DET KONGELIGE DEPARTEMENT
FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT

SKRIFTER

Nr. 114

GLACIERS AND SNOWFIELDS IN NORWAY

BY

ADOLF HOEL

AND

WERNER WERENSKIOLD

OSLO 1962

DISTRIBUTED BY OSLO UNIVERSITY PRESS

DET KONGELIGE DEPARTEMENT FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT

Observatoriegt. 1, Oslo, Norway

Short account of the publications of Norsk Polarinstitutt

The two series, Norsk Polarinstitutt — SKRIFTER and Norsk Polarinstitutt — MEDDELELSER, were taken over from the institution Norges Svalbard- og Ishavsundersøkelser (NSIU), which was incorporated in Norsk Polarinstitutt when this was founded in 1948. A third series, Norsk Polarinstitutt — ÅRBOK, is published with one volume per year.

SKRIFTER includes scientific papers, published in English, French or German. MEDDELELSER comprises shorter papers, often being reprints from other publications. They generally have a more popular form and are mostly published in Norwegian.

SKRIFTER has previously been published under various titles:

Nos. 1—11. Resultater av De norske statsunderstøttede Spitsbergen-ekspeditioner.
No. 12. Skrifter om Svalbard og Nordishavet.
Nos. 13—81. Skrifter om Svalbard og Ishavet.
» 82—89. Norges Svalbard- og Ishavs-undersøkelser. Skrifter.
» 90— . Norsk Polarinstitutt Skrifter.

In addition a special series is published: NORWEGIAN—BRITISH—SWEDISH ANTARCTIC EXPEDITION, 1949—52. SCIENTIFIC RESULTS. This series will comprise 6 volumes. Hitherto 20 papers have been published, and the series will probably be completed in 1963.

Topographic and hydrographic surveys make an important part of the work done by Norsk Polarinstitutt. A list of the published maps and charts is found on the back of SKRIFTER.

A complete list of publications (including maps and charts) is enclosed in SKRIFTER NR. 123.

ÅRBØKER

Årbok 1960. 1962. Kr. 15.00.
Årbok 1961. 1962. Kr. 24.00.

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A. W. BRØGGERS BOKTRYKKERI A/S

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PREFACE

The first reliable accounts of Norway's glaciers date back to the first half of the 18th century, when the greatest advance ever to take place in this country occurred. This catastrophe caused a great deal of damage to farms adjacent to Jostedalsbreen and an arm of the Svartisen in the county of Nordland.

Apart from descriptions of these disastres we hear nothing of Norway's glaciers until the late 18th century.

As time went on, works on glacier investigation increased, and the number of scientists interested in glaciology grew by leaps and bounds (see p. 14).

In 1948 glacier research in Norway acquired the status of a permanent state organisation when the work was taken over by the Norsk Polarinstitutt.

The first comprehensive description of all glaciers in Norway was published in the years 1898—1920 by Amund Helland, professor at the University in Kristiania (Oslo). It is printed in an important topographical — statistical description of Norway. The title of this work is Norges Land og Folk (Norways land and people). For the description and calculations of areas, etc., he was, however, to a great extent obliged to use old and inaccurate maps, most of them published in the years 1849—1883. Furthermore, during the time that elapsed since these maps were surveyed, the glaciers had shrunk considerably owing to the general rise in air-temperature (see the chapter on Fluctuations of the Climate, p. 74).

As Hellands work, for the above mentioned reasons, had partly become obsolete the undersigned considered it desirable to start new investigations of Norwegian glaciers, based on the Geographical Survey's new maps and all the available glaciological literature.

For our work in the field we employed modern instruments (theodolites, tachymeters and stereophotogrammetric instruments) that had not been used earlier for glaciological investigation in Norway.

Our work comprised three glacier regions: Jotunheimen in Central Norway from 1927—1948 and two areas in Northern Norway, where Hoel started the investigations in 1906 and 1908.

The literature studied and referred to in connection with the present work is published in a separate number of Skrifter, namely Norsk Polarinstitutt Skrifter Nr. 126.

Oslo, February 1961.

Adolf Hoel. Werner Werenskiold.

ACKNOWLEDGMENT

Most of the observations of snow accumulation, ablation and ice flow of the glaciers of the Jotunheimen mountains were, as will appear from this account, carried out by Alfred Koller, civil engineer of Norges Svalbard- og Ishavs-undersøkelser during the years 1927 to 1946. He also took the chief part in the mapping of Hellstugubreen, Tverråbreen and Svellnosbreen. The work of calculating and collating this material was carried out by Mr. Koller right up to 1951, when he died. He therefore, did not reach to sift all the material he had obtained. At the request of the authors, Mr. Olav Liestøl, glaciologist of Norsk Polarinstitutt (the successor of Norges Svalbard- og Ishavsundersøkelser from 1948), undertook the work of drawing up the general results of Koller's material. As Koller's cartographic work also provides a basis for studies in the changes of the glaciers, it has proved convenient to include, in Liestøl's adaption of Koller's material, the measurements of variations observed in the above mentioned three glaciers carried out by W. Solheim and W. Werenskiold, and of the other glacier investigations undertaken by them. It has, therefore, fallen to Liestøl to undertake the general work of preparing all the material collected during our glacier investigation in Jotunheimen during the period 1927 to 1946.

Moreover he has calculated the areas of a great number of glaciers and has computed the total number for the whole country.

The topographers B. Lunke and W. Solheim of Norges Svalbard- og Ishavs-undersøkelser have taken part in the field work in the computation of trigonometrical material and the preparation of maps.

We should also mention the excellent work carried out by the late Mr. Gunnar Scott-Ruud, of Norsk Polarinstitutt, a draughtsman and painter of great reputation, in preparing the fair copies of all the maps of Jotunheimen.

Major Per Tang, late topographer of Norges geografiske oppmåling (N.G.O.), and Mr. Gustav Tajet, also topographer of N.G.O., have assisted us in various ways with information on maps available, and given us other information of a topographical nature.

Norges geografiske oppmåling has rendered the authors very valuable assistance in allowing us access to their archives, and the right to publish extracts from them. In this connection we should especially mention Mr. Kr. Gleditsch, director of N.G.O., and the heads of the Topographical Department of N.G.O., major N. Sire and G. Hagene.

The government, municipal authorities and industrial undertakings and concerns, and public scientific funds have rendered liberal contributions, which have made possible the field work, and the working up of the results. A list of the names of contributors is to be found on p. 11.

A number of individuals and tourist organisations have provided a wealth of information on Folgefonni, Jostedalsbreen, the glaciers of Jotunheimen, Flatkjølen, Strupbreen and Øksfjordjøkulen.

Olav Koltveit, editor, of Odda, and Knut L. Måge, farmer, of Odda in Hardanger, have provided a great deal of material on the export of ice and the traffic accross Folgefonni, as well as indicating various written sources.

From Statsarkivet in Bergen we have received a copy of a document from 1677 dealing with the advance of Buarbreen during the period immediately preceding that year.

T. O. Eide, farmer, of Olden has in numerous letters furnished us with a great many valuable photos and information on the traffic accross Jostedalsbreen and variations in this glacier as a supplement to his book "Breden og bygda".

Lars Sulheim, farmer and guide, of Lom, has given us in a letter an account of routes accross the Jotunheimen glaciers.

To assist us in our researches into the Øksfjordjøkulen Troms and District Tourist Association and Alta and District Tourist Association have furnished the names of persons with knowledge of Øksfjordjøkulen and the export of ice from this glacier. We have had particularly detailed information from Otto G. Thomassen, farmer, who lives only a couple of kilometres from the glacier.

Others who have supplied us with material and photographs are: Einar Eriksen, chairman of Kvænangen District Council, Øyvind Johansen, of Skjervøy, and Dr. Hans Eng of Burfjord.

Thor Werner-Johannessen, head of department of Norsk Meteorologisk institutt, has also provided us with valuable information on the climate during the last few years. J. Norvik, secondary school teacher, pastor Kristian Nissen and dr. Knut Bergsland, Professor of Finno-Ugric languages, have helped us with various linguistic problems, and the former has sifted a great mass of material on Folgefonni, Jostedalsbreen and Flatkjølen.

To all the institutions and persons who in this way have rendered us very valuable assistance, we wish to express our most sincere and hearty thanks.

Adolf Hoel. Werner Werenskiold.

CONTRIBUTIONS

Contributors' name		
Scientific funds:	Years	Norw.kr.
Norges almenvitenskapelige forskningsråd....	1951—1957	55 000
Statens vitenskapelige forskningsråd av 1911	1927—1950	39 600
Andrée-fondet Stockholm	1933—1956	7 436
		102 036
Official sources:		
Norges vassdrags- og elektrisitetsvesen	1939—1956	11 450
Kirke- og undervisningsdepartementet	1942—1946	20 500
		31 950
Municipal authorities:		
Oslo lysverker	1947	1 000
Aker elektrisitetsverk	1942—1944	3 000
Oslo kommune	1942—1944	3 000
		7 000
Private contributors:		
Drammenselvens Brukseierforening	1937—1942	500
Øst-Telemarkens Brukseierforening	1937—1942	6 000
Norsk Aluminium Company	1927	500
Glommens og Laagens Brukseierforening	1937—1958	7 000
A/S Saudefallene	1937—1958	2 000
A/S Norsk Hydro	1937—1956	10 000
Reguleringsforeningenes Landssammenslutning	1956	4 000
Vadheim Electrochemiske Fabrikker	1958	50
Årdal og Sunndal Verk A/S	1958	1 000
Tyssefaldene A/S	1958	1 000
		32 050

Total:

Scientific funds	102 036
Official sources	31 950
Municipal authorities	7 000
Private contributors	32 050
	173 036
In addition, we have received from Norges almenvitenskapelige forskningsråd to final printing cost	22 000

The rest of the printing cost, including drawing of figures, printing of maps etc. has been paid by Norsk Polarinstitutt.

We should like to express our gratitude to the above contributors, whose generosity has enabled us to compile and publish the present work on The Glaciers and Snowfields in Norway as well as the "Glaciological bibliography of Norway", Norsk Polarinstitutt Skrifter Nr. 126.

Oslo, 1961.

Adolf Hoel. Werner Werenskiold.

HISTORY

Norway's participation in international collaboration on glaciology

Glaciers are a striking feature of a landscape, whether they are framed by dark mountains or stretch down between green slopes, extending even as far as into the forests. In countries like Norway, or in the Alps, glaciers make their influence felt in many ways in the daily life of the people. In many places a route from one community to another passes across a glacier; and the advances of glaciers have often caused tremendous damage to arable land and buildings. In our times, now that waterfalls have been harnessed for hydro-electric power plants, glaciers have acquired considerable importance to the economic well-being of a community, as a great many power plants owe a considerable quantity of their power to rivers which in summer are fed with water from glaciers. The warmer and drier the weather is at this time of the year, the greater is the flow of water. For that reason glaciers play a great part in providing these rivers with a steady flow of water.

This alone would be sufficient reason for paying considerable attention to glaciers. Scientists, however, have realized that a great many problems are connected with the investigation of glaciers: how they move, their fluctuation, their relation to climatic changes, etc., — many problems which to a large extent have not yet been finally solved.

The oldest information available about glaciers, icebergs and sea-ice originate from the famous publication *Speculum regale,* written in Norway about 1220 in Old Norse and translated into many other languages.

In a chapter on Greenland the author gives an admirable description, accurate in every detail, of the ice surrounding the Greenland coasts. He mentions that this arctic land is covered by glaciers.

After the description of the pack-ice he gives the following statement concerning icebergs (cited from the English edition):

"There is also ice of a different shape, which the Greenlanders call fall glaciers. In appearance these resemble high mountains rising out of the sea. They never mingle with other ice." The author means that icebergs drift in a different manner from pack-ice.

The true science of snow and glaciers was first developed in Switzerland. As early as the 17th century several important works on glaciers were published there.

J. J. Scheuchzer (1672—1733) and M. A. Cappeler (1685—1769) may be regarded as the founders of glaciology. This science went through its classical period during the 19th century. The investigations on snow and ice were also extended to other parts of the Alps, and glaciology gradually became a subject of world-wide research.

A particularly important sphere for research was the fluctuations in glaciers, determined by measurements with various kinds of instruments (measuring tapes, tachymeters and photogrammetric instruments) which were undertaken from year to year. An important stimulus to this research work was provided by the inauguration of international co-operation in the recording of glaciers variations, when the international Geographical Congress in Zürich in 1897 started the International Glacier Commission. This body published annual reports entitled "Les variations périodiques des glaciers". This international co-operation, as well as the publication, ceased when the first world war broke out, but was resumed again at the end of the twenties when a Commission Glaciologique, a subsection of the Union Géodesique et Géophysique, took over its work. Meanwhile the second world war once again put an end to the activities of the organization. The work of recording changes in glaciers continued, however, during the war. As in previous years it was undertaken to some extent by various associations in the different countries — in the Alps, for example, by various Alpenvereine — and by state officials in the forestry department, water conservancy board, etc.

In Norway we have had no such bodies or government institutions for this work before 1948 when it was taken over by Norsk Polarinstitutt. Earlier it was carried out mainly by geologists attached to the University in Oslo and Norges Geologiske Undersøkelse.

History of glaciological research in Norway

Glacier investigations in Norway have been carried out mainly by interested geographers and geologists, both foreigners and Norwegians. The Norwegian work in this field has been made possible by grants and contributions from scientific funds, from several industrial companies and corporations, and also from the Norwegian government. In 1943, all those engaged in glacier research were heartened by the news that Norsk Polarinstitutt had appointed a glaciologist as a regular member of the staff. This post was filled by Olav Liestøl. His work covers an immense field, embracing not only the glaciers of Norway, but also the Norwegian spheres of interest in the Arctic and Antarctic regions — Svalbard, Jan Mayen, Bouvetøya, Peter I Øy, and Dronning Maud Land.

Our knowledge of the glaciers in these polar regions is primarily connected with Norwegian cartographic work, which began in Spitsbergen in 1906. Numerous special investigations have also been carried out in Spitsbergen and Jan Mayen by foreign explorers. Among Norwegians may be mentioned Adolf Hoel, H. U. Sverdrup and Olav Liestøl.

The first reliable reports on Norway's glaciers date from the first half of the 18th century. For about 50 years (1700—1750) the glaciers advanced to such a degree that serious damage was done to several farms situated in Nordfjord and Jostedal and below the front of Engabreen, an outflow glacier of Svartisen. Some of these farms had to be struck off the tax register. (See pp. 60—63.)

Apart from the description of the above-mentioned destructive glacier advance, we hear nothing about the glaciers before the end of the 1700's.

We shall briefly mention Norwegian and foreign explorers, the glaciers investigated, and the year of publication of their works. We shall also give some general information concerning conditions for glaciological investigations in Norway.

Martin Vahl (1749—1804), Danish botanist, professor in Copenhagen. Jostedalsbreen, 1792.

Christen Smith (1785—1816), botanist, professor in Christiania (Oslo). Jostedalsbreen and Folgefonni, 1813.

Niels Hertzberg (1759—1841, dean in Hardanger. Folgefonni, 1818.

C. F. G. Bohr (1773—1832), teacher, Bergen. Jostedalsbreen, 1820.

Christopher Hansteen (1784—1873), astronomer, professor in Christiania. Hardangerjøkulen and Folgefonni, 1822.

Jens Edvard Kraft (1784—1853), historian and statistician, an official in Christiania. Hardangerjøkulen and Folgefonni, 1822 and 1829.

Carl Friedrich Naumann (1797—1873), German geologist, professor in Leipzig. Jostedalsbreen, 1824.

Jacob Neumann, bishop of Bergen (1772—1847). Jostedalsbreen, 1824.

Thomas Forester. Folgefonni and Hurrungane, 1850.

C. M. Doughty (1843—1926), English explorer. Jostedalsbreen, 1866.

Karsten Tank Lorange (1838—1909), officer in the service of Norges Geografiske Oppmåling. Jostedalsbreen.

L. Holmström (1840—1919), Swedish teacher, geologist. Buarbreen and Jostedalsbreen, 1879.

Albrecht Penck (1858—1945), geographer, professor in Vienna and Berlin. Jostedalsbreen and Folgefonni, 1879.

Fig. 1. Buarbreen, an outflow glacier of Folgefonni.
(Photo: B. **Luncke, Norsk Polarinstitutt.** 1955.)

Yngvar Nielsen (1843—1916), geographer, professor in geography at the University in Christiania. Folgefonni, 1879, 1880.

All these early pioneers visited the glaciers of western Norway, especially Jostedalsbreen, Folgefonni and Hardangerjøkulen. These glaciers are easily accessible from populated valleys, and even from the coast.

Some scientists travelled through large parts of Norway, describing the glaciers they visited:

Leopold von Buch (1774—1853), German geologist, 1810.

E. R. Vargas Bedemar (1770—1847), director, Museum of Natural History, Copenhagen, 1819.

J. M. E. Durocher (1817—1858), French geologist, 1847.

James D. Forbes (1809—1868), English physicist and geologist, professor, Edinburgh, 1853.

Charles Rabot (1856—1944), French geographer, Paris. Numerous papers between 1882 and 1909.

Two glacier investigators must be especially mentioned, as they have written exhaustive monographs of some glaciers. One is Sjur Amundssøn Sexe (1808—1888), professor of mining and physical geography, the University, Christiania; the other is Christen de Seue (1843—1892), army officer and meteorologist.

Sexe published in 1864 a monograph on Folgefonni. Here he deals with the height of the firn limit, the glacier flow, the temperature of the ice and of the glacial rivers, and makes various theoretical observations.

In 1869 he published a treatise on Bøyumbreen, an outflow glacier of Jostedalsbreen. He studied the temperature of the ice and of the water on the surface of the glacier and of the glacier river, the flow of the glacier, crevasses and moraines.

De Seue published two comprehensive descriptions of glaciers. One of them deals with Jostedalsbreen (1870). It is chiefly a topographical description of the glacier, with its major outflow glaciers, the structure of the ice, the crevasses and glacier flow and the temperature of ice and rivers are also dealt with.

In 1876 he published an account of Svartisen. The major part is a topographical description of the glacier and determination of the ice flow rate of one of the outflow glaciers. It also contains a report on temperature conditions in some of the northern fjords.

From the beginning of the 1890's the number of works published on Norwegian glaciers increased considerably.

Gradually glacier investigations assumed more systematic forms, especially after the inauguration of the "International Glacier Commission". The programme of international collaboration on variations of glaciers also included research of Norwegian glaciers.

In Norway, two pioneers in this field deserve a special mention: J. B. Rekstad (1852—1934), of Norges Geologiske Undersøkelse, Oslo, and P. A. Øyen (1863—1932), curator of Quaternary Geology at Paleontologisk Museum, Oslo.

Rekstad studied chiefly the glaciers of western Norway. His first work on glaciers was a thorough investigation of the hitherto little-known Svartisen, on the Arctic Circle. This is the second largest ice-field in Norway.

During the years 1899, 1900, 1903, 1904 and 1906 he visited the largest glaciers of Vestlandet (the southern part of western Norway): Folgefonni, the glaciers of Sogn and Nordfjord — outflow glaciers of Jostedalsbreen.

In 1903 he made geological and glaciological investigations in the north-western part of Jotunheimen.

Rekstad's work included every branch of glaciological investigation. He determined the height of the firn limit of many glaciers, estimated the areas and number of glaciers, and also measured the ice flow and the ablation of several, as well as the mud content of glacial rivers.

His study of the variations of the glaciers deserves a special mention. This was done by placing stone cairns in the front of the glaciers. The distance from cairn to glacier was measured every year. This was mostly done by mountain guides and others living in the neighbourhood of the glaciers according to Rekstad's instructions. In this way the variations of most of the largest glaciers in western Norway were recorded. Rekstad was in charge of this work till 1932, in co-operation with Bergens Museum. In 1933 Knut Fægri, professor of Botany, Universitetet i Bergen, took over this work.

P. A. Øyen commenced his glacier studies on a journey through the Jotunheimen mountains in 1891. The following year he also went to the same district, and began his studies on the variation of glaciers. In the year 1893 he undertook a journey to the glaciers of western Norway: Folgefonni, Hardangerjøkulen, Jostedalsbreen, glaciers in Olden, Nordfjord. In the following years, up to 1912, he devoted special attention to the variations of the glaciers in Jotunheimen. Like Rekstad he too placed stone cairns near the front of the glaciers and measured the distance cairn—glaciers. His work in this district will be dealt with on p. 128. Øyen was Norway's deputy in the International Glacier Commission.

The glaciers of Northern Norway have been investigated chiefly by the following:

Christen de Seue, Svartisen, 1876.

Karl Pettersen (1826—1890), geologist, Tromsø. Sulitjelma glaciers, glaciers in Finnmark—Tromsø, among them Øksfjordjøkulen and Seilandjøkulen.

Archibald Geikie (1835—1924), director of the British Geological Survey. Svartisen, 1882.

J. B. Rekstad. Svartisen, 1892, 1893.

J. Westman (1867—1922), Swedish meteorologist. Sulitjelma and Almajalos glaciers, 1899, 1900, 1910.

Adolf Hoel (1879—), geologist, glaciologist, of Universitet i Oslo, polar explorer. Frostisen 1906, Okstindan glacier 1910.

Rolf Marstrander (1885—1936), engineer geologist. Svartisen, 1911.

Gunnar Holmsen (1880—), state geologist of Norges Geologiske Undersøkelse, Oslo. Flatisen, 1916, Veikdalsisen, 1917.

Thorolf Vogt (1888—1958), geologist, professor, Trondheim. Sulitjelma glacier, 1923.

The first comprehensive descriptions of all glaciers in Norway were as mentioned in the preface written by Amund Helland (1846—1918), professor of mining and geology at Universitetet i Christiania. We shall return to Helland and his work on p. 28.

THE GLACIERS

Topographic maps of Norway

MAPS WORKED OUT AND PUBLISHED BY NORGES GEOGRAFISKE OPPMÅLING

In the following account reference is often made to the various districts in Norway where glaciers are situated. The locality may be described in terms of geographical regions or more frequently administrative districts. We have therefore given a summary of the last-mentioned on p. 286.

For a detailed study of glaciers good maps are required. Topographic maps of Norway are worked out and published by Norges geografiske oppmåling, which was founded in 1773. For large parts of the country, however, accurate maps are not available. This applies to the county of Møre og Romsdal, and Setesdal. There is still also a dearth of accurate topographical maps covering the mountainous districts of the counties of Aust-Agder and Vest-Agder, and to a certain extent the high mountain areas of Rogaland and Telemark counties are still without modern maps. For all those areas we have only the so-called *amtskart* (fylkeskart) (county maps) to the scale of 1 : 200 000 (Finnmark, however 1 : 500 000), which have no contour lines.

The maps of 14 counties were published between 1826—1885. The map of Finnmark county dates from 1907, the county maps of Sør-Trøndelag and Nord-Trøndelag from 1897—1917. The county maps have contour lines showing the topography, except Sør-Trøndelag and Nord-Trøndelag counties, where the contours from the 1: 100 000 maps are inserted; and the Finnmark county map, which shows neither contour lines nor formlines.

The county maps vary considerably in quality. They cover the whole of Norway with the exception of Nordland county.

Concerning this map series and the following ones see the annual publication of Norges Geografiske Oppmåling: Katalog over landkart.

The main map series of Norway are maps to the scale of 1: 100 000 with 30 m contour interval. These maps are thus the first maps with contour lines ever published in Norway.

Of these maps there are two kinds: *rektangelkart* and *gradteigskart.*

The *rektangelkart* are of rectangular form, four Norwegian miles E—W and three miles N—S.[1] The area of each sheet is consequently 1530.85 sq.km. They appeared in the years 1870—1942, and since then publication of these maps ceased. There are 102 such sheets in all. They

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[1] One old Norwegian mile is 11.295 km. An old Norwegian sq.mile is consequently 127.57 sq.km.

cover the coastal areas of southern Norway and the eastern part of the country up to about 63° N, and between this latitude and 65° N (the southern part of Nordland fylke) they comprise all the country.

The *gradteigskart* in southern Norway cover a region E—W of 30 minutes of longitude and N—S of 20 minutes of latitude. The publication of these maps began in 1916, and the latest one is from 1956. 76 map sheets have so far appeared. They cover southern Norway from 58° 20′ N from about the meridian of Oslo, up to 62° N, apart from some mountain regions. The *gradteigskart* in northern Norway cover a region E—W of one degree of longitude and N—S of 20 minutes of latitude. The publication of these maps began in 1893 and the latest one is from 1953. 125 map sheets have so far appeared. They cover northern Norway from the southern boundary of Nordland county (65° N) except the eastern part of Troms county, where 14 sheets have not as yet been published in 1 : 100 000.

The area not covered by the 1 : 100 000 maps is 53 200 km^2 or 16.4 per cent of the whole of Norway.

The oldest rektangel- and gradteigskart of the south-eastern parts of Norway as well as those of Finnmark county do not satisfy the requirements one is entitled to make in the case of maps to this scale.

For some parts of the country, maps to the scale of 1: 50 000 and 1: 25 000 are also published.

Of other topographic maps published by Norges Geografiske Oppmåling may be mentioned two small-scale series. The first one to the scale of 1 : 400 000, was published in the years 1868—1910, and is called *generalkart*. There are 18 map sheets and they cover the southern part of Norway up to 65° N. They are all obsolete and out of print.

The other series is called *landgeneralkart,* comprising maps to the scale of 1: 250 000. The first sheet was published in 1914 and the last one in 1955, 26 in all. Each sheet is confined by meridians and parallels. The distance between the confining meridians is south of 65° N two degrees, north of 65° N three degrees, between the parallels one degree. These maps cover the eastern part of Norway up to about 65° N and to the north of this latitude they comprise the whole of the country up to 69° N.

Norsk Polarinstitutt publishes topographical maps of Spitsbergen to the scale of 1 : 100 000, of Bjørnøya 1 : 10 000 and 1 : 25 000 and of Jan Mayen 1 : 50 000. The Spitsbergen maps are gradteigskart. The sheets comprise 2° 30′ of longitude and most of them 20 minutes of latitude. In all, nine sheets have been published in the years 1948—1962. In the main they cover the western part of Vestspitsbergen from Sørkapp to the north coast of Isfjorden.

MAPS WORKED OUT AND PUBLISHED AS A RESULT OF COLLABORATION BETWEEN NORGES GEOGRAFISKE OPPMÅLING AND THE U.S. ARMY MAP SERVICE

An entirely new situation in the topographical survey of Norway arose when it was decided that the NATO-countries should co-operate in the protection of military maps. This raises new problems in mapping because the standardization of military maps vitally affects the topographic mapping of each country.

The following information about recent years' survey work is from *Beretning om Norges geografiske oppmålings virksomhet i året 1955,* Oslo, 1956.

Already in 1953 the US Army Map Service (AMS) published a map series to the scale of 1 : 250 000 of the whole of Norway, 46 sheets, i. e. on the same scale as our landgeneralkart, but they suffered from certain shortcomings, which Norges Geografiske Oppmåling brought to the attention of the AMS. It is interesting to note that on these maps a distinction was made between glaciers and snow-fields, a distinction which had never previously been shown on the Norwegian maps.

The AMS is now preparing a new edition of the series 1: 250 000 M 515. In 1954 it was agreed that Norges Geografiske Oppmåling should help to make these series as good as possible, especially as regards names and habitations, roads and woods. In accordance with this NGO has handled all the sheets covering Norway (46) and sent the manuscript to the AMS.

In 1955 the Norwegian Government accepted a most generous offer of assistance from AMS. Under the scheme the greater part of southern Norway (south of the 65 parallel) was covered by aerial photographs. Maps will be compiled from these and from Norwegian aerial photographs for the south coast and eastern — and central Norway for the areas where the present 1 : 1000 000 is based on very old surveys. In addition NGO will go on compiling maps for the two areas in southern Norway still without topographic maps.

The new maps will be to 1 : 50 000. The limitations of these sheets will be different from those of the gradteig maps. These new series of 1: 50 000 maps will be in future the main topographic series of Norway for the areas covered by the new surveys. In the areas not covered by the new maps the existing 1: 100 000 maps will be maintained as the main topographic, and enlargements as the main military series.

It must also be noted that the enlargements of our 1: 100 000 maps to 1: 50 000 were made by the Germans during the occupation of Norway. In 1951—1952 they were revised with regards to communications by NGO and redivided according to new sheet lines and printed by the AMS.

THE INSTRUCTIONS OF NORGES GEOGRAFISKE OPPMÅLING CONCERNING MAPPING OF GLACIERS

It is worth mentioning that NGO realized how important it was that their topographers, while undertaking survey work, should also accurately determine the front of such glaciers as they surveyed. This will be apparent from the following statements.

In the annual report of NGO for 1878 we find i. a. this record:

"In the course of surveys undertaken in the Jotunheimen mountains, geometrical lowest points have been marked in for the ten most important glaciers, and at the same time the height of these points has been fixed, with a view to obtaining the first account, and thus finally determining to what extent the most interesting snow and ice glaciers in our mountains are increasing."

It is rather remarkable that NGO should at such an early stage have been alive to the importance of obtaining the necessary evidence of changes in the areas of glaciers.

Rules on this subject are also contained in a later publication from NGO, viz. "Instruks for Detaljmåling og Revision", Kristiania 1913, § 44, p. 68, also contains rules on this subject.

"If glaciers occur within the area of operations, surveyors shall accurately determine the position of the edge of the front, in order that changes in the glacier may be observed in subsequent years.

For this purpose the surveyor should measure the distance from a fixed mark to the front of the glacier, e. g. a cross hewn in the solid rock about 70—100 m from the edge of the glacier. The distance should be measured to the nearest 10 cm approximately. The tape should be stretched in the longitudinal direction of the arm of the glacier, and, apart from the fixed mark, should also be determined with the help of a large stone cairn which should be erected 300—500 m away from the edge of the glacier, and where the compass direction of the tape should also be taken.

If the front of the glacier is wide, it would be an advantage to fix two distances to it, one on either side of the river which generally flows out of the front.

Finally a sketch should be made depicting the front of the glacier, fixed points, and stone cairns, as well as the ground between, and furthermore the front with its surroundings, should be photographed, both from the front and from the side."

Reports on this work sent in by surveyors have been included in the usual map descriptions in the archives of the topographical section of NGO. For the surveying of Jotunheimen, see p. 121.

The instructions also contain rules for the measuring of glaciers, and for plotting them on the maps. The following is an extract:

Glacier plateaus are to be shown on the map covering an area corresponding to that covered after a summer of average warmth. Lesser snow-fields, which melt away in the course of the summer, are therefore not to be included.

In drawing glaciers, a distinction should be made between those portions which appear as hard ice in late summer and those which are generally covered with eternal snow. The former should be marked with unbroken (blue) contours, and the latter with dotted (blue) contours.

Glacier arms which are also partly covered with snow in early summer should thus be plotted in the same way as the firm, smooth ice. Accurate plotting of the tongue of the glacier is of special importance. For information regarding the extent of the hard ice on glaciers and outflows, people with local knowledge should be contacted.

Permanent crevasses should be marked with thin lines in the direction of the crevasses, without undue importance being attached to accuracy of minor details or exact position. People with local knowledge should be asked about the changes occuring from year to year in the formation of crevasses.

The maps show — as mentioned above — no distinction between glaciers and snow-fields.

It is reasonable to suppose that the interest in glaciers evinced in these instructions resulted in a more accurate plotting of glaciers.

The above survey of glacier fronts was carried on right up to the year 1936, when NGO started mapping with the help of aerial photogrammetry, now exclusively used for the mapping of the country.

Here in conclusion are a few words on the accuracy of different scales.

It is clear that the calculation of areas based on a small-scale map gives less accurate results than those based on a large-scale map. In the first case the survey has been executed with less accurate instruments and methods, and hence it follows that such maps will be of a poorer quality than maps based on a survey with good instruments and modern methods.

But even if we compare two maps based on surveying with the same instruments and plotted by the same method, but on different scales, the calculation of areas will give different results for the two maps. It is obvious that the areas resulting from the large-scale map are greater than those from the small-scale map.

As an illustration we may mention the following.

Thor Askheim, topographer of Norsk Polarinstitutt, has made an interesting investigation of this question. He has computed the areas of the glaciers in Sørkapplandet in Spitsbergen, using maps to the scale of 1 : 50 000 and to the scale of 1 : 200 000, both maps having been constructed on the basis of aerophotograms from 1936 and 1938. According to the first map, the area covered by glaciers and snow-fields amounts to

Fig. 2. Rembesdalsskåki, an outlet glacier of Hardangerjøkulen.
(Photo: B. Luncke, Norsk Polarinstitutt. 1955.)

66.5 per cent of the land area, but according to the last map, only 61 per cent.

For the topographical survey of Norway's possessions in the Arctic and the Antarctic, see p. 55.

Geographical outline of the glaciers

TYPES AND POSITIONS OF THE GLACIERS

A great many mountain groups in Norway extend above the snow-line, and consequently numerous glaciers occur, some of them attaining considerable dimensions. Jostedalsbreen with an area of 815 sq.km is the largest in Norway, and also the largest in Europe with the exception of the glacier area in Iceland. Of all the countries on our continent, Norway has the largest glacial area, appr. 4000 sq.km or 1.23 per cent of the entire land area; next come the Alps with 3600 sq.km, and Caucasia with 2000 sq.km. The glaciers of Iceland, however, cover an area of 11.800 sq.km or 11.5 per cent of the whole land surface.

It must however be admitted that our knowledge of the area covered

Fig. 3. Jostedalsbreen, the southern part of the main plateau.
(Photo: Widerøes Flyveselskap A/S. 1947.)

by Norway's glaciers and snow-fields is incomplete, as modern topographical survey is still lacking for large parts of the country. The final figures will therefore deviate somewhat from those now available. Moreover, the glaciers have shrunk considerably in the last 40 years, and many snow-fields have disappeared entirely.

The firn areas are frequently situated on high plateaux bounded by steep sides, and from these icefields outflow-glaciers stretch down the valleys. This kind of plateau glacier is common in Norway, and has therefore been called the Norwegian type, but is now usually termed glacier cap.

The largest glaciers belong to this class including Folgefonni, Hardangerjøkulen, Jostedalsbreen, Svartisen and Blåmannsisen.

Very many glaciers of the Alpine type are found in Norway. Here valley glaciers issue from snow-filled cirques surrounded by steep rock-walls. Glaciers of this kind are specially numerous in the Jotunheimen mountains, and in Sunnmøre and Romsdal and also in Nordland.

The higher mountains are everywhere characterized by cirques — many empty, often with a little lake, but many occupied by glaciers.

With regard to the distribution of glaciers in the different parts of Norway, the following may be stated:

The land to the south of Breifonn (59° 46′ N) and the whole south-eastern part of the country are entirely without glaciers and further, the area between 62° 30′ and 65° 15′ N. Likewise the areas to the east of Seilandsjøkulen (70° 20′ N), including the interior of Finnmark. All

Fig. 4. Ålfotbreen, resting on devonian sandstone.
(Photo: Widerøes Flyveselskap A/S. 1947.)

islands, with the exception of Seiland, are lacking in glaciers; but there are however some small cirque glaciers in the Lofoten islands.

The largest glaciers in Norway are situated in the mountains to the west of the main divide, from the county of Hordaland and northwards to the county of Finnmark. The county of Sogn og Fjordane has the largest precentage of snow and ice, in all 996 sq.km or 5.38 per cent of the land area of the county. Next comes Nordland with 1710 sq.km or 4.46 per cent of the surface of this county. For the other counties see table p. 54.

The glaciers of southern Norway are mainly grouped around the inner branches of the Hardangerfjord, Sognefjorden and Nordfjord, and in the Jotunheim mountains. In northern Norway, glaciers are situated in the Okstindane to the south of Ranafjorden. The largest is Svartisen, on the Arctic Circle; farther to the north are Sulitjelma and Blåmannsisen, near the Swedish border, to the east of Bodø. Other glaciers are found in the mountains between Sørfolda and Ofotenfjorden; near Øksfjord and on the island of Seiland, the two last-mentioned in the county of Finnmark.

The southernmost glacier in Norway is Breifonn (59° 46′) and the northernmost is Seilandsjøkulen (70° 20′ N).

Some few years ago two of our glaciers extended to sea level: Øksfjordjøkulen (70° 10′ N) in Finnmark and Troms counties, and Frostisen (68° 13′ N) in Nordland county. They were both regenerated glaciers. The glaciers belonging to Frostisen disappeared short before the Second World War, but Øksfjordjøkulen still exist. (See p. 262 and p. 116.)

FIRN LIMIT

The preponderance of glaciers in western Norway is due to the high mountains in this part of the country and to the prevailent oceanic character of the climate, with cool summers and ample precipitation.

The farther one moves into the country, away from the coast, the higher the summer temperature, and the smaller the amount of precipitation.

To the west of Jostedalsbreen (appr. 61° 30′ N) the mean temperature of the summer months (May—September) is + 11.5° C. but in the eastern parts of Jotunheimen, at the same latitude, appr. + 13° C. These temperatures are all reduced to sea-level. The annual precipitation in the same places is, in the west, 2000 to 3000 mm — or more — but in the east, only 300 to 500 mm.

Farther north, the summer temperature decreases, and is + 7.5° C. in Hammerfest (70° 39′ N), with an annual precipitation of 722 mm.

On these climatical and topographical conditions depends of course the altitude of the firn limit and the distribution of the glaciers.

In the western part of Jostedalsbreen the firn limit lies at a height of about 1300 m, and in the eastern parts of the same glacier at 1600 m, while in the eastern parts of the Jotunheimen mountains, at the same latitude, the firn limit is now to be found at about 2000 m. In other words, this limit rises some 700 m over a distance of about 100 km. This increase in the altitude of the firn limit from the coast towards the interior is a dominant feature throughout Norway.

In a south to north direction the height of the firn limit drops gradually. From Ålfotbreen to Seilandsjøkulen, a distance of 950 km and a difference in latitude of 8° 40′, the firn limit drops from 1300 to 900 m, i. e. only 400 m.

In Norway and in the regions bordering the Atlantic and the Arctic Oceans the dominant feature of the isoglacihyphses is, as Ahlmann (1948) has stated, their parallelism with the coast.

Investigations on the position of this limit have been carried out by many scientists, i. a. A. M. Hansen, A. Helland, J. B. Rekstad, A. Hoel, G. Holmsen and H. W:son Ahlmann.

The table below shows the areas of the 26 largest glaciers in Norway.

NORWAY'S LARGEST GLACIERS

Name	County	Area sq.km	When surveyed	Kind of maps	Computed by
Jostedalsbreen	Sogn og Fjordane	815.0	1945	F (A)	L
Svartisen	Nordland	476.5	1894—97	R	L
Folgefonni	Hordaland	225.0	1932—53	R	L
Blåmannsisen (the part situated in Norway)	Nordland	123.5	1906—08	R	N.G.O.
Hardangerjøkulen	Hordaland	78.2	1955	F	L
Ålfotbreen, Gjenget	Sogn og Fjordane	68.4	1945	F (A)	L
Okstindbreen	Nordland	65.6	1893	R	N.G.O.
Glacier on Lappfjellet and Flatkjølen	Nordland	43.0	1906—08	R	N.G.O.
Sulitjelmabreene (the part situated in Norway)	Nordland	40.1	1906	R	N.G.O.
Høgtuvbreen	Nordland	38.8	1895—96	R	L
Øksfjordjøkulen	Finnmark	36.6	1945	F (R)	L
Frostisen	Nordland	33.5	1915—16	R	N.G.O.
Sproteggbreen	Sogn og Fjordane	27.2	1945	F (A)	L
Glacier on Kvitlenova	Sogn og Fjordane	27.0	1945	F (A)	L
Grovebreen	Sogn og Fjordane	25.2	1945	F (A)	L
Fortundalsbreen	Sogn og Fjordane	23.2	1939—42	R	N.G.O.
Langfjordjøkulen	Finnmark	21.0	1878—93	R	N.G.O.
Nupsfonn	Hordaland	21.0	1920—30	H	L
Vestre Jostefonn	Sogn og Fjordane	20.6	1945	F	L
Fresvikbreen	Sogn og Fjordane	16.7	1947	F (R)	L
Seilandsjøkulen	Finnmark	15.3	1956	R	S.I.E.
Smørstabbreen	Oppland	15.3	1931—38	V	N.G.O.
Strupbreen	Troms	14.0	1953	F	L
Austre Jostefonn	Sogn og Fjordane	13.4	1945	F	L

Abbreviations: A — Amtskart. 1 : 200 000.
H — Hardangervidda. 1 : 200 000.
R — Rektangelkart or gradteigskart. 1 : 100 000.
V — Map of Vest-Jotunheimen. 1 : 50 000.
F — Air photos.
L — Olav Liestøl.
N.G.O. — Norges geografiske oppmåling.
S.I.E. — Seiland Ice-Cap Expedition.

Areas and number of the glaciers and the snow-fields

THE INVESTIGATIONS OF GLACIERS BY NORGES GEOGRAFISKE OPPMÅLING AND AMUND HELLAND

From the very start of N.G.O. in 1873 the topographers were requested to prepare geographical descriptions of the areas they had surveyed in accordance with detailed instructions. These reports are thus first-hand sources concerning the natural conditions of our country. The descriptions also contain information about the glaciers.

The reports of the topographers were intended to form the basis for a topographical and statistical description of the whole country. But it was not until 1875 and 1876 that the Storting granted a sum of kr. 9000 for this work. This publication was planned to comprise 20 parts, each covering a separate county. The official title was to be "Norges Land og Folk". Its various volumes were later as a rule called "Amtsbeskrivelser".

In 1876 a special department, the Statistical-topographical office, was established at N.G.O. It was charged with the task of procuring and working out the topographical material, which was to form a part of the planned publication. Among other things the office was to compute the areas of geographical units such as lakes, islands, forests and glaciers. Some of these computations should comprise single map sheets, others were arranged according to administrative districts.

At first it was planned that N.G.O. should publish the results of the work of this office, but in 1876 it was decided that this task should be taken over by an editor outside N.G.O.

To start with, this publication proceeded very slowly. The first county-description appeared in 1885, and by 1897 only five, by three different editors, had been issued. They all deal with the southern counties. They are brief (one volume each) and contain little or nothing about glaciers. The publication was then entrusted to Amund Helland (1846—1918), professor of mining and geology at Universitetet i Christiania. The reason for charging Helland with this work was that, already some years before, he had published four large papers in the series of Norges Geologiske Undersøkelse (N.G.U.). In these Helland had made very important contributions to the same material as treated in the county-descriptions. These works are: "Jordbunden i Norge" (1893), "Jordbunden i Romsdals amt" (1895), and "Lofoten og Vesteraalen" (1897). All these works also deal with the glaciers. He had also written a work on the soil in Vestfold fylke, where there are no glaciers, viz. "Jordbunden i Jarlsberg og Larviks amt" in N.G.U., Skr. Nr. 16, Kristiania 1894.

Now the work proceeded at a brisker pace. Helland's first county description appeared in 1898 and the last one in 1921 — in all 17, each comprising from two to four volumes.

The county descriptions contain in the first volume a general part describing the county as a whole, and then follow volumes with a description of each district (herred).

This work contains ample information abous Norway's glaciers. Here is found the first comprehensive description of our glaciers and perennial snow-fields, covering all available knowledge on this subject, at the time in question: the topographical situation, the areas and number, variations, etc., of the glaciers.

In the general part he deals with the *glaciers,* and also the *perennial snow-fields.* But as a rule he gives no figures for the areas of these. In the special part he enumerates the glaciers for each district. These figures are summed up, giving the total areas of glaciers and snow-fields in each county and the whole country.

Fig. 5. Engabreen, an outlet glacier of Svartisen.
(Photo: Widerøes Flyveselskap A/S. 1949.)

In many cases it is difficult to distinguish between glaciers and snow-fields. On the topographical maps the large snow-fields are represented in the same manner as the glaciers and consequently the areas entrusted by N.G.O. to Helland comprise both kinds of glacial cover. For future studies of the glaciers it will be of importance to make such a distinction, because the snow-fields are always thinner and also less compact than the glaciers, and as a consequence they have melted away more rapidly than the glaciers during the recent years. Therefore the figures given by Helland for the areas of the glaciers must certainly for the above mentioned two reasons by considerably reduced.

There are 12 counties with glaciers in Norway, viz. Finnmark, Troms, Nordland, Nord-Trøndelag, Sør-Trøndelag, Møre og Romsdal, Sogn og Fjordane, Hordaland, Rogaland, Oppland, Telemark and Buskerud.

As mentioned above Helland's last county description was published in 1921, and the whole Norway had thus been covered.

Norges Geografiske Oppmåling then decided to publish similar descriptions itself, each covering a single map sheet (scale 1 : 100 000) and based upon the material available in its archives. Five of these descriptions have been published, viz. Hellemobotn, Skjomen, Tysfjord in 1922;

Hamarøy and Nordfold in 1823; all in the northern part of Nordland county; but the publications have subsequently ceased. All these were amply illustrated with photographs. (The county descriptions had no illustrations).

The descriptions of the map sheets with glaciers contain valuable information about the latter.

DEFINITION OF THE CONCEPT "GLACIER" IN THE TABLES OF AREAS AND NUMBER BELOW

It is necessary to define what we mean in this chapter by a glacier.

There are a great many single glaciers in Norway: glaciers of alpine type, cirque glaciers, etc. All these are naturally regarded as each constituting one single glacier.

Some few single glaciers are connected in the firn area. If the boundary line between such glaciers is obvious from the topography, as is the case e. g. in the Vestre Memurubre-Hellstugubre in the Jotunheimen mountains, each is regarded as a separate glacier. The largest glaciers in Norway are glacier caps, from which outlet-glaciers descend into the valleys and down the mountain sides. A glacier cap with its outlet is here regarded as forming one single glacier. As both glaciers and snow-fields are represented in the same manner on the maps it is impossible to make any distinction between these two kinds of glacial cover.

All glaciers and snow-fields shown on the maps, even the smallest, are included in our lists of areas and number. Most of these small glaciers have no name.

Where there are two or more small glaciers without names in the same region they are grouped together with information of the total area and number.

MATERIAL USED IN THE COMPUTATION OF AREAS AND NUMBER OF GLACIERS

As mentioned above, N.G.O. has carried out calculations of glacier areas. The first of these calculations were made from old and inaccurate maps, but in recent years N.G.O. har recalculated the areas of glaciers on the basis of new topographical maps to the scale of 1 : 100 000, for some counties in Norway, namely Finnmark, Troms, Nordland, all in northern Norway; Buskerud and Hordaland in southern Norway. Some of the counties not mentioned here have still only the old amtskart, scale 1 : 200 000.

In 1956 Widerøes Flyveselskap og Polarfly A/S at the request of Hoel and Werenskiold computed the areas of many glaciers in Jotunheimen and its surroundings.

The tables below showing the areas and number of the country's glaciers have been worked out by Olav Liestøl. The material at his disposal was as follows:

1. The latest report on such areas available in the archives of N.G.O.
2. Widerøe's computations.
3. Liestøl has computed the areas of glaciers not included under 1. and 2. The areas have been arrived at by calculations on the latest maps and by measurements on aerial photos taken during recent years. The last-mentioned cover the following areas:

Lyngen peninsula and area inland	Photos taken in 1953
Øksfjordjøkulen	» » » 1945
Langedalsjøkulen	» » » 1945
Frostisen	» » » 1945
The whole Jostedalsbreen with surroundings ..	» » » 1945
The whole Ålfotbre	» » » 1945
Hardangerjøkulen	» » » 1955

Below will be found a more detailed statement of the material. This material varies greatly. As mentioned above some parts of the country are well mapped, and for other parts only old inaccurate maps are available. It must also be taken into consideration that the measurement cannot be referred to a definite date, the maps and aerial photos which are used having been obtained in different years, as shown in the tables.

In the case of northern Norway the areas have been measured off from regular gradteigskart, scale 1 : 100 000, with the exception of the areas around the Lyngen peninsula. In this area surveys are based on aerial photographs made in the summer of 1953 and in part on maps that have not as yet been published. In measuring from aerial photographs the degree of accuracy is not the same all over the area, owing to the variable scale of the photos, which cannot always be accurately deduced. The surveying for gradteigskartene of northern Norway commenced as early as 1878, but the work has not yet been completed.

In view of the great ablation which has taken place on the glaciers during the period under review, the glacier areas here recorded are considerably in excess of actual areas. Thus the Øksfjordjøkul, surveyed in 1891—1902, as computed from a gradteigskart, shows an area of 50.8 sq. km, while measurement based on aerial photographs from 1945 shows an area of 36.6 sq.km.

As a consequence of the general retreat of the glaciers three large glaciers in the western part of southern Norway (Jostedalsbreen, Ålfotbreen and Folgefonni) have been split up into several minor glaciers.

Snow conditions during the years when surveying took place must also be taken into account. S. Foslie of N.G.U. states in his geological

Fig. 6. Frostisen with Mereftasbreen in the background.
(Photo: Widerøes Flyveselskap A/S.)

map description of "Hellemobotn and Linnajavarre" (Oslo 1942, pp. 89—90):

"On the Linnajavarre map sheet the glacier area, in relation to the topographical map, is 26 sq. km in all . . . These areas, however, are much too large, and this can be explained by the fact that the Linnajavarre survey took place at a comparatively early stage in the summer, in a year when there had been a considerable fall of snow, so that large areas of snow that had fallen that year have been included in the area of the glacier . . . During my investigations in the districts as recently as August 1929 the true glacier surface was bare . . .

Consequently the real glacier area on this map sheet is only 8.5 sq.km".

Thus, according to Foslie, the glacier area is reduced to approximately one-third of that shown on the map.

In the case of southern Norway the maps available are possibly even more varied. Here some of the calculations of the glacier areas are based on the old "amtskart" (scale 1: 200 000) from the middle of the 19th century. In the large glacier areas around Jostedalsbreen and Ålfotbreen, where these old maps still form the basis of calculation, the glacier areas have been corrected with the help of aerial photographs.

Modern maps are available for the other large glacier areas, Jotunheimen, Hardangerjøkulen and Folgefonni. For the glacier areas in Møre og Romsdal, as well as in the northernmost part of Sogn og Fjordane, the old amtskart still have to be used.

Fig. 7. Øksfjordjøkulen with Langedalsjøkulen in the foreground.
(Photo: Widerøes Flyveselskap A/S. 1952.)

It is difficult, therefore, as the foregoing remarks will have shown, to make an accurate assessment of the total glacier area today. In the case of southern Norway, where estimates for the large glacier areas are fairly reliable, the total should be rather accurate. Regarding of northern Norway, as already mentioned, a considerable reduction must be made, possibly about one-third.

As mentioned above, Helland has also calculated not only the areas of the glaciers, but also the numbers. But this information of the numbers is not complete. The numbers of the major glaciers are correct, but the minor ones are mentioned in groups without indicating their numbers.

Rekstad, too, in his work on the glaciers of Southern Norway (1911) has a survey giving the numbers of glaciers in this part of Norway based mainly on the inaccurate amtskart. He comes to the result that there are 332 glaciers in southern Norway. But he has not taken into account a great number of glaciers in Møre og Romsdal fylke; and none of the glaciers in Sør-Trøndelag and Nord-Trøndelag. Helland puts the numbers in Møre og Romsdal to about 200 and in the two Trøndelag counties to 24 and 9 respectively.

According to Rekstad's and Helland's calculations there should be about 500 glaciers in southern Norway. In his county descriptions Helland comes to the conclusion that the figure is probably around 600. As will be seen from the tables below the correct number is approx. 960.

Below follow the tables in two groups. In the first (p. 35) the areas and numbers are arranged according to natural geographical units. In the second (p. 51) these figures are grouped according to districts.

List of the areas and number of glaciers

BY OLAV LIESTØL

GROUPED ACCORDING TO NATURAL GEOGRAPHICAL UNITS

The latitudes and longitudes relate to the middle of the areas.

Northern Norway.

	Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
1.	Seiland	70° 25′—23° 20′	1956			
	Seilandsjøkulen			15.29		
	Nordmannsfjordjøkulen			7.52		
	Gyfjorddalbreen			0.22		
					23.03	3
2.	Around Øksfjordjøkulen	70° 10′—21° 55′	1878—1945			
	Øksfjordjøkulen			36.60		
	Langfjordjøkulen			21.05		
	Svartfjelljøklene			8.60		
	6 small glaciers			6.60		
					72.85	9
3.	Ringvassøy	69° 55′—19° 10′	1929—37			
	3 small glaciers				0.10	3
4.	Lyngshalvøya to the N. of Kjosenfjord	69° 45′—19° 50′	1953			
	Strupbreen			14.0		
	9 other glaciers			20.8		
					34.8	10
5.	Nordreisa—Kvænangen	69° 45′—21° 10′	1953			
	6 small glaciers				4.0	6
6.	Kåfjord—Nordreisa	69° 40′—20° 50′	1953			
	5 small glaciers				4.0	5
7.	Around Balsfjord—Ullsfjord	69° 35′—19° 20′	1928—35			
	6 small glaciers				8.30	6
8.	Kvaløy	69° 40′—18° 30′	1928—37			
	4 small glaciers				3.05	4
9.	Lyngshalvøya: Kjosenfjord—Balsfjordeidet	69° 25′—19° 45′	1953			
	12 glaciers				38.0	12
10.	Malangen—Balsfjord	69° 25′—19° 40′	1928—35			
	4 small glaciers				2.25	4
11.	Senja	69° 20′—17° 30′	1893—1925			
	17 small glaciers				1.62	17

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
12. Rossfjord—Målselv-fjord—Sørreisa	69° 15′—18° 20′	1921—35			
8 small glaciers				0.51	8
13. Breitind—Blåtindan (Malangen)	69° 15′—18° 50′	1921—33			
8 small glaciers				0.92	8
14. Balsfjord—Rosta—Signaldalen	69° 10′—19° 10′	1953			
Garanasgai'sibreene (2)			1.0		
Jettanasgai'sibreene			1.9		
Marknestindbreene (3)			1.8		
Other glaciers (6)			2.7		
				7.4	17
15. Signaldalen—Ski-botn—Helligskogen	69° 20′—20° 00′	1953			
6 small glaciers				0.8	6
16. Rosta—Dividal—Frontier Norway—Sweden	68° 50′—19° 50′	1953			
Liggavarribreen				0.7	1
17. E. of Kirkesdalen	68° 50′—19° 40′	1925—33			
Madagaissabreene			3.03		
Alappenbreene			1.85		
Middagsfjellbreene			0.85		
Njunisbreene			1.50		
				7.23	18
18. Kirkesdalen—Bardu—Altevasskardet	68° 50′—18° 45′	1925—33			
Bæssegčckkabreene			2.69		
Store Istindbreene			2,83		
Rypelarsbreene			0.24		
Bangsklettbreene			1.32		
Isogaissabreene			3.80		
Røyvassbergbreene			0.44		
Lille Istindbreene			1.05		
Tverrfjellbreene			0.75		
Various small glaciers			1.08		
				14.20	21
19. Salangen—Bardu—Solbergfjorden	69° 00′—18° 00′	1909—33			
Breitindbreen			0.17		
Fakstindbreen			0.21		
Storalabreen			0.60		
Snefjellbreen			0.93		
5 small glaciers			0.82		
				2.73	9
20. Andørja	68° 50′—17° 15′	1909—14			
Blåisen			1.90		
3 small glaciers			0.35		
				2.25	4

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
21. Gratangen—Salangen	68° 45′—17° 50′	1909—14			
Trosenbreen			3.04		
Reitindbreen			1.87		
Skavensklettbreen			0.27		
Sølfjellbreen			0.50		
6 small glaciers			0.26		
				5.94	10
22. Salangselva—Sørdalen	68° 40′—18° 25′	1925—33			
Glaciers between Sørdalen—Isdalen			5.20		
Stordalen—Isdalen—Melhusskardet			15.82		
Lifjellbreen			3.45		
Eriksfjellbreene			4.30		
				28.77	25
23. Sørdalen—Altevatn	68° 35′—19° 00′	1925—33			
12 glaciers				8.10	12
24. Austvågøy	68° 20′—14° 45′	1894—99			
Trolltindbreene			5.20		
Blåfjellbreene			2.04		
Various small glaciers			3.19		
				10.43	32
25. Hinnøy	68° 40′—15° 45′	1899—1911			
Memurutindbreen			1.03		
Møysalbreen			0.67		
Øvre Storelvvatn			0.52		
Forselvtindbreen			0.40		
Djupfuttindbreen			0.23		
Durmålstindbreen			0.11		
Vestbotntindbreene (2)			0.87		
Løbergdalstindbreene (6)			1.40		
Botntindbreene (2)			0.36		
Stortindbreene (3)			0.63		
Bloktindbreene (3)			0.20		
Småfjellbreen			0.40		
Various small glaciers			1.04		
				7.86	29
26. Ofoten—Gratangen—Tjeldsundet	68° 35′—17° 10′	1900—02			
Stitendalsfjellbreen			3.53		
Slettfjellbreene (3)			0.17		
Dragvikfjellbreen			0.92		
				4.62	5
27. Rombakken—Gratangen—Salangselva—Frontier Norway—Sweden	68° 35′—18° 00′	1900—01			
Nevertindbreen			6.54		
Istindbreen			3.97		
Snøtindbreen			2.84		
Rivtindbreen			4.47		
Vassdalsfjellbreen			0.19		
Melkefjellbreen			2.77		
Grønfjellbreen			2.10		
Leigastindbreen			0.71		
				23.59	8

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
28. Rombakken—Skamdalen—Norddalen	68° 15′—17° 50′	1900—16			
Storsteinsfjellbreen			29.03		
Oalláčókkabreen			20.69		
Sækačókkabreen			5.92		
Bassečókkabreen			2.17		
Vambtind			0.50		
Blåisen			10.45		
Helligvatn			4.33		
Nikkivatnbreen			5.10		
Beisfjordtøttbreen			1.08		
Silviktindbreen			0.23		
Detasjementbreen			0.42		
13 small glaciers			0.64		
				80.56	24
29. Skamdalen—Skjomen	68° 15′—17° 30′	1900—16			
Sandvikfjellbreen			3.13		
Elvegardstindbreen			1.57		
Stortindbreen			0.87		
Rapisflagbreen			0.70		
Haugbaktindbreen			0.13		
Gangnestindbreen			0.10		
Nikkitoppbreen			0.34		
Tverrdalstind			0.20		
Kongsbakktindbreene			2.81		
Other small glaciers			0.64		
				10.49	20
30. Frostisen and surroundings	68° 15′—17° 10′	1909—16			
Frostisen			33.45		
Reintindbreen			1.58		
Mereftasbreen			8.24		
Storitbreen			0.53		
Rånkeipbreen			0.47		
Rundtindbreen			0.40		
Tverrfjellbreene (2)			1.13		
Sepmollfjellbreen			0.97		
				48.77	10
31. Skamdalen—Frontier Norway—Sweden	68° 05′—17° 50′	1915—16			
Čaarvvevarrebreen			14.77		
Unnariepasvarrebreen			8.87		
Durmålstindbreen			7.02		
Čainnačokkabreen			2.44		
Trehakkfjellbreen			2.93		
Jovaskjørisbreen			1.64		
Juovvavarrebreen			0.40		
				38.07	7
32. Frostisen—Giccečokka	68° 05′—17° 10′	1907—16			
Fonntindbreene			12.30		
Isfjellbreene			10.05		
Baugefjellbreene			5.70		
				28.05	7

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
33. Indre Tysfjord—Efjorden	68° 10′—16° 30′	1909—16			
Norddalsisen			1.47		
Koptindbreen			1.17		
Hundhodbreen			0.57		
Mølntindbreen			0.37		
Gammelloffjellbreen			0.23		
Presttindbreene			1.20		
5 small glaciers			2.14		
				7.15	13
34. Giccečokkabreen					
35. Sagfjord—Hellemofjorden	67° 55′—16° 10′	1904—08			
Spisstindbreene			0.92		
Skuŋkivarrebreene			0.83		
Gussavarrebreene			0.80		
Various small glaciers			1.50		
				4.05	6
36. Nordfolda—Sagfjorden	67° 50′—15° 40′	1904—08			
Nondagstindbreen			3.90		
Kalvtindbreen			2.92		
Røntindbreen			0.80		
Stordalstindbreen			0.37		
Durmålstindbreen			0.27		
3 small glaciers			1.50		
				9.76	8
37. Tjorrofjell	67° 45′—16° 30′	1907—15			
Tjorrofjellbreen				1.90	1
38. Korken—Agjagvarre—Frontier Norway—Sweden	67° 40′—16° 00′	1904—15			
Korkenbreen			1.40		
Agjagvarrebreen			7.14		
Kirkefjellbreen			2.27		
Slædovagvarrebreen			3.43		
Langfjellbreene			0.97		
Sildhopfjellbreene			1.99		
Njuorjovarrebreen			1.03		
Raskavarrebreen			3.37		
Various small glaciers			1.50		
				23.10	19
39. Sørfolda—Nordfolda	67° 35′—15° 30′	1904—08			
Helldalsisen			4.50		
Reinviksisen			3.27		
Snøskavlstindbreen			0.60		
				8.37	3
40. Nordfolda—Leinesfjord	67° 40′—15° 00′	1901—02			
Kråktindbreene				0.97	3

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
41. Veikdalsisen—Hurrejiekna	67° 40′—16° 20′	1904—15			
Veikdalsisen			10.63		
Gaskačokkabreen			0.56		
Slædočokkabreen			1.10		
Ridoalkebreen			18.97		
Snjaskavarrebreen			6.30		
Langvassfjellbreene			1.76		
Small glaciers south of Reinoksvatn			1.42		
				40.74	12
42. Sørfolda—Frontier Norway—Sweden	67° 25′—15° 50′	1906—08			
Flatkjølen			43.27		
Siidasjiekŋa			16.66		
Gieddoaivejiekŋa			6.17		
Veikekčorrobreene (3)			6.06		
11 small glaciers			1.25		
				73.41	17
43. Blåmannsisen and surroundings	67° 15′—16° 10′	1904—07			
Blåmannsisen (Olmaiallojiegŋa)			123.53		
Fagerbakkfjellbreen			7.27		
Store Tverråfjellbreen			5.30		
Stormfjellbreen			4.67		
Skoffedalsfjellbreen			4.00		
Laksåtuvabreen			0.13		
Småsorjusvatnbreene			0.33		
				145.23	9
44. Sulitjelma and surroundings	67° 05′—16° 10′	1904—07			
Sulitjelmabreen (the part of the gl. in Norway, 28 sq.km in Sweden)			40.10		
Sorjusčokkabreene			10.16		
Meňemfjellbreene			2.46		
Vaššavarrefjellbreene			3.55		
Kjærtoppenbreen			0.53		
				56.80	10
45. Saltdalen—Sulitjelma	67° 05′—15° 50′	1904—07			
Storfjellbreen			1.80		
Baldoaivvebreene			0.30		
				2.10	7
46. Junkerdal—Balvatnet	66° 55′—15° 40′	1908—14			
Biierdnačokkabreene			6.22		
Argaladeičokkabreene			5.74		
Salefjellbreene			4.96		
Various small glaciers			3.37		
				20.29	20
47. Junkerdalen—Nasa	66° 40′—15° 30′	1895—1914			
Dybenåfjellbreene			3.10		
Viskisfjellbreene			3.20		
				6.30	9

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
48. Bjellådalen—Dunderlandsdalen—Lønsdalen	66° 40′—15° 10′	1894—1914			
Stabursfjellbre, Nordre			1.30		
Stabursfjellbre, Søre			1.83		
Stabursfjellbre, Vestre			0,26		
Lønstindbreene			4.41		
Steindalstindbreene			3.42		
Semskefjellbreene			2.42		
Ørfjellbreene			2.17		
Akjektindbreene			0.20		
Bolnabreene			2.90		
Fetterbakbreene			1.00		
Raudfjellbreene			0.85		
Various small glaciers on Kjærringfjellan			4.20		
				24.96	21
49. Stormdalsåga—Bjellådalen—Beiardalen	66° 40′—14° 50′	1894—1905			
Steinfjellbreen			23.30		
Hængefjellbreen			8.86		
Steintoppbreen			2.77		
Staupåtindbreen			0.83		
7 small glaciers			3.97		
				39.73	11
50. Gråtådalen—Beiardalen—Bogvatnet	66° 45′—14° 30′	1898—1905			
Spisstindbreen			20.49		
Skjelåtindbreene and Stormyrtindbreene			7.80		
Bogvatnbreen			3.70		
Spisstindbreen			2.07		
				34.06	6
51. Gråtådalen—Glomdalen—Arstaddalen	66° 55′—14° 30′	1898—1905			
Nordre Glomvassfjellbreen			4.60		
Vegdalsfjellbreen			2.53		
Heinberget—Simleelven			34.20		
Habretind—Svarttind			32.42		
Skavlfjellbreen			0.57		
6 glaciers on Nansfjell—Klampen			5.16		
				79.48	11
52. Glomfjord—Arstaddalen and the coast	66° 55′—14° 00′	1896—1899			
Glombreen			11.70		
Sokumfjellbreen			1.63		
Urfjellbreen			0.53		
Rebenfjellbreene			0.40		
Ruffenbreene			0.55		
				14.81	8
53. Svartisen	66° 35′—14° 00′	1894—1905			
Vestre Svartisen			268.35		
Østre Svartisen			199.75		
Skaviktindbreen			3.20		
Glomvassfjellbreen			1.50		
Mugskogtindbreene			3.70		
				476.50	5

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
54. Dunderlandsdalen—Blakkådalen—Stormdalsåga	66°30′—14°30′	1894—99			
Stormdalsfjellbreene			20.70		
Ørtfjellbreene			16.10		
Svartisfjellbreene			13.00		
Kuhaugfjellbreen			0.36		
				50.16	4
55. Dunderlandsdalen—Mofjell—Frontier Norway—Sweden	66° 20′—15° 00′	1891—99			
Melkfjellbreen			4.75		
Junkerbreen			4.77		
Blerekvassbreene (2)			1.65		
				11.17	5
56. Melfjord—Langvatnet	66° 25′—13° 40′	1895—97			
Høgtuvbreen			38.80		
Raudskredbreen			3.18		
Kjerringviktindbreen			1.00		
5 glaciers on Snefjell			7.30		
				50.28	8
57. Okstindan — Mo i Rana	66° 10′—14° 10′	1891—94			
6 glaciers in S. Rana			2.40		
8 glaciers in N. Rana			1.76		
				4.16	14
58. Okstindan	66° 00′—14° 10′	1885—94			
Okstindbreen			65.60		
Oksskoltbreen			1.00		
Charles Rabots Bre			0.80		
Corneliussens Bre			3.00		
Svartfjellbreen			3.20		
				73.60	5
The last mentioned four names do not exist on the official maps, only in Hoel: Okstindene (1910).					
58a. Surroundings of Okstindan	66° 00′—14° 10′	1885—94			
Glaciers N. of Okstindbreen (2)			0.40		
Glaciers E. of Okstindbreen, on Skullenfjell (2)			0.50		
Glaciers S. of Okstindbreen (10)			5.00		
				5.90	14
59. Toven	66° 05′—13° 20′	1891—94			
Tovenbreene (6)				5.40	6
60. Røsvatn—Frontier Norway—Sweden	65° 45′—14° 30′	1890—92			
13 small glaciers				11.10	13
61. Røsvatn—Vefsendalen	65° 45′—14° 30′	1888—94			
Luktindbreene			10.40		
Brurskankbreene (3)			1.50		
Gjeittindbreene			1.50		
				13.40	9

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
62. Velfjorden—Nordland Railway	65° 25′—13° 10′	1885—89			
Blåfjellbreene (4)			4.95		
36 glaciers on Langskardnesen—Langskardfjell—Jordhulefjell			20.12		
43 small glaciers Vestfjell—Maskardtind			14.27		
			——	39.34	83
63. The Nordland railway—Vefsna and Fiplingvatn	65° 25′—13° 30′	1883—92			
Kapfjellbreene				2.31	13
64. Børgefjell	65° 25′—14° 50′	1883—92			
Golverfjellbreene (3)			4.38		
Løypskardtindbreene (9)			11.95		
Løypskardfjellbreene (3)			3.70		
Sandskardfjellbreen			2.05		
Lilleveiskardklumpen			1.65		
Storklumpen			1.65		
Skinnfjellbreene			2.40		
Kvigtindbreen			4.30		
Simskardfjellbreene			2.60		
Mjølkolskardbreene			1.50		
Sklettfjellbreen			1.20		
Gaksfjellbreene			1.90		
Rørskardfjellbreene			0.70		
Møsskardfjellbreen			0.80		
Various small glaciers			5.20		
			——	45.98	45
65. Store Børgefjell	60° 05′—14° 00′	1883—89			
Sipmektindbreene (3)			1.10		
Govletefjellbreene			1.65		
Viermafjellbreene			1.25		
14 small glaciers			3.70		
			——	7.70	27
Total area of glaciers and of perennial snow-fields in Northern Norway			1954 sq.km		
Total number of glaciers and perennial snow-fields in Northern Norway			792		

Southern Norway.

	Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
66.	Lesja—Drivdalen	62° 30′—9° 10′	1869—79 1877—81 1919—35		7.2	26
67.	Romsdal—Sunndalen	62° 40′—8° 10′	1869—79		20.0	41
68.	Skjåk—Tafjord—Romsdalen	62° 20′—7° 40′	1869—79		57.5	74
69.	Geiranger—Tafjord	62° 20′—7° 15′	1869—79			
	Breidalsbreen			14.3		
	Other glaciers			14.4		
					28.7	18
70.	Hjørundfjorden—Storfjord—Sunnylvsfjord—Norangsfjord	62° 20′—6° 40′	1869—79		13.0	41
71.	Volda—Vartdal Hjørundfjorden	62° 15′—6° 20′	1869—79		9.2	35
72.	Hornindal—Geiranger—Grotli—Strynsvatn	62° 00′—7° 00′	1863—79		48.3	38
73.	Norangsfjord—Sunnylven—Hornindal	62° 10′—6° 35′	1869—79		10.5	17
74.	Dalsfjord—Ørstafjord—Hornindalsvatn	62° 00′—6° 10′	1869—79		7.9	8
75.	Ålfotbreen	61° 45′—5° 40′	aerial photo 1945		68.4	12
76.	Breimsvatn—Gjengedal	61° 40′—6° 10′	aerial photo 1945			
	Blådalsbreen			2.3		
	6 small glaciers			2.6		
					4.9	7
77.	Jostedalsbreen with surrounding glaciers	61° 40′—7° 00′	Amtskart 1: 200 000 (county map) 1863—71 revised aerial photo 1945			
	Vestre Jostefonn			20.6		
	Austre Jostefonn			13.4		
	Grettenbreen			1.7		
	Melsnipabreene			0.9		
	Gotoppfjellbreen			0.2		
	Grovbreen			25.2		
	Steindalbreen			6.4		
	Søre Svartdalsbre			8.4		
	Nordre Svartdalsbre			4.4		
	Vestre Eldedalsbre			0.1		
	Midtre Eldedalsbre			0.4		
	Austre Eldedalsbre			0.4		
	Vestre Bukkabre			1.6		
	Nordre Bukkabre			1.2		
	Søre Bukkabreene (2)			0.9		
	Nordre Torstadnakkbreen			2.0		

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
Tverrdalsbreen			5.2		
Nordre Hestebre			4.8		
Søre Hestebre			0.8		
Vassdalsbreen			4.0		
Listølbreen			2.8		
Røykjedalsbreen			2.6		
Veslenib-breen			1.4		
Lodalsbreen			1.0		
The main plateau of Jostedalsbreen with outflows			473.3		
Ramnafjellbreen			6.4		
Snønipabreen			72.0		
Gls. bordered by Loen, Strynsvatnet and Lodalskåpa			19.8		
Glaciers N. of Seterfjellet			2.2		
Kvitenåvbreene (2)			27.1		
Raneggbreen			5.6		
Sandgrovbreen			6.0		
Skridulaupbreen			2.8		
Sikkel- and Sikkebreene			22.2		
Tverreggbreen			1.8		
Austdalsnutbreen			3.2		
Sproteggbreen			27.2		
Vangsbreene			1.6		
Rivenåskulen			10.4		
Fortundalsbreen			23.2		
				815.2	76
78. Jotunheimen	61° 20′—61° 50′— 7° 40′—9° 00′				
a. Hestbrepiggene—Lomseggi		1939—42			
Høybreene			9.95		
Lundadalsbreen			1.71		
Ystebreen			3.78		
Heimstebreen			3.68		
Gjeitåbreen			1.19		
Runningsbreen			4.91		
Sulbreen			1.06		
32 small glaciers			6.17		
				32.45	36
b. Glittertind—Trollstein		1931—34			
Smiugjelsbreen			1.00		
Vestre Grotbreen			4.30		
Austre Grotbreen			3.17		
Gråsubreen			3.65		
Glitterbreen			2.35		
Lauvhøbreen			0.07		
5 small glaciers			0.80		
				15.34	11
c. Memurutind—Surtningssuen		1931—34			
Leirhøbreen			3.15		
Veobreen			10.97		
Stygghøbreen			6.59		
Blåtjønnbreen			4.33		
Surtningsbreene			2.79		
V. Memurubre			9.96		
Hellstugubreen			4.44		
A. Memurubre			10.04		
15 small glaciers			5.15		
				57.42	23

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
d. Smørstabbtindane—Loftet		1936—38			
Smørstabbreen			15.30		
Leirtjønnbreen			6.03		
Bjønnbreen			1.81		
Storbreen i Leirdalen			6.05		
Veslebreen			1.81		
Hurrbreen			2.55		
Høgskriubreen			0.50		
Brangsbreen			0.44		
16 small glaciers			2.53		
				37.02	24
e. Fannaråki		1936			
Fannarådbreen			9.70		
6 small glaciers			1.07		
				10.77	7
f. Hurrungane		1936—38			
Styggedalsbreen			2.35		
Gjertvassbreen			2.05		
Maradalsbreen			2.70		
Skagastølsbreen			1.55		
Ringsbreen			2.79		
Midtmaradalsbreen			1.29		
Stølsmaradalsbreen			2.68		
Berdalsbreen			1.25		
Isvassbreen			1.30		
19 small glaciers			4.53		
				22.49	28
g. Galdhøpiggen and surroundings		1931—34			
Storgjuvbreen			5.18		
Storgrovbreen			1.45		
Heimre Illåbre			1.85		
Nordre Illåbre			4.03		
Søre Illåbre			5.83		
Veslgjuvbreen			1.22		
Styggebreen			6.08		
Svellnåsbreen			5.01		
Tverråbreen			6.50		
Bukkeholsbreen			3.65		
Tverbotbreen			1.65		
14 small glaciers			4.65		
				47.10	25
h. Tyin—Utladalen—Gravdalen—Langvatnet—Veslådalen		1931—38			
Skogadalsbreen			3.40		
Urdanåsbreen			3.72		
Sagabreen			1.46		
Mjølkedalsbreen			3.80		
Koldedalsbreen			3.92		
Stølsnåsbreen			2.75		
Falkebreen			1.75		
Kristenbreen and Alvebreen			2.95		
Sjogholstindbreen			0.26		
Høgvaglbreen			2.71		
Visbreen			2.71		
Semmelbreen			1.52		
51 small glaciers			8.90		
				39.85	63

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
j. To the west of Svartdalen		1871—74			
Slettemarkbreen			2.10		
Uksedalsbreen			1.88		
Langedalsbreen			1.04		
Turfinnsbreen			1.29		
Svartdalsbreen			1.65		
10 small glaciers			3.17		
				11.13	16
k. To the north of Leirungsdalen		1871—74			
Knutsholbreen			4.50		
Skarflybreen			1.60		
Skarflyløyftbreen			2.10		
Tjønnholbreen			2.30		
Steinflybreen			1.00		
18 small glaciers			5.42		
				16.92	23
l. To the south of Leirungsdalen		1871—74			
Leirungsbreen			1.97		
Steindalsbreen			2.45		
Kalvåholsbreen			1.31		
12 small glaciers			4.67		
				10.40	15
m. Besshø		1931—34			
Vestre Besshøbre			1.50		
1 small glacier			0.02		
				1.52	2
n. Nautgarstind		1932			
5 small glaciers				2.67	5
o. Kvittingskjølen		1932			
1 small glacier				0.12	1
p. Tundradalen—Lundadalen		1932—42			
Holåbreen			15.82		
Ytre Gjelåbre			3.18		
Midtre Gjelåbre			2.60		
Grjotåbreen			2.46		
23 small glaciers			4.88		
				28.94	27
The total area in Jotunheimen			333.84	sq.km	
The total number of glaciers in Jotunheimen			306		
79. Vangsmjøsi—Tyin—Bygdin	61° 15′—8° 30′	1922—31			
Vennisfjellbreene (5)			1.80		
Var. small glaciers NE of Høgeggi			1.80		
Hundesteinbreen			0.10		
Skavletjernbreen			0.65		
Trollfonni			0.20		
Snøseggbreen			0.60		
Mathamarskarvbreene			1.50		
Remmiskinntjernbreene			1.20		
Landetjernbreen			0.40		
				6.65	18

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
80. Årdal—Tyin—Lærdal	61° 10′—7° 50′	1934—38			
Raudbergsnutbreen			0.45		
Berdalsekbreene (5)			1.25		
				1.70	6
81. Fillefjellsvegen—Hemsedalsvegen—Helin	61° 05′—8° 20′	1917—38			
Storebottfonni			0.50		
Bjørnosbreene			0.10		
Gls. SW of Sulevatn			0.25		
Tverrfjellbreene			0.10		
Glacier S. of Sulevatn			0.30		
Glacier on Juklegg			0.20		
Sulefjellbreene (3)			0.13		
				1.58	14
82. Aurlandsdalen—Lærdalsøra—Sognefjorden	61° 00′—7° 20′	1932—47			
Blåskavlen			4.70		
3 glaciers W. of Blåskavlen			1.13		
Glacier SE of Blåskavlen			0.25		
Langfonnen			0.38		
Tissedalsskavlen			0.10		
Fagerdalsnutbreene			0.06		
Bleiefjellbreene (2)			0.55		
				7.17	11
83. W. of Voss—Nærøyfjorden	60° 50′—6° 20′	1929—47			
Fresvikbreen			16.69		
Blåfjellbreen			0.44		
Fossfjellbreen			0.30		
Nordhaugfjellbreene (3)			0.44		
Syringfjellbreen			0.30		
Moldbakkefjellbreen			0.18		
Engjafjellbreen			0.11		
Bassfonni			0.09		
7 small glaciers			4.31		
				22.75	17
84. The Oslo—Bergen railway—Strandafjorden—Aurland	60° 40′—7° 40′	1920—29			
Hallingskarvbreen			18.03		
Eimefonni			0.30		
Storskavlen			9.13		
Vargebreen			2.06		
Dyranosbreene (2)			0.40		
Various small glaciers at Skomåvatn			9.59		
4 glaciers at Omnsvatn (4)			0.35		
Svartvassbreen			0.50		
Store Vargenutbreene (2)			0.45		
Glacier S. of Storskavlen			0.15		
Glacier S. of Hednedalsvatn			0.12		
Glacier E. of Lille Vargevatn			0.06		
Glacier E. of Hallingskeid			0.11		
Glacier W. of Vargebrefjell			0.20		
Glacier W. of Nydlovatn			0.33		
Various small glaciers			16.26		
				51.14	95

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
85. Oslo—Bergen railway—Flåmsdalen—Vossestrand	60° 50′—7° 00′	1929—36			
Nordre Øyaskavlen			0.95		
Søre Syrdalsbreen			0.73		
Fossdalskavlen			0.50		
5 small glaciers			0.86		
				3.04	8
86. Simadal—Hallingskeid—Oslo—Bergen railway—Bergen—Eide railway	60° 35′—6° 50′	1927—35			
Onenbreene			3.15		
5 glaciers on Osaskavlen (5)			3.37		
Såteskavlen			1.45		
Vassfjørabreene (2)			1.75		
Kyrelvfjellbreen			0.05		
Bratteskavlen			0.50		
Vossaskavlen			0.95		
Various small glaciers			3.37		
				14.07	33
87. The Oslo—Bergen and Bergen—Eide railways Hardangerfjorden	60° 30′—6° 20′	1927—34			
11 small glaciers				0.53	11
88. Hardangervidda	60° 20′—7° 30′	1936			
Nupsfonn			21.0		
Middyrsrustbreen			0.6		
Nupseggbreen			0.5		
Rekingsnutbreen			0.5		
Sandfloeggbreene			7.0		
Årmoteggbreen			0.7		
Belganutbreene			5.4		
Bjørnarnutbreene			3.2		
Storafonn			10.0		
Revseidbreen			0.8		
Svartnutbreen			1.0		
Solfonn			5.2		
Storekallbreene			2.1		
Veslekallbreene			0.8		
Tresfonn			2.8		
Vargbreene			1.7		
Blåbergseggbreen			0.4		
Selbreen			0.5		
Langvassfjellbreen			0.4		
Svartenutbreen			0.4		
Dyrafonn, E.			1.5		
Dyrafonn, W.			0.2		
Kvannefjellbreen			0.8		
Vassdalsnutbreen			0.1		
Hardangerjøkulen (1955)			78.2		
				145.6	33
89. Folgefonni and glaciers around Folgefonni	6° 10′—6° 30′	1927—53			
Nordre Folgefonni			31.05		
Midtre Folgefonni			13.45		
Søre Folgefonni			180.55		
				225.05	3

Name of glaciers	Lat. N. Long. E. Gr.	Surveyed year	Area sq.km	Area sq.km	Number
Brottefonn			1.20		
Solnutbreen			0.43		
Torsnutbreen			0.33		
Botnahorgbreen			0.25		
Vreanutbreene			1.58		
Small glaciers W. of Blådalen			0.75		
				4.54	11
90. Breifonn	59° 46′—6° 40′	1955		3.2	1

Total area of glaciers in southern Norway .... 1910 sq.km

Total number of glaciers in southern Norway 950

Total area of glaciers and snowfields in Norway ca. 3900 sq.km
or 1.2 per cent of the area of the country.

Total number of glaciers and snowfields in Norway ca. 1750.

GROUPED ACCORDING TO ADMINISTRATIVE DISTRICTS

The figures according to the tables above.

District	Area of the glaciers sq.km	Area of the district sq.km	Percentage of the glaciated area to the district
Finnmark			
Kvalsund	6.80	1 779.82	0.38
Loppa	52.05	694.53	7.49
Sørøysund	24.40	857.09	2.85
Talvik	28.02	1 649.97	1.68
Troms			
Andørja	2.25	135.36	1.66
Astafjord	4.62	310.06	1.49
Balsfjord	12.90	1 228.29	1.05
Bardu	51.87	2 667.21	1.94
Berg	0.19	287.77	0.07
Dyrøy	1.27	253.08	0.50
Gratangen	1.30	312.76	0.41
Hillesøy	1.56	461.22	0.34
Karlsøy	10.90	772.57	1.41
Kvæfjord	2.04	658.01	0.31
Kvænangen	35.00	2 081.40	1.68
Kåfjord	2.20	879.56	0.25
Lavangen	5.05	312.24	1.61
Lenvik	0.69	705.02	0.10
Lyngen	41.50	554.86	7.48
Målselv	16.31	1 185.14	1.38
Nordreisa	3.10	2 832.37	0.11
Salangen	2.17	449.35	0.48
Skjervøy	2.80	1 160.95	0.24
Storfjord	9.30	1 583.19	0.59
Sørreisa	0.38	374.22	0.10
Tranøy	0.58	469.66	0.12
Tromsøysund	3.90	1 529.93	0.25
Ullsfjord	14.40	657.79	2.19
Øverbygd	7.00	2 103.95	0.33
Nordland			
Ankenes	157.47	2 028.03	7.77
Ballangen	3.72	500.94	0.74
Beiarn	119.88	1 223.34	9.80
Bindal	1.07	1 511.97	0.07
Bodin	0.43	663.30	0.06
Drevja	2.60	195.68	1.33
Elsfjord	8.90	286.98	3.10
Evenes	27.82	246.03	11.31
Fauske	162.58	1 208.10	13.46
Gildeskål	7.92	664.44	1.19
Grane	49.96	2 017.43	2.48
Hadsel	7.46	710.26	1.05
Hamarøy	43.75	1 200.26	3.65
Hattfjelldal	68.04	3 108.60	2.19
Kjerringøy	0.50	176.13	0.28
Korgen	51.90	625.54	8.30
Leiranger	5.05	185.24	1.61
Leirfjord	2.53	271.67	0.93
Lurøy	0.05	262.32	0.02
Lødingen	16.53	1 050.05	1.58

District	Area of the glaciers sq.km	Area of the district sq.km	Percentage of the glaciated area to the district
Meløy	199.98	871.18	22.95
Nesna	8.12	588.49	1.38
Nordfold	17.45	560.81	3.11
Nord-Rana	373.41	3 980.84	9.48
Rødøy	60.95	705.66	8.64
Saltdal	51.40	2 213.14	2.32
Sortland	1.81	425.82	0.42
Sørfold	142.52	1 558.70	9.14
Sør-Rana	24.00	776.95	3.09
Tjeldsund	0.40	222.82	0.18
Tysfjord	72.56	1 449.24	5.01
Vefsn	14.95	1 197.51	1.25
Velfjord	0.69	600.21	0.12
Vågan	3.35	283.27	1.18
Nord-Trøndelag			
Røyrvik	3.60	1 584.96	0.23
Sør-Trøndelag			
Ålen	0.4	718.08	0.05
Oppdal	13.86	2 466.31	0.56
Rennebu	0.13	724.36	0.018
Selbu	0.1	1 254.20	0.007
Møre og Romsdal			
Eresfjord and Vistdal	15.79	758.23	2.08
Grytten and Hen	39.37	1 044.48	3.77
Hjørundfjord	34.23	479.11	7.14
Norddal	62.43	947.67	6.59
Øksendal—Ålvundeid	11.44	408.06	2.80
Ørskog	0.73	200.85	0.36
Rindal	0.70	600.53	0.12
Stangvik	1.23	510.99	0.24
Stordal	0.79	259.28	0.30
Stranda	3.77	267.67	1.41
Sunndal	22.49	1 229.84	1.82
Sunnylven	29.60	566.32	5.23
Surnadal	1.60	870.52	0.18
Sykkylven	12.82	261.05	4.91
Vartdal	0.79	123.44	0.64
Vestnes	1.00	158.31	0.63
Voll	9.51	260.81	0.36
Sogn og Fjordane			
Aurland	31.2	1 484.08	2.10
Balestrand	74.1	612.74	12.09
Breim	32.9	373.50	8.81
Davik	39.4	651.18	6.05
Førde	20.1	522.55	3.85
Gloppen	21.2	701.04	3.02
Hafslo	110.2	645.60	17.07
Innvik	70.0	511.35	13.69
Jostedal	150.1	532.97	28.16
Jølster	91.3	670.76	13.61
Kinn	10.0	166.51	6.01
Leikanger	17.8	460.01	3.87
Luster	151.6	1 526.87	9.93

District	Area of the glaciers sq.km	Area of the district sq.km	Percentage of the glaciated area to the district
Lærdal	3.1	589.55	0.53
Sogndal	9.7	434.65	2.23
Stryn	134.9	904.79	14.91
Vik	6.8	723.66	0.94
Årdal	21.8	988.47	2.20
Hordaland			
Eidfjord	71.90	1 501.95	4.79
Evanger	0.22	590.55	0.04
Hålandsdal	2.81	130.66	2.15
Jondal	4.36	233.07	1.87
Kinsarvik	2.65	392.48	0.68
Kvinnherad	87.68	847.01	10.35
Odda	70.36	908.10	7.75
Røldal	6.40	670.85	0.95
Samnanger	1.59	265.46	0.59
Ullensvang	17.44	1 209.34	1.44
Ulvik	56.75	841.42	6.74
Voss	2.78	928.01	0.03
Vossestrand	0.75	536.16	0.14
Rogaland			
Suldal	1.0	1 219.46	0.08
Telemark			
Vinje	3.0	1 261.32	0.24
Buskerud			
Hemsedal	0.07	831.91	0.008
Hol	17.21	1 765.47	0.97
Oppland			
Dovre	3.20	1 484.07	0.22
Lesja	12.70	2 218.76	0.57
Lom	157.14	1 954.98	8.04
Skjåk	144.95	2 137.50	6.78
Vang	25.10	1 638.52	1.53
Vågå	41.33	1 313.06	3.15
Ø. Slidre	0.78	869.50	0.09

TOTAL GLACIER AREA BY COUNTIES

Name of the county	Area of the counties sq.km	Area of the glaciers sq.km	Percentage of glaciated area to the area of the county
Finnmark	48 690	111	0.23
Troms	26 084	234	0.90
Nordland	38 325	1 710	4.46
Nord-Trøndelag	22 423	14	0.06
Sør-Trøndelag	18 823	4	0.02
Sogn og Fjordane	18 499	996	5.38
Rogaland	9 177	1	0.01
Oppland	25 318	385	1.52
Møre og Romsdal	15 047	129	0.86
Hordaland	15 865	393	2.47
Telemark	15 217	3	0.02
Buskerud	14 764	18	0.12

Areas of total land surface and glaciers in the Norwegian territories in the polar regions

SVALBARD

The figures for this archipelago have been computed on the basis of maps of very varying quality, viz.:

1) Maps on the scale of 1:50 000 constructed from aerial photographs from 1936 and 1938. These maps, some of which are published on the scale of 1:100 000, comprise the west part of Vestspitsbergen between Sørkapp and Isfjorden. The total land area covered by these maps is 5,300 sq.km and the area of the glaciers 1,700 sq.km.

2) Maps on the scale of 1:200 000 constructed from aerial photographs taken in 1936 and 1938. They comprise the eastern portion of Vestspitsbergen between Sørkapp and Agardhbukta. The total land area is 6,900 sq.km and the area of the glaciers 4,400 sq.km.

3) Maps on the scale of 1:200 000, surveyed by Gunnar Isachsen's expeditions in 1906, 1907, 1909 and 1910. They comprise the western portion of Spitsbergen between Isfjorden and the north coast of the country. The total land area is 9,700 sq.km, and the area of the glaciers 5,500 sq.km.

4) Maps on the scale of 1:1 000 000. Many of these are old maps or sketches, comprising the eastern part of Spitsbergen from the north coast to Agardhbukta, Nordaustlandet, Barentsøya and Edgeøya. The total land area mapped to this scale is 39,900 sq.km and the area of the glaciers 23,500 sq.km.

As the eastern parts of Spitsbergen have been measured on the maps on a scale as small as 1:1 000 000 the glacier areas given are undoubtedly too small.

JAN MAYEN

The figures for this island have been calculated on maps on the scale of 1 : 50 000, based on aerial photos made in 1949 and 1955 by Norsk Polarinstitutt.

BOUVETØYA

The computations referred to were carried out in 1950 from Riiser-Larsen's map to the scale of 1 : 100 000 made on the third "Norvegia" expedition in 1929—30. This map was first published in BjarneAagaard's work, "Fangst og Forskning i Sydishavet", Vol. 3, Oslo 1934, p. 887.

PETER I ØY

Computations were undertaken from Nils Larsen's map constructed in 1929 to the scale of 1: 200 000. This map, too, was first published in Aagaard's work mentioned below, p. 889.

DRONNING MAUD LAND

The computation was carried out in 1939 on the basis of a map constructed by Norges Svalbard- og Ishavs-undersøkelser on the basis of Stieler's Atlas. It was published in the press the same year. The computation is included in Bjarne Aagaard's work, "Antarktis 1502—1944", Oslo, 1944. Norges Svalbard- og Ishavsunders., Meddelelser Nr. 60.

These three antarctic areas comprise the entire land area, but the area of the ice-free land is in every case very small, so that the figures may be taken to apply to the glacial cover.

THE RESULTS

Name	Total land area sq.km	Area of the glaciers sq.km	Glacier area shown as a percentage of the total land surface
In the Arctic:			
Svalbard			
Vestspitsbergen	39 044	21 240	54.4
Nordaustlandet	14 530	11 135	76.6
Edgeøya	5 030	1 880	37.4
Barentsøya	1 330	490	36.8
Prins Karls Forland	640	109	17.0
Storøya	35	17	49.0
Kvitøya	265	253	95.5
Other islands with only minor glaciers	331	0	0
Bjørnøya	178	0	0
Total	61 383	35 124	57.2
Jan Mayen	375	125	33
In the Antarctic:			
Bouvetøya	59	close on 59	close on 100
Peter I øy	249	close on 249	close on 100
Dronning Maud Land	2 756 000	close on 2 765 000	close on 100

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GLACIER FLUCTUATIONS

Glacier fluctuations in pre-historic times

During the glacial periods of the Quaternary Ages, glaciers were far more extensive than they are today. In the last Ice Age glaciers at their maximum extent covered a total of approximately 27 per cent of the earth's land surface, as opposed to 10.1 per cent today. This maximum occurred some 20 000 years ago. The country at that time was probably entirely covered with glaciers, apart from some small areas, nunataks and costal stripes in the west and north, which were possibly ice-free.

The general retreat following the maximum extent was interrupted by minor advances. One of these, at about 8 500 B.C. left conspicious terminal moraines on both sides of Oslofjorden and further down the southern part of Norway.

During the postglacial warm period the summer temperatures were much higher than at present. Birch and pine extended 200—300 m higher than they do today and most of the glaciers disappeared in Norway.

From c. 500 B.C. air temperature was sinking and humid and cold climate set in. Under these climatic conditions the glaciers reappeared, and large stretches of what had been forests became peat bogs. This climate has since in the main continued, even though there have been better conditions in some periods.

Glacier fluctuations before the 18th century

Trustworthy reports of the variations of our glaciers were forthcoming only from the beginning of the 1700's. Some knowledge of older variations can be deduced, however, from archeological finds.

The oldest available evidence of glacier variation in Norway is provided by arrow-heads found near snow-fields in the Oppdal—Dovre district.

The first of these arrow-heads were found in 1937 by a hotel manager Michael Thøring and his son on Storhø in the Dovre Massif. At the spot where these weapons were found there was no snow. They were believed to have been shot by a reindeer hunter.

These arrow-heads have been preserved complete with wooden shafts and lashing, and in some cases even with feathers intact. They are so well preserved that they must have been hidden in snow almost from the day they were lost until they were found. This proves that the surface of their resting place must have been more or less the same when the arrows were shot, as it is today.

The oldest of these arrow-heads dates back to 400—500 A. D. The youngest to about 1500. Since that time the snow- and ice-cover must on the whole have increased until about 1750, when a general retreat of our glaciers set in. This retreat has, as will be shown below, continued up to our time, though interrupted by some minor advance.

Bjørn Hougen (1937, pp. 197—204) has described the arrow-heads from Storhø. Other finds of such weapons were made in Oppdal 1936 (ibid. p. 199). Knut Fægri has also dealt with the problem (1937, p. 12; 1940, pp. 5—14; 1948, pp. 230—243).

But these arrow-head finds are not the only direct evidence of glacier oscillations in comparatively recent time.

Another kind of find was made in 1936 by the farmer and tourist guide Ola T. Eide in Olden. He found a coir rope 1 cm thick on the mountain of Sesiliekruna between Innvik, Breim and Olden in Nordfjord, western Norway. The rope was mounted on poles some 1.5 m high. There was a pasture at this place. He has described the find in the newspaper "Aftenposten" (August 8th, 1936, No. 396).

He considered the rope must have been a fence to protect domestic animals, especially sheeps and goats, against wolves that harassed the herds. In 1951 Eide found a new rope that had been attached to the first one. The total length of these two ropes was about 10 km.

The pasture was originally completely encircled by the fencing, but in the places where no glacier has covered it, no traces of the rope or the poles were left.

It may seem strange that such a rope should have prevented wolves from obtaining access to the pastures. That the farmer could believe that a fencing could have such protective qualities was due to two factors: the superstition that wolves passing under a rope were struck with a mortal disease in their backs, and the fact that wolves are very wary and afraid of things that seems unnatural, especially something made by men, and objects hanging over their heads. This is also known to hunters and zoologists.

The Norwegian businessman, Jonas Lied, for many years a Norwegian consul in Russia, has given a vivid account of the method by wolfhunters in that country.[1]

When a pack of wolves has eaten the bait laid out by the hunters, they eat it in the night and go to sleep in a nearby forest in the day. When the hunters have localized the sleeping pack they encircle the animals with a rope about one meter above the ground. The effect of this measure is that the animals dare not cross the fencing by creeping under it or jumping over it. They therefore try to escape through an opening in the fencing where the hunters have taken up their position, and they can then easily be shot.

Other wild animals, too, show a similar attitude. Reindeer herds in

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[1] Jonas Lied: Return to happiness. London, 1944, pp. 266—72. Norwegian edition: Over de høye fjelde. Oslo 1940, pp. 265—70.

the Norwegian mountains for example dare not cross telephone or telegraph lines or railway tracks.

As to the date when the fencing was set up the following may be alleged:

1. The fencing had been set up at a time when there was a pasture at this place. The glaciers were then of about the same extent as now, or perhaps a little smaller. Afterwards the pastures were buried by snow and ice, and when this glacial cover melted avay they came to light.
2. Salve Solheim (1952, pp. 264—271) also deals with this problem. He mentions that a slab of wood attached to the rope had been found. On this slab were carved letters that have been interpreted as the initial letters of the name of the farmer who mounted the fencing and the name of his farm. With the help of registers of farmers and farms, Solheim has succeeded in identifying the farmer and his farm. He was the owner of the farm in the years 1602—24. The rope must consequently have been set up during this period.

   This is the most reliable evidence we have of the extent of the glaciers in the 17th century.

Glacier advance in the last years of the 17th and in the first half of the 18th century

The oldest information on the behaviour of the glaciers in the northern countries is supplied by sources from Iceland. This island has the largest glaciers in the world outside the polar regions. Many of the inhabitants live close to these glaciers, and advances of the glaciers and inundation of the glacier rivers therefore often cause damage to both settlements and cultivated ground. The Icelanders are a nation with strong literary traditions and in medieval Icelandic literature we find valuable information on glacier variations. These sources have been studied by modern scientists, and the results of their studies have been published in recent times.

We find an abstract of these Icelandic investigations in a paper by Ahlmann (Norsk geogr. tidsskr., Vol. XIII, Oslo 1953. Pp. 60—62), from which the following passage has been taken.

From the beginning of the Norwegian colonization about 870 A. D. till the middle of the 13th century the glaciers of Iceland were considerably smaller than they are now.. After this period the glaciers began to increase, and at the end of the 17th and the beginning of the 18th century several farms had to be abandoned.

According to Sigurdur Thorarinsson it is probable that the climatic deterioration which was the cause of the advance of the glaciers began in the 13th century, reached its peak in the next century and culminated during the 17th and 19th centuries (Ahlmann op. cit. p. 62).

During the last few decades the general trend in the development of climate has been the same in all the northern countries. It is therefore probable that the regime of the Norwegian glaciers in the Middle Ages was the same as those in Iceland.

That the climate must have been good in the last part of the Middle Ages is apparent from the above-mentioned find of arrow-heads, and the statement that the farmers in Norway had to pay tithes of their hazelnuts. The ripening of these nuts requires a warm climate.[1]

It is not till the last decades of the 17th century that we have written records of the glaciers in Norway.

In the latter half of the 17th century there began a marked advance of the glaciers that continued to about 1750.

The exact date of the beginning of the glacier advance in the 17th century is impossible to ascertain. No scientific investigation gave sure figures about the growth and spread of the glaciers, but when pastures and corn-fields were covered by ice and debris, when the houses of outfarms (seters) and farms proper were swept away, this had to be recorded, because of the necessity for lowering the taxes and rents of the farms arose. "Tings" (court of justice assizes) were held to inspect the ground in question and hear witnesses. The preceedings of these "tings" is to be found in official documents.

For the start of this advance of the glaciers we also have some information in official documents, which may indicate references to the approximate time of this event.

We have some few pieces of information on the glaciers in the 1600's. As mentioned above a wolf fencing has been found on a mountain in Nordfjord indicating an extent of our glaciers about the same as the present one.

Øyen (Zeitschr. f. Gletscherk., Berlin 1907) points out that the glaciers in the 1600's and especially in the middle of this century were very small.

In 1667 a new tax rate for the whole country was worked out. On this occasion the landskyld (basis for assessment of the land rent) was raised in Jostedal (Rekstad, 1900, p. 4). This might indicate a certain degree of prosperity. The climate must have been mild with no glacier threatening the farmsteads.

In the Court of Justice held in Jostedal 1742, there appeared two men, 64 and 70 years old, who stated that Tverrbreen in Jostedal in their youth could only be seen high up in the mountains in Tufteskard. This takes us back to about 1690. After that time the glacier had ad-

[1] Oscar Albert Johnsen: Norges Bønder, Oslo 1919, p. 164.

vanced, once 100 favner (nearly 200 m) in the course of 10 years, and was threatening farmhouses in the valley.

Many investigators, especially Øyen (Klima- und Gletscherschwankungen .... 1907, p. 50), Helland (1901, I, p. 129) and T. O. Eide (1955, pp. 21—23) have described this event. Most of these authors are of the opinion that the advance of Tverrbreen must have taken place before 1700. For particulars see Indre Sogns Justitsprotokol nr. 37, fol. 157, 1742. It is included in Rekstad, 1900.

But we have also evidence of advancing glaciers in the last decades of the 17th century.

In documents from the years 1680—1690 it is related that the glaciers and the glacier rivers destroyed meadows and pastures (T. O. Eide, 1955, p. 6).

The opinions of investigators on the beginning of the advance differ considerably. Rekstad (1900): "The great advance in the 18th century began 1700—1710. Our glaciers thus had a minimum extent about 1700."

Rekstad (1901, p. 28): "The advance of the glaciers in Nordfjord must have begun a little before 1700 .... In Jostedal the advance came later, about 1712."

Helland (1901, I, p. 129): "The great advance in the 18th century began 1700—1710. The glaciers in our country had a minimum extent about 1700 or, according a communication from P. A. Øyen, a little earlier before 1675."

Helland (1901, I, p. 129) considers that the advance has begun in 1675 or some years before, according to information he received from Øyen.

According to the information available, T. O. Eide (1957) sets the beginning of the great advance of the glaciers to about 1660—1670.

From the summary given above of the known facts concerning the beginning of the great advance and of the opinions of glaciologists on this matter, it will be seen that views differ on this question and it seems impossible to fix an exact year. But in all probability it must have happened between 1660 and 1700. It is also probable that the great advance began at different years in different glacier regions.

After about 1750 the general trend of the glaciers is one of recession but the protracted retreat has been interrupted by short-term advances at several times during the last 200 years.

But concerning the exact year of *maximum* extent of our glaciers in the 1700's no exact information is available. It is quite understandable that we find fewer records of the retreats of the glaciers than of their advances, because the former do not affect the interests of the inhabitants to the same degree as the advance. But the investigators who have studied this problem agree that it must have occurred in the 1740's, most probably at the end of this decade. It undoubtedly took place at different times in the different glacier regions.

During this advance, which lasted about 90 years, the glaciers in western Norway increased in length, often as much as several km, with the result that considerable areas of arable land were destroyed at Folgefonni, in Nordfjord, Jostedalen and at Svartisen. Since the reappearance of the glaciers after the post-glacial warm periods in the Sub-Atlantic Age, they have never been as large as they were around 1750.

On the destruction caused by the advancing glaciers, the following statements deserve to be quoted:

In 1677 a session was held by a Court of Survey at Buar farm on the east side of Folgefonni. This farm is situated near the front of Buarbreen, an out-flow glacier from this glacier. The fields and the meadows on the farm were destroyed by landslides and torrents the year before. The Court had to estimate the damage caused by this disaster. The tax was considerably reduced by the Court.

Helland (1921, I, p. 81) mentions this catastrophe in a way that probably may be misunderstood. The reader gets the impression that Buarbreen has caused the damage, but that is not right. The owners of the farm have related to Olav Kolltveit, Odda, that it was a large landslide on the north side of Buardalen that caused the damage striking the farm houses on the south side of the valley. Large boulders from this landslide can still be seen here.

It is, however, in the central western parts of Norway that the greatest disasters caused by glaciers have taken place, viz. the region between Sognefjorden and Nordfjord, including the out-flow glaciers of Jostedalsbreen.

The glaciers in Nordfjord advanced from 1695—1743.

Jostedalsbreen sent an out-flow glacier down Åbrekkedalen, also called Brenndalen, a "hanging" side valley. This glacier is called Åbrekkebreen (Brenndalsbreen). Before the glacier began to advance about 1695 the valley was forest-clad and had fine pastures.

In Olden valley there were two farms situated near the south of Åbrekkedalen, viz. Tungøyane and Åbrekke. Before this glacier began to advance Tungøyane had according to the list of taxpayers three farmers with three houses, 38 head of cattle and a corn crop of 28 tønner (110 bushels).

In 1728 the farmers had to move their houses, as they believed, out of the danger zone for fear of the advancing Åbrekkebreen in the side valley. In 1743 the glacier suddenly swept the new buildings away and only two persons were saved. The farm Åbrekke in the same valley suffered great damage, but escaped wholesale devastation. But the taxes were reduced.

The advance of Åbrekkebreen is described as follows:

The glacier filled its own valley to the very ledge above the main valley, where the ice could be seen, towering above the steep slope just behind the Åbrekke and Tungøyane farms. Raging torrents rushed down the ledge, at some places digging deep gullies through the corn-fields, at other places burying the cultivated soil beneath large masses of gravel and boulders. An account of these disasters is dealt with in Nordfjord Thingbog, A 27 for 1728—1730, pp. 43—46, and Nordfjord Sorenskriveris Thingprotocol, pp. 177—179, included in Rekstad (1902, pp. 177—179). Accounts of the advance of the glacier and the reduction of taxes in Helland (1901, P. I, pp. 120—121). Most detailed in T. O. Eide (1955, pp. 8—14).

The destruction of the farms in Oldendalen is typical of the damage caused by advancing glaciers.

Similar happenings took also place east of the great Jostedalsbreens glacier cap.

The glaciers in Jostedal began to increase in 1712 doing damage to farms. Nigardsbreen, an outflow glacier of Jostedalsbreen, devasted the farm Nigard in 1742, but no people perished. Of this glacier advance we have evidences in assize minutes from 1736 and 1742. Moreover, the parson of Jostedal, Mattias Foss, wrote his "Jostedalens kortelige Beskrivelse" about 1750. He had witnessed the devastation of the farm. See also Helland (1901, P. I, pp. 115—116). This is described in greater detail by T. O. Eide (1955, pp. 28—30).

This advance was not confined to the above mentioned and other glaciers in western Norway. About 1725 a tongue of Svartisen, Engabreen in Holandsfjord, Nordland county, thrust forward across tilled fields, completely destroying one farm, and severely damaging another. See Rekstad (1892 and 1893).

All the above-mentioned glaciers are situated near the western coast of Norway, but in the other high mountain areas of the country, too, the glaciers must have advanced. Most of these glaciers are situated far from inhabited regions and therefore no great damage was done here, and no account has come down to us.

In Jotunheimen, the highest mountain group in Norway, the glaciers and their moraines are especially well known, and we have here a proof of the great advance provided by 8—10 moraine walls that lie like crescents before the fronts of most of the glaciers. The outermost and largest was deposited during the maximum extent of the glaciers about 1750.

These old terminal moraines are strongly marked in front of Svellnosbreen. The outermost great moraine wall is built of earth, gravel and stones — evidently the old cover of ground moraine, which has been plowed up by the advancing glacier. The younger moraines, nearer to the glacier front, are on the contrary built up of big boulders, that have been split away from the rocky bed of the glacier. The mountain slopes on both sides of this glacier are covered by ground moraine, and the torrents have dug gullies right down to the solid rock beneath. Thus the glacier must have been quite small, about the present size, for a long period prior to the great advance.

In Jotunheimen, the ground outside the outermost moraine is covered by common alpine vegetation, but the different belts between the moraines nearer to the glacier front have poorer vegetation right up to the band next to the ice, where the ground is barren. Among the plants that first appear after the withdraw of the glacier, may be mentioned the little *Oxyria digyna,* and the grass *Poa vivipara.* The succession of plant associations that invade the ground before the margin of the glaciers, has been dealt with by K. Fægri (1934). He has especially studied some of the moraine fields of the glaciers in Jostedal.

This great advance in the 18th century must clearly be considered in connection with a marked deterioration of the climate, which reached a peak during the years 1740, 41 and 42. Barley and oats did not ripen, with resulting widespread famine, still remembered as the "green years". In 1740—41 deaths exceeded births by 31,000 out of a total population of 700,000 (Olafsen, 1914).

Two hundred years of general retreat from about 1750 to recent years

The following are the most important variations of the glaciers after 1750.

It is possible that the great flood in Gudbrandsdalen in 1789, called ofsen, is connected with a glacier advance (Øverland, 1895).

It is, however, not until the beginning of the 19th century that we are in possession of the necessary evidence to support our knowledge of the glacier variations.

Between about 1807 and 1812 there was a general advance by all glaciers in southern Norway. In the central parts of the country, including the Jotunheimen area, many glaciers increased till they reached the same size as in the middle of the 18th century. During these years the climate was wet and cold, and once again, the summers were so cold that the corn failed to ripen. These years were among the worst experienced in Norway, and are still known in popular tradition as "green years". The people were forced to make bread out of bark.

During the following years the glaciers were in marked retreat, but from the year 1835 they seem to have advanced again. In 1850 the weather was cooler and wetter than at any time before or after — so far as is known — and the glaciers pushed forwards in the years 1850—55. In the central parts of the country there were indications of a retreat already in 1855. In the coastal districts the glaciers shrank mar-

Fig. 9. Stegahåltbreen, an outlet glacier of Jostedalsbreen. (1937.)

kedly till about 1870, and during the 80's the glaciers were in retreat all over the country.

In the year 1902 the amount of snow in the mountains started to increase, and this continued for some years. The tongues of the glaciers in western Norway, however, did not start to advance before 1903—1904, and only a few of them were concerned in this growth. It was not till 1904—1905 that the advance became general. In other words, it took $1^1/_2$—3 years before the effect of the pressure from the increased masses of snow had reached the lowest parts of the glaciers.

The time-lag between the beginning of a climatic fluctuation and the ensuing marginal variation has been studied by Georg Schou (1941).

He examined Bondhusbreen (Folgefonni) and Briksdalsbreen (Jostedalsbreen). These glaciers are situated 175 km from each other. He compared the variations in length of these glaciers with the snowfalls in February in two neighbouring meteorological stations. The measurements began in 1901 and 1902. The result of his studies is represented by two diagrams, the one showing the annual observed variations in the glaciers, the other the variations in the precipitation of snow (measurements started 1896) after 10 years smoothing.

The diagrams show the same waves, but maximum and minimum in the two curves on the glacier variations are, on the whole, situated two years after the maximum and minimum values of the snow precipitation curves.

It is likewise apparent that variations on the glaciers must result from the variations in the mass of snow during a period of well over ten years, as the curves of the glaciers give the impression of strongly smoothed curves, unlike the curves of the snow precipitation that have several secundary (even if small) wave-crests.

In Jotunheimen only a few glaciers advanced at that time, most of them showing a shrinking.

From 1906 a general retreat began over the whole country, and this continued with some minor interruptions till 1921; then a sharp advance followed, till 1925. But after 1930 an unbroken and growing retreat set in. It may be mentioned that Nigardsbreen in Jostedal diminished more than 100 m in vertical direction and more than one km in length from 1937—51.

For many years the Jotunheimen glaciers have been situated for almost their entire extent below the snow line, and they continue melting off, more or less rapidly. The large glaciers facing south have suffered most, as for instance the two Memurubreene, but Storegjuvbreen for example has fared better, facing as it does towards the north, between high steep rocky walls.

Measurements during the last few years show that a number of glaciers have even advanced. This applies to Storbreen in the Jotunheimen, while three other glaciers have also registered an advance for the first time for over 20 years. These are two tongues of Jostedalsbreen, viz. Suphellebreen and Briksdalsbreen and Engabreen in Svartisen. (Liestøl 1954, p. 18.) This is due to the deterioration in climate that has taken place during the decade 1940—1950. (See Hesselberg and Birkeland, 1956, and the chapter on "The Fluctuations of Climate".)

Fluctuations of the glacier volume

However, if one is to obtain a complete picture of the changes in the glaciers, one has to try to determine their total so-called material balance in the course of the year. Professor Ahlmann deserves great credit for the studies of this kind that he has undertaken in Scandinavia, Iceland, Spitsbergen and Greenland.

The material balance is determined by measuring in spring the total mass of snow that has fallen in the course of the winter. Measurements are then made in the autumn, with the help of stakes placed in the snow and ice, of the mass that has melted away. There will always be more snow melting at the lowest point of the glacier than has fallen in the course of the winter, but on the upper parts of the glacier a certain amount of snow will as a rule be left lying. With the help of these measurement it will be possible to establish whether the volume of the glacier has increased or decreased in the course of the year.

Measurements of this kind were started by Liestøl in 1949 on Storebreen in the Jotunheimen. (Liestøl, 1953, pp. 17—18.)

Liestøl's computations showed that in 1949—1950 there was a deficit of 0.6 million tons per sq.km, while the deficit in 1950—1951 was 0.5 million annually. On an average the decrease has undoubtedly been considerably greater during recent years, and if it had continued at the same rate the glacier would have disappeared in the course of about 100 years. Meanwhile measurements for 1955—1957 show a surplus of 0.3 million tons per sq.km. This lessened rate of decrease and the recent increase are due to the failling off in the rise of temperature for 1940—1950.

The study of the variations in glacier mass is also of importance in order to estimate the influence that glaciers in the precipitation area of a river may exercise upon the available water power.

Olaf Rogstad, former Director-General of Norges vassdrags- og elektrisitetsvesen has investigated this matter. The basis f●r his computations is as follows:

The computations are based on hydrological measurements undertaken by Norges vassdrags- og elektrisitetsvesen and measurements of the retreat or advance in length of outflow glaciers which flow from the ice cap. The latter have been carried out by Bergens Museum. Rogstad has started with the assumption that the decrease in the glacier masses must have manifested itself as an addition to the runoff which precipitation alone would have caused in the same period. He has therefore computed the ratio between the run-off in glacier rivers and the run-off in neighbouring rivers in the same general locality which are not fed by glaciers in their precipitation area. He has assumed that variations in this ratio could serve as a basis for determining year to year variations in the decrease or increase of the mass of the glaciers. This assumption is approximately correct only if the annual precipitation in the areas under consideration varies from year to year in a similar manner relative to average conditions. Such may not always be the case, for which reason one cannot expect to determine the decrease or increase of the mass of a glacier in a single year with great accuracy, but if the computation can be carried out over a long period, the errors should in part cancel out and one should arrive at a result which should be approximately correct. (Rogstad, Jour. of Glaciology, Vol. I, Nr. 10, 1951, p. 551.)

Rogstad has made investigations into the decrease of the mass of Jostedalsbreen from 1900 to 1940. (Rogstad, 1941, pp. 273—293; 1943, pp. 149—152 and 157; 1943, pp. 10—16.) More especially he has studied the behaviour of two outflow glaciers from Jostedalsbreen: Mjølkevollbreen and Briksdalsbreen. He computed the shrinking of the mass of Jostedalsbreen based upon hydrographical observations and measurements of the length of the glacier tongues. He compared the values found in this manner with the temperatures recorded at Oppstryn, the nearest meteorological station during the period from May 1st to September 30th.

The annual deviation from the average decrease of the glacier volume during these 40 years is defined by the variation in the proportion between, on the one hand, the run-off of the glacier-river systems Oldeelv and Loelv in Nordfjord whose catchment areas are to an extent of 55 percent covered by glacier, and, on the other hand, the run-off of the neighbouring river Eidselv whose catchment area is devoid of glaciers. During the whole period from Oct. 1, 1900 to Sept. 30, 1940 the run-off of the two glacier-streams has been 1.358 times greater than the run-off in Eidselv. It has next been assumed, that