.2 - 4.0 m.

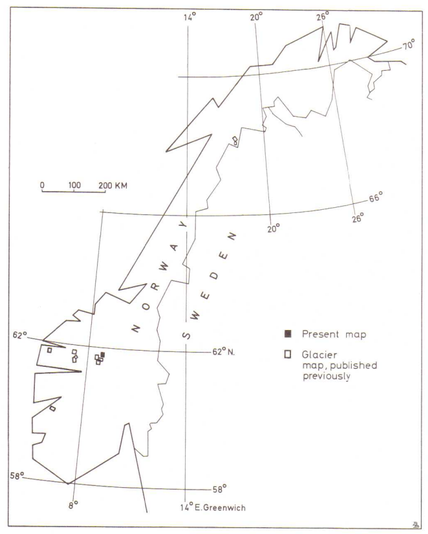
The outline of snow and ice-covered areas were plotted with a minimum of generalization. To emphasize the ice-free areas a brown colour was chosen to indicate "bare ground" as of the date of photography. Melt water streams were also plotted in detail even in cases when they were very small. A number of predominant boulders and triangulation points in the local network were plotted on the map and their elevation given. This was made to facilitate navigation and triangulation work for movement studies etc. on the glacier. As the plotting was limited to only a part of the total map sheet area, parts of the map would be left blank. To separate these white areas from the glacier surface proper (which is usually left white on previous glacier maps in the series) a green colour (screen) was used on all the mapped snow and ice areas.

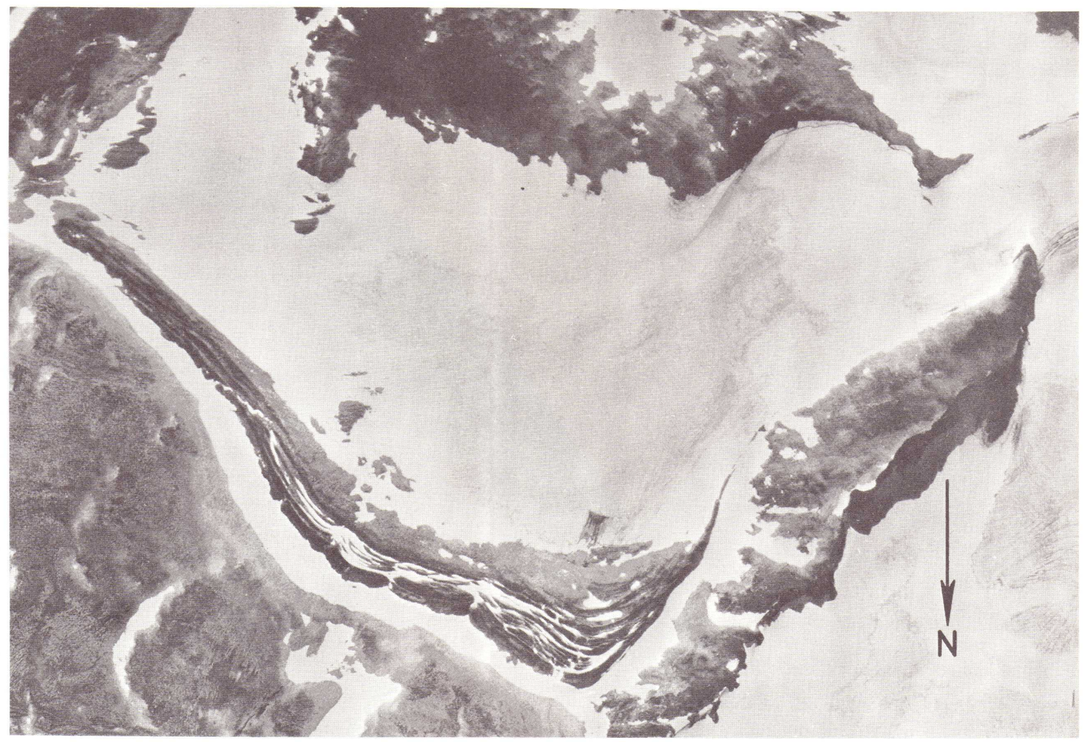
The accuracy is estimated to be better than 1,5 metres in relative height determination and better than 5 metres in absolute height determination. For spot elevations of single points it is better than 1,5 metres. The maximum error in horizontal determination is less than 5 m.

The Universal Transversal Mercator grid net, Zone 32, is marked in the map frame for each 1000 metres. Geographical coordinates are plotted for one latitude (61°40'N.) and one longitude (8°35'E. Greenwich) on each map sheet. The location of all recent glacier maps in Norway is shown on the index map.

The large end moraine system in front (northeast) of the glacier consists of a great number of more or less parallel ice-cored ridges. To emphasize the topography of the moraine system 5-m contours are plotted and the existence of more or less perennial snow patches between these ridges indicated with the green colour (screen). This end moraine system is probably one of the largest in Norway, at least in relation to the size of the glacier. An air photograph, (picture No. 10129 on Roll 66) taken by AMS on July 29, 1955 is shown to demonstrate the individual ridges on the end moraine system. Note, however, that the glacier outline in 1968 (as shown on the map) has changed due to the general trend of glacier retreat since the picture was taken.

LOCATION MAP





HELLSTUGUBREEN

JOTUNHEIMEN - NORWAY

SCALE 1:10 000

100 0 200 400 600 800 1000 m

Contour interval 10 m on glacier and 10 m and 50 m elswhere

Air photography by Fjellanger Widerøe A/S 26 sept. 1980

Plotted by O. Liestøl, Norsk Polarinstitutt 1980

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN

NORSK POLARINSTITUTT

1980

LEGEND:

- △ Trig. point
- 1450 Contour line
- Water stream with glacier mill
- Crevasses
- Morainic debris
- Moraine ridge
- ■ Observation hut

Hellstugubreen

Hellstuguholet

Hellstuguhø △2070.5

△1611.7

△1759.15

△2167.9

Hellstugutind △2338.0

△2107.9

Jerveløyfte △2238.0

Bandet

y2 8°26′ EAST GREENWICH (NGO DATUM) y3 8°27′ y4 8°28′

470 471 472

61° 35′ 61° 34′ 61° 33′

x399 6828 x398 6827 x397 6826 x396 6825

Sekkelsten & Sønn - 80

BRIEF COMMENTS ON THE MAP

The compilation of this glacier map, covering one of the valley glaciers in the central part of Jotunheimen — an area of the highest mountains in South Central Norway — was based upon vertical air photographs taken for this purpose on 26 September 1980 by Fjellanger Widerøe A/S (Sortie No. 6555). This special air photography was made at the end of an unusually long summer after a winter of little snow accumulation. Consequently, most of the glacier was uncovered from last winter's snow,but during the days just before the photography some new snow fell on the upper part of the glacier. This made it difficult to construct contour lines there.

The photography and the compilation of this map was made entirely to produce a glacier map, thus it was possible to emphasize glaciological features such as crevasses, surface drainage pattern, moulines, etc.

The scale (1:10 000) and the contour interval (10 m on the glacier, 10 and 50 m elsewhere) were selected according to a recommendation made at the International Symposium on Glacier Mapping held in Ottawa, Canada, in 1965. The Universal Transversal Mercator Grid (The UTM net, Zone 32) is drawn on the map for each kilometre. Geographical coordinates are marked with reference to the Greenwich meridian. The local Norwegian coordinate system is also indicated by tick-marks.

A number of triangulation points were used in the construction of this map. Some of them has been established by the Norwegian Geographical Survey (NGO). All these ground control points were used for the orientation of the stereo models in the Wild A-7 plotter.

Due to the fact that this glacier has been mapped several times before, both by terrestrial photogrammetry (1941), plane table mapping (1962) and aerial photogrammetry (1968), it has been possible to determine the variations in glacier thickness (or, more correctly, the surface elevation) along a longitudinal profile. The work was done by Liestøl already in 1962 (Hoel & Werenskiold, 1962 p. 190) when he published profiles based upon measurements performed in 1929, 1937, 1944, and 1948. By the additional information obtained from the present map and the maps from 1962 and 1968 he has continued this work, and the result is shown in the diagram below.

A comparison between the photogrammetric map from 1941 and the present map demostrates a drastic change of the tongue and of the cirque glacier south of Hellstuguhø. It has been completely separated from the main glacier body — see the map near the upper right corner.

It is assumed that the plotting accuracy on this map is better than 0.2 m for single points in the horizontal direction and in the order of 0.5 m in the vertical direction on the lower part of the glacier, whereas — due to the new-fallen snow — it may be a vertical error up to 5 m on the uppermost part of the glacier. However, the existence of many crevasses and short distances to bedrock makes it probable that the contours on the larger part of the map area show the height with an accuracy which is better than 1—2 meter.

The location of the present map as well as the location of previously produced glacier maps are shown in the upper right corner.

The production of this map was a result of a team-work between Norsk Polarinstitutt and the Glaciology Section within the Norwegian Water Resources and Electricity Board (NVE).

G. Østrem

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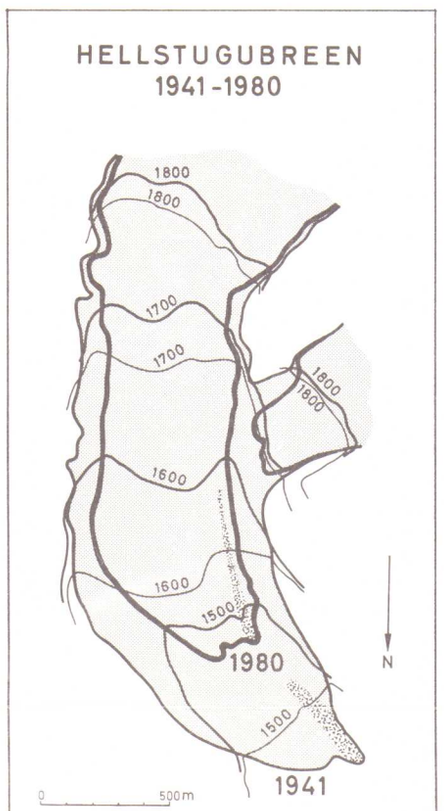
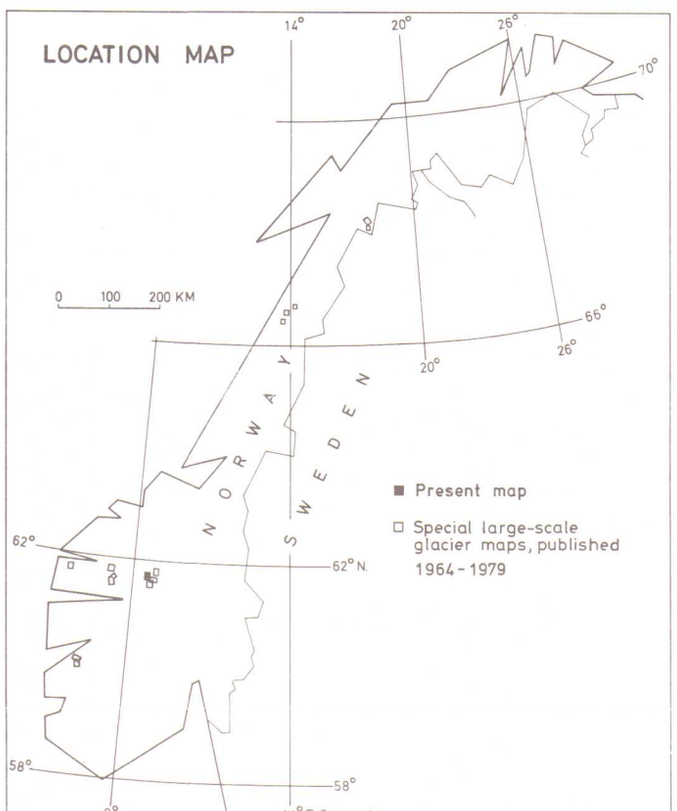
Liestøl, O. 1962: Special investigations on Hellstugubreen and Tverråbreen, *in:* Hoel & Werenskiold: Glaciers and snowfields in Norway, p. 175—207.

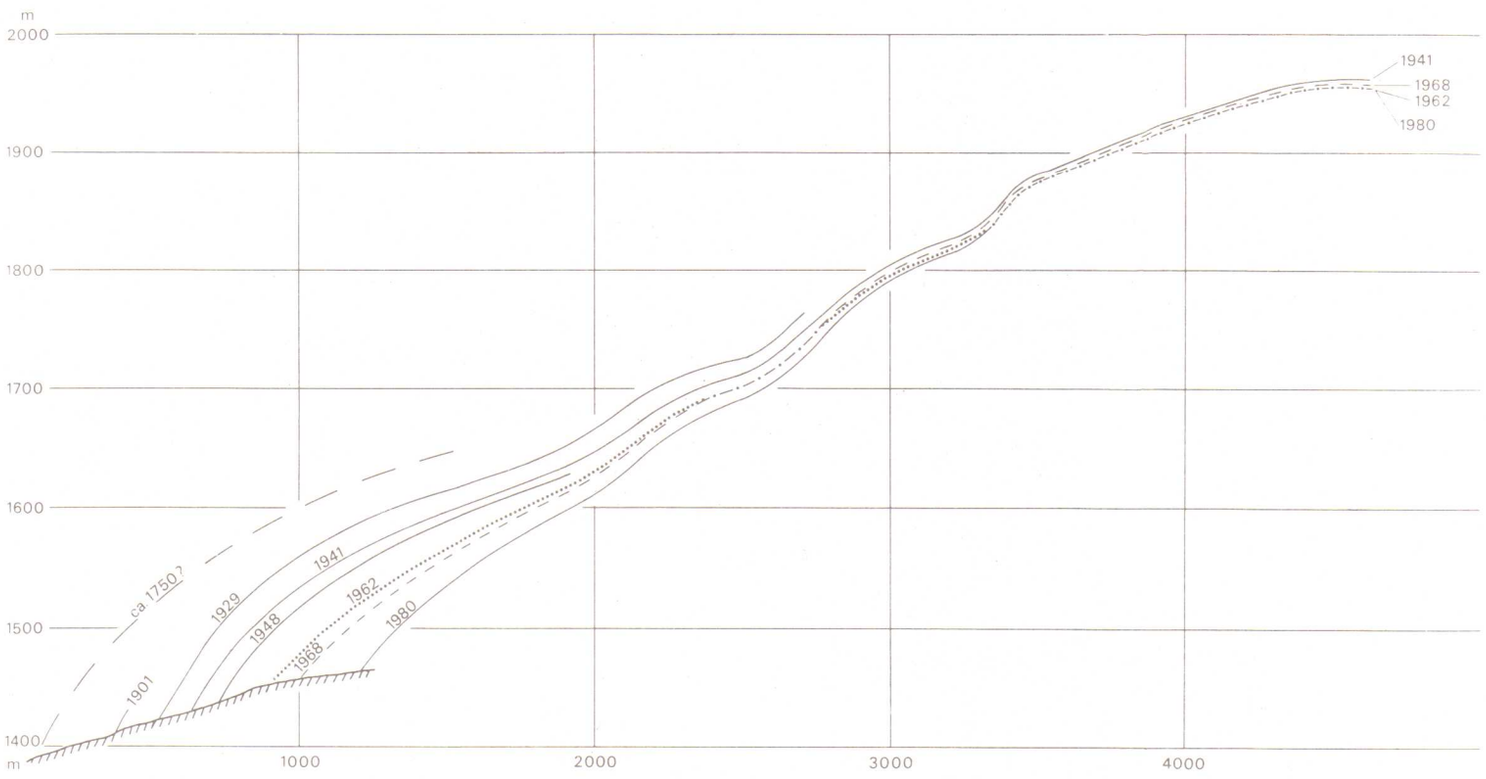
Østrem, G., Haakensen, N. & Melander, O. 1973: Atlas over breer i Nord-Skandinavia. — Medd. nr. 22, Hydrologisk avdeling, NVE, and Medd. nr. 46, Naturgeografiska Institutionen, Stockholms Universitet. 315 p.

Østrem, G. & Ziegler, T. 1969: Atlas over breer i Sør-Norge. — Medd. nr. 20, Hydrologisk avdeling, NVE. 207 p.

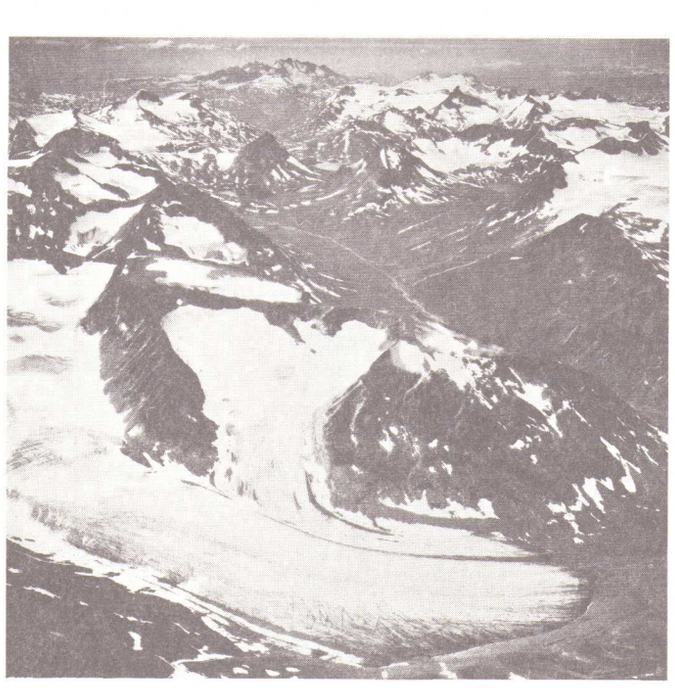


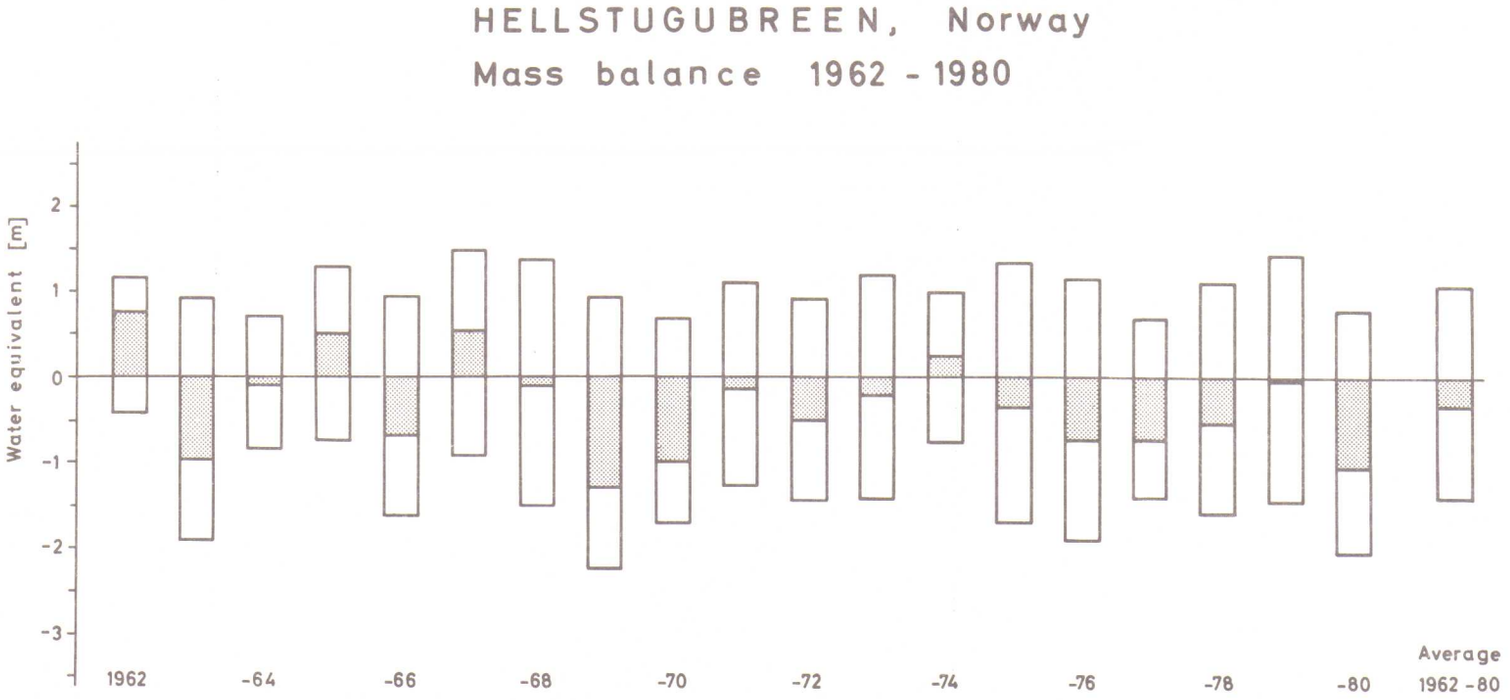


When Hoel and Werenskiold (1962) started a glaciological program in Jotunheimen in 1927, a great number of glacier scenes were taken with photogrammetric cameras. Two of these pictures are reproduced here.



Longitudinal profile along the centerline of Hellstugubreen showing the height (in m a.s.l.) of the glacier surface at selected intervals. The maximum extent of this glacier occurred probably about 1750. This stage is reconstructed in the diagram from the outermost moraine ridges which are clearly visible in the valley. Note that the glacier increased in thickness on its upper part between 1962 and 1968.





Hellstugubreen has been selected as a representative for the Mid-Jotunheimen glaciers on an East-West profile, running from the continental Gråsubreen, via Jostedalsbreen to the extreme maritime Ålfotbreen. These glaciers are included in a long-term mass balance observation program. The general trend of negative glacier mass balance since 1930 was broken in the beginning of the 1960-ies, when strongly negative years were exchanged by less negative or even positive balance years, particularly at the westernmost glaciers in the profile. Hellstugubreen has experienced a total net loss of about 7 m water equivalent during the period 1962—1980.

The upper picture was taken on 26 August 1929 by A. Koller, the next picture was taken on 12 September 1942 by W. Solheim. The air photographs were taken by Norsk Polarinstitutt, in August 1955 by B. Luncke. Only four vertical air photographs are available from 1980, taken by Fjellanger Widerøe A/S, Oslo, on 26 September.

HELLSTUGUBREEN

Jotunheimen

Scale 1:10000

0 100 200 300 400 500 m 1000 m

Contour interval 10 m

Glacier outline and contours surveyed 1962 by Randi Pytte.
Ground contours by A. Koller, W. Solheim and W. Werenskiold.

2°18' 2°16'

61°35' 61°34' 61°33'

x=399000 x=398000 x=397000 x=396000

y=2000 y=3000

Hellstuguåi

Hellstuguhö 2070.5

P7 1502.9

P6 1629.0

K1 1732.2

P5 1756.0

P4 1802.7

Sm3 2167.9

P3 1952.5

P2 1964.4

Hellstugutind 2338.0

W. Memurutind 2281.3

Jervelöyfte 2238.0

NEE

UBREE

HELLSTUGU

BANDET

1500 1450 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050 2100 2150

West Oslo

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN

BREKART
OVER
SØR-NORGE

UTARBEIDET PÅ GRUNNLAG AV TOPOGRAFISKE KART KORRIGERT MED FLYFOTOGRAFIER
VESENTLIG FRA PERIODEN 1958 – 68

VED

TOR ZIEGLER OG GUNNAR ØSTREM

1969

GLACIER MAP OF SOUTHERN NORWAY

COMPILED FROM TOPOGRAPHICAL MAPS REVISED BY AID OF AIR PHOTOGRAPHS
MAINLY FROM THE PERIOD 1958 – 68.

0 10 20 30 40 50 KM

BREDEKKET OMRÅDE, DVS. ISBREENES TOTALE UTSTREKNING.
RENE SNØFONNER ER IKKE TATT MED.

GLACIER COVERED AREA

TRYKT I NORGES GEOGRAFISKE OPPMÅLING 11–69.

15° 16° 17° 18° 19°

67° 68°

Hinnøy
Austvågøy
SVOLVÆR
Vestvågøy
LOFOTEN
Ærfjord
TYSFJORD
Frostisen
Rabots glaciär
Kaitumälven
Sitasjaure
Giđđečákka
Ritsemjaure
Stora Luleälven
Mikkajekna
SAREK
Vastenjaure
Virihaure
Pårtejekna
Duolpajiekna
Kvikkjokk
Blåmannsisen
Salajekna
Sulitjelma
Fauske
FOLDA
BODØ
SALTFJORD
Piteälven
Beiarelv
Skellefteälven
Saltfjell
Glomfjord
Glombreen
Engabreen
SVARTISEN
Trollbergdalsbreen
Østerdalsisen
SVERIGE
NORGE
Rana elv
Vindelälven
Høgtuvbreen
MO I RANA
Okstindbreen
Ranafjord
Rossåga
Tärnaby
Umeälven
Rösvatn
MOSJØEN
Vefsna
Børgefjell
Ånn
Storlien
Sylane
Nesjöen
Sylsjön
63° N
12° E
66°

1 Brekart over Sør-Norge
2 – II – Nordskandinavia (S)
3 – II – Nordskandinavia (N)

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
OG
STOCKHOLMS UNIVERSITET

BREKART

OVER

NORDSKANDINAVIA

SØNDRE BLAD

UTARBEIDET PÅ GRUNNLAG AV TOPOGRAFISKE KART KORRIGERT MED FLYFOTOGRAFIER
VESENTLIG FRA PERIODEN 1952–71

VED

NILS HAAKENSEN, OLLE MELANDER OG GUNNAR ØSTREM
1972

GLACIER MAP OF NORTHERN SCANDINAVIA

SOUTHERN SHEET

COMPILED FROM TOPOGRAPHICAL MAPS REVISED WITH AIRPHOTOGRAPHS
MAINLY FROM THE PERIOD 1952–71

1 : 500 000

0 10 20 30 40 50 KM

BREDEKKET OMRÅDE
GLACIER COVERED AREA

RIKSGRENSE
INTERNATIONAL BORDER

HOVEDVANNSKILLET
MAIN WATER DIVIDE

12° 13° aust Greenwich meridian 14°

Trykk: Sekkelsten & Sønn, Oslo

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
OG
STOCKHOLMS UNIVERSITET

BREKART

OVER

NORDSKANDINAVIA

NORDRE BLAD

UTARBEIDET PÅ GRUNNLAG AV TOPOGRAFISKE KART KORRIGERT MED FLYFOTOGRAFIER
VESENTLIG FRA PERIODEN 1952 – 71

VED

NILS HAAKENSEN, OLLE MELANDER OG GUNNAR ØSTREM

1972

GLACIER MAP OF NORTHERN SCANDINAVIA

NORTHERN SHEET

COMPILED FROM TOPOGRAPHICAL MAPS REVISED WITH AIRPHOTOGRAPHS
MAINLY FROM THE PERIOD 1952 – 71

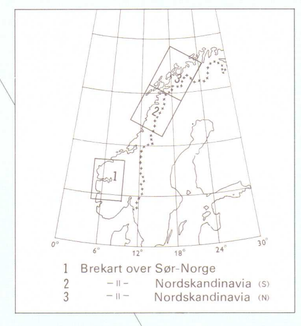
1 : 500 000

0 10 20 30 40 50 KM

BREDEKKET OMRÅDE
GLACIER COVERED AREA

RIKSGRENSE
INTERNATIONAL BORDER

HOVEDVANNSKILLET
MAIN WATER DIVIDE



1 Brekart over Sør-Norge
2 – II – Nordskandinavia (S)
3 – II – Nordskandinavia (N)

21° 22° 23° 24°

70° 69° 68°

14° 15° aust Greenwich meridian 16° 17° 18° 19°

Söröy
Seilandjøkulen
ALTAFJORD
ALTA
Øksfjordjøkulen
Langfjordjøkulen
KVÆNANGEN
Arnøy
Kågen
Vanna
Uløy
Reisaelv
Ringvassøy
ULLSFJORD
LYNGEN FJORD
Strupbreen
NORGE
FINLAND
Jiekkevárri
TROMSØ
Kvaløy
BALS FJORD
FINLAND
SVERIGE
Konkamäälven
MALANGEN
Råstojaure
Senja
Målselv
Bardufoss
Istind
Barduelv
Altevatn
NORGE
SVERIGE
Torneträsk
Abisko
Riksgränsen
Kärsajökeln
Rautasätno
HARSTAD
NARVIK
Blåisen
Storsteinsfjellbreen
Kalixälven
OFOTFJORD
KEBNEKAISE
Frostisen
Riukojiekna
Nikkaluokta
Storglaciären
VESTERÅLEN
Hinnøy
Sitasjaure
Kaitumälven

Trykk: Sekkelsten & Sønn, Oslo

SALAJEKNA

(SULITJELMA-ISEN)

NORTHERN SCANDINAVIA

Scale 1 : 20 000

0 1 2 km

Contour interval 10 m on glacier and 100 m elsewhere

COORDINATE SYSTEM: U T M, Zone 33

Heights in metres above sea level

Air photography by the National Land Survey of Sweden 18 August 1980 and 2 August 1982 (Infrared false colour 28 6015 and 27 68 95, scale 1 : 60 000)

Plotted by Bertil Fagerlund. Drafted by Yiva Brolin

LEGEND:

- 239 ⊡ 998.7 — *Border cairn (with number and height)*
- *Snow bank*
- *Glacier outline, clearly visible*
- *Glacier outline, snow covered*
- *Glacier outline, estimated (insufficient data)*
- *Crevasses*
- *Large moraine ridge*
- ▲1261 — *Triangulation point, with height*

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
STOCKHOLMS UNIVERSITET
1983

Per Larsen & Co. - 1983

SALAJEKNA

1950

Scale 1 : 50 000

0 1 2 km

Contour interval 10 m on glacier and 100 m elsewhere

Constructed from verticals taken on 23 August 1950 (Widerøe, Contract No. 415. Scale 1 : 15 000)

Plotted by Jan Bolstad

Drafted by Bjørn Selvåg

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
STOCKHOLMS UNIVERSITET
1983

SALAJEKNA

1957/58

Scale 1 : 50 000

0 1 2 km

Contour interval 10 m on glacier and 100 m elsewhere

Constructed from verticals taken on 25 September 1957 and 21 August 1958 by the National Land Survey of Sweden (Sng 57 - 106[a] and Sng 58 - 107[c], Scale 1 : 32 000)

Plotted by Bertil Fagerlund

Drafted by Sonja Axelsson Hallkvist

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
STOCKHOLMS UNIVERSITET
1983

SALAJEKNA

1971

Scale 1 : 50 000

0 1 2 km

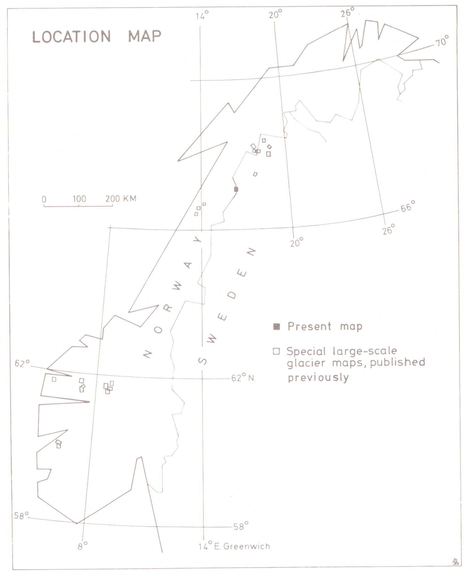
Contour interval 10 m on glacier and 100 m elsewhere

Constructed from verticals taken on 23 August 1971 (Widerøe, Contract No. 3842. Scale 1 : 30 000)

Plotted by Are Areschoug

Drafted by Bjørn Selvåg

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
STOCKHOLMS UNIVERSITET
1983



BRIEF COMMENTS ON THE MAPS

The production of this glacier map series was made possible by the fact that Salajekna is situated at the International border between Norway and Sweden. Thus, it has been photographed much more frequently than would normally have been the case because air photography activities are seldom coordinated across the border. Several of the flight lines were not always terminated exactly at the border and thus a Swedish flight may contain pictures of Norwegian territory, and vice versa. This has been a benefit for the production of the present glacier map series.

The earliest air photography of Salajekna was made in 1950 when Widerøes Flyveselskap A/S completed a large photography task for a mining company in Sulitjelma, Norway. On 23 August 1950 no less than 1 259 vertical air photographs were taken of the mountain areas south and east of Sulitjelma at a scale of 1:15 000 (flying height 4 500 m). This large operation consisted of 28 east-west flight lines and some of these crossed the border. Stereoscopic coverage was obtained for certain Swedish mountain areas, including the glacier Salajekna.

In preparation for the official ground inspection of the border in 1959—62, it was decided by the Border Commission that a complete air photography should be made of the Norwegian—Swedish border (as well as the borders between Norway and Sweden and Finland in the north). This task was divided between the Norwegian company Widerøes Flyveselskap A/S and the Swedish official mapping agency, Rikets Allmänna Kartverk (RAK), Stockholm. Parts of the border line in the Sulitjelma area was flown by RAK on 25 Sept. 1957 but due to various circumstances one flight line happened to run completely within Norway. Another flight was therefore made on 21 August 1958 along the border and these two series of good photographs made possible the construction of the second glacier map. In both cases the flying height was about 5 000 m and the picture scale about 1:32 000.

For the production of the new Norwegian topographic map series (1:50 000) a special air photography was arranged. This photography was completed on 23 August 1971 by Widerøes Flyveselskap A/S at a scale of 1:30 000. However, the flight lines run from North to South and the pictures did not cover completely the entire glacier. This is the reason why the third map in the series is slightly incomplete.

Finally, for the purpose of making a map of mountain vegetation in Sweden a special series of infrared false colour photography was completed in 1980. For technical reasons, however, some of the flights had to be repeated during the summer of 1982. In this case the flights were made in an east-west direction and fortunately the camera was not stopped exactly at the border. Thus a complete high-altitude stereo-coverage was obtained for the entire glacier Salajekna and some adjacent glaciers. The result from this photography is shown on the main map in this series. The photography was made on 18 August 1980 and 2 August 1982 at a scale of 1:60 000. In the latter case snow conditions were not as good as in 1980 but the photographs, mainly covering the lower parts of the glacier, presented no real problem in the map compilation because most of the glacier ice was exposed.

The construction of the 1950-map was made in a A-8 stereo plotter by the Fjellanger-Widerøe Company in Oslo, whereas all the other construction work was made in a B-8 stereo plotter at the Department of Physical Geography, University of Stockholm. The accuracy is therefore slightly different — the first map, which is based upon large-scale photographs, has errors which are only within 0.5 m in all directions whereas the other maps may have an accuracy which is within 2 m or so in *relative* determination. The error in *absolute* determination may be slightly larger, partly due to problems connected to the relatively small number of control points and to a special technical problem for the 1980-photography where parts of the stereo plotting was made at the very edge of the photograph without support from a neighbouring stereo model to the west.

The first International Symposium on Glacier Mapping held 1965 in Ottawa, Canada, recommended the scale of 1:10 000 and the contour interval 10 m for glacier maps. Due to the size of Salajekna it proved impractical to use this large scale, so the scale of 1:20 000 was selected to keep the size of the map within reasonable limits. (This scale has also been selected for certain maps of large glaciers in Norway.)

All the four maps were *constructed* at the scale of 1:20 000 but only the main map is reproduced without reduction in scale. The three others, used for comparison and intended for calculations of glacier volume variations, were reduced to 1:50 000 before printing. In all cases the recommended contour interval, 10 m, was used both in the compilation procedure and in the printed versions.

The Universal Transverse Mercator grid net, Zone 33, is drawn for each 2 km on all maps. In addition, the local Norwegian rectangular net, used by the Norwegian Geographical Survey (NGO, Zone 5) is marked in the frame by X and Y coordinates on the western (Norwegian) part of the maps, whereas coordinates for the National Swedish net (Rikets nät) are marked in the frame on the eastern part of the maps. Finally, geographical coordinates for 16°20' East Greenwich and for one North latitude are shown by tick marks in the inner frame on all maps.

The production of this map series was made possible through a cooperation between the Hydrological Department within the Norwegian Water Resources and Electricity Board (NVE) and the Department of Physical Geography at the University of Stockholm.

For the location of the map area and for previously published glacier maps in Norway and Sweden, see the location map to the left. Note, however, that some of the older maps are no more available or very difficult to obtain.

Gunnar Østrem

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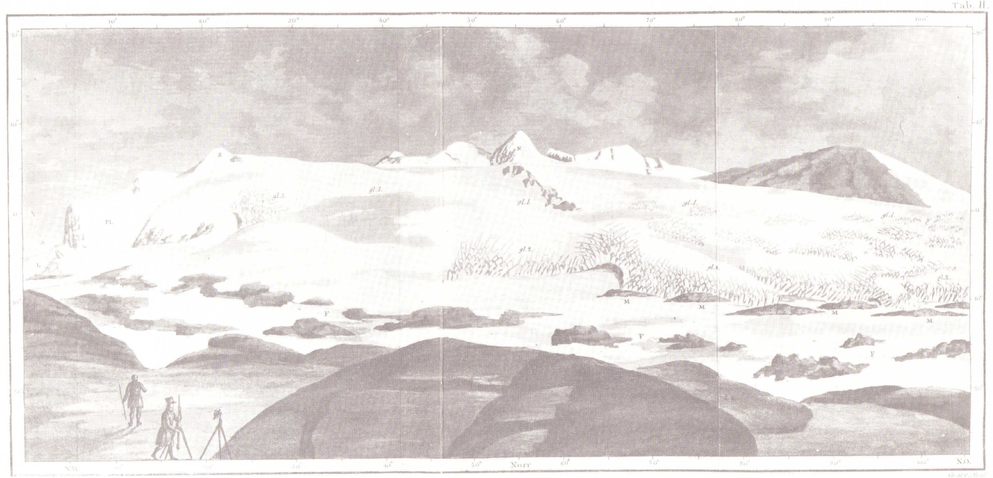


Vhain af Sulitelma och dess Glacierer från Sydöst Sidan.

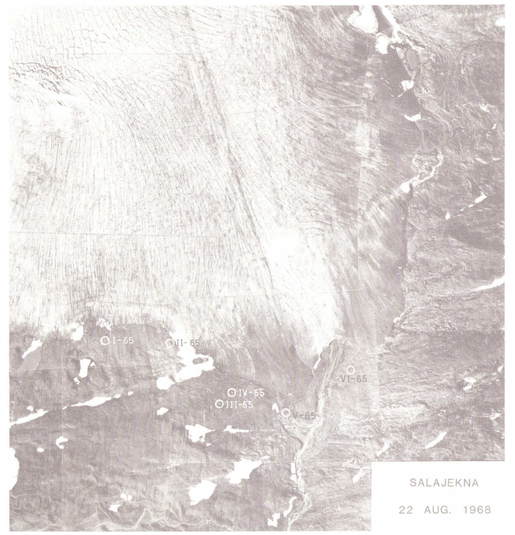
The Swedish geographer, Gösta Wahlenberg, made this drawing on 14 July 1807 from a point near the International Border Cairn No. 239. This is the first scientific observation made of Salajekna (Wahlenberg 1808). The drawing is based upon angle measurements, compare annotations in the frame. (Left picture.)

Another Swedish geographer, Dr. J. Westman took photographs from the border Cairn No. 239 on 19 July 1898 (Westman 1899). Se panorama below.

On 5 August 1983 photographs were taken from the same point as in 1898, this time by fil.kand. Per Holmlund. Note that snow is present in the same depressions on both photographs, but the glacier has become much thinner. (Bottom panorama.)

Södra Sulitelmas Glacier — Salajekna

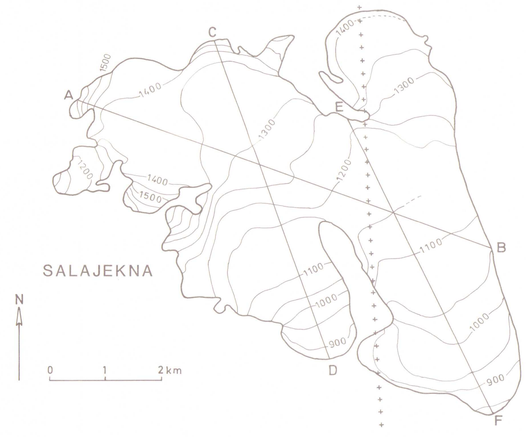
Salajekna och Södra Sulitelmas glacier
från Riksröset N:o 239.
Efter fot. af Dr J. WESTMAN den 19 Juli 1898.



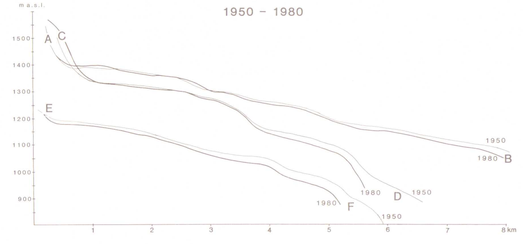
Combination of verticals taken on 22 August 1968 by the Royal Swedish Air Force. (Permission for publication given 30 November 1983 by Försvarsstaben). Some survey points, used for glacier retreat measurements, are marked by white or black circles. Approximate scale 1:13 500.

Large rocks, used as survey points, were painted in August 1965 to make them clearly visible on aerial photographs, compare the picture above. Photo: Valter Schytt.

A small section of the ice margin 1968 (enlargement of one of the verticals shown above) showing annual (?) moraines located between I-65 and II-65.



Profiles showing surface variations
1950 – 1980



The diagrams indicate that the glacier surface in many places has lowered several tens of metres during 30 years. Note, however, that the glacier seems to grow in its upper parts. The profile A-B indicates variable growth (two "waves") in the area about 1350—1400 m a.s.l.

ENGABREEN
(Svartisen, Norway)

1 : 20 000

0 1 2 KM

Contour interval 10m on glacier, 50m elsewhere

LEGEND

△1453.70 *Triangulation point*

· 1202 *Spot elevation*

Recording water gauge

Observation hut

COORDINATE SYSTEM: UTM ZONE 33

Air photography by Wideröes Flyveselskap A/S 25 August 1968.
Contract nr. 3205 Flying height 5800 m a.s.l.
Plotted by Fjellangers oppmåling 1970

NORGES VASSDRAGS- OG ELEKTRISITETSVESEN
HYDROLOGISK AVD.
1970

HOLANDS FJORD

Svartisen gård

ENGABREVATN

Helgelandsbukken
1455.70

Mösbruntua
1128

Snötind
△1594.09

444 000 M 13° 45′ 445 446 447 448 13° 50′ 449 450 451 452 13° 55′ 453

7399 7398 7397 7396 66°40′ 7395 7394 7393 7392 7391 7390 000 M

13° 45′ east Greenwich meridian

Sekkelsten & Sønn - IV. 71

ERDALSBREEN - VESLEDALSBREEN

(Part of Jostedalsbreen, Norway)

1: 20 000

0 1 2 km.

Contour interval 10 m on glacier, generally 50m elsewhere

LEGEND

- △2082.8 Triangulation point
- ·1424 Spot elevation
- Houses
- ----- Trail
- Snow-bank
- Crevasses
- "Sandur"-field
- Debris on glacier

COORDINATE SYSTEM: UTM ZONE 32

Air photography by Widerøe's Flyveselskap A/S, 19. July 1966
Flying height 7300m a.s.l.
Plotted in Wild B-8 Aviograph by P. Vold in December 1966

NORGES VASSDRAGS - OG ELEKTRISITETSVESEN

HYDROLOGISK AVDELING

1967

3. 67

TRYKT I NORGES GEOGRAFISKE OPPMÅLING

SOME COMMENTS TO THE MAP

The compilation of this map is based upon vertical air photographs taken on 19 July 1966 from 7300 metres elevation. (Widerøes Flyveselskap, contract No.1833)

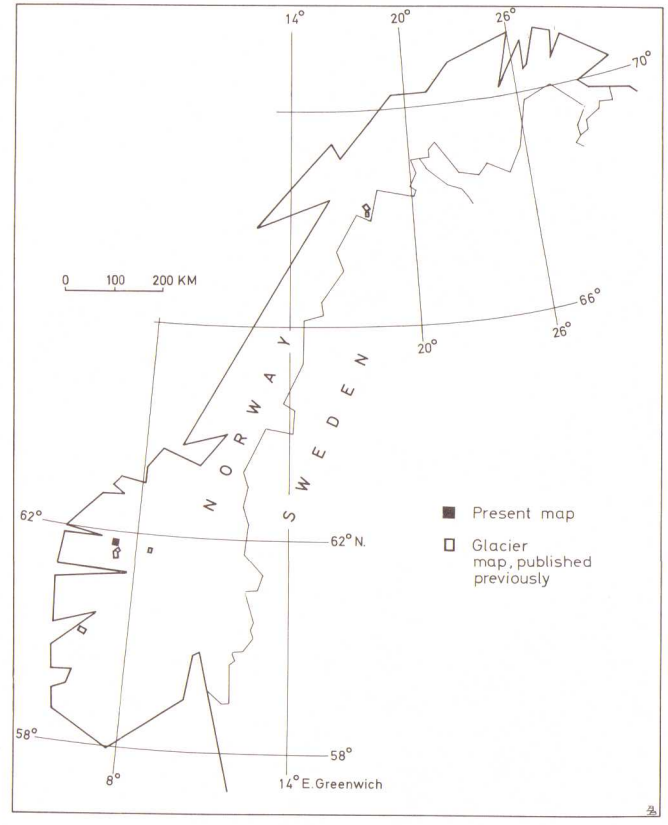
The photography was made for the Norwegian Geographical Survey to form the basis for modern topographic maps (scale 1:50.000) of this part of Southern Norway The plotting, however, was made independently for the purpose of making a glacier map. This is contrary to what has been the case for earlier maps in the series.

Consequently, particular glaciological features could be emphasized in the plotting procedure. Large and predominant boulders (marked "Stein" on the map) that can be used for navigation or triangulation on the glacier are plotted and their elevation marked. Furthermore, ice-free areas - although small - were plotted with a minimum of generalization. To emphasize these ice-free areas as well as the glacier outline, a brown colour was selected to indicate "bare ground" (as of the date of photography).

Scale (1:20.000) and contour interval (10 m on glacier, generally 50 m elsewhere) were selected according to the size of the glacier, and as far as possible following the recommendations given at the International Symposium on Glacier Mapping held in Ottawa in 1965.

An attempt was made to divide independent snow-banks from snow areas that were considered to be a part of the glacier's accumulation area. In general, the latter were given 10-metre contours (similar to the rest of the glacier), whereas more or less permanent independent snow-banks are shown on the map without contours or with 50-metre contours only. (Note: Outside the contoured area, e.g. in the north-eastern corner and south-west of Erdalen, no such classification was made. Some independent snow-banks on the west-facing slope of Strynekåpa were given 10-m contours by error.)
The accuracy in the main part of the map is estimated to be better than 3 metres in relative height determination, better than 5 metres in absolute height determination, and for spot elevations on single points better than 3 m.

LOCATION MAP



The maximum error in horizontal determination is less than 6-8 m. For a section in the north-eastern corner and in a small area around Strynekåpa the accuracy in contours and outline is less because in these areas another (older) air coverage had to be used. For the main purpose of the map this is of relatively minor importance. The location of this map as well as that of similar glacier maps published previously are shown on an index map.

GLACIER MAPS

issued in Norway

No	Map name	Scale	Year of photo	Year of issue	Issued by*	Colours	Remarks
1	Storbreen	1:10.000	1951	1952	NPI	Three	
2	Østerdalsisen	1:20.000	1954	1956	NPI	One	Manuscript only lower part
3	Tverråbreen	1:10.000	1927	1962	NPI	Three	
4	Hellstugubreen	1:10.000	1941	1962	NPI	Three	
5	Blåisen ved Sildvikvann	1:10.000	1960	1963	NVE	One	Manuscript
6	Part of Folgefonni	1:10.000	1959	1964	NVE	Three	
7	Storsteinsfjell	1:10.000	1960	1964	NVE	Four	
8	Nigardsbreen	1:20.000	1955, 1964	1965	NVE	Three	
9	Hellstugubreen	1:10.000	1962	1965	NVE	Three	
10	Tunsbergdalsbreen	1:20.000	1955, 1964	1966	NVE	Four	
11	Cainhavarrebreen	1:10.000	1960	1967	NVE	Two	
12	Erdalsbreen - Vesledalsbreen	1:20.000	1966	1967	NVE	Four	
13	Gråsubreen	1:10.000	1968	1968	NVE	Four	
14	Austre Memurubre	1:10.000	1966	1968	NVE	Four	
15	Vestre Memurubre	1:10.000	1966	1968	NVE	Four	
16	Ålfotbreen	1:10.000	1968	1969	NVE	Four	
17	Hellstugubreen	1:10.000	1968	1969	NPI	One	Manuscript
18	Engabreen	1:20.000	1968	1970	NVE	Four	
19	Trollbergdalsbreen	1:10.000	1968	1970	NVE	Four	
20	Storbreen	1:10.000	1968	1971	NPI	Four	
21	Høgtuvbreen	1:10.000	1972	1973	NVE	Four	
22	Nigardsbreen	1:20.000	1966, 1974	1975	NVE	Four	
23	Bondhusbreen	1:10.000	1959, 1979	1979	NVE	Four	
24	Hellstugubreen	1:10.000	1980	1980	NVE&NPI	Four	
25	Riukojietna	1:10.000	1960, 1978	1983	NVE&SU	Three	Two maps
26	Salajekna (Sulitjelma)	1:50.000 1:20.000	1950, 1957/58 1971, 1980/82	1983	NVE&SU	Four	Four maps
27	Midtre Folgefonni	1:20.000 1:10.000	1959, 1981	1984	NVE&SU	Four	Two maps
28	Gråsubreen	1:10.000	1984	1985	NVE&SU	Four	

*NPI = Norwegian Polar Research Institute
NVE = Norwegian Water Resources and Electricity Board
SU = University of Stockholm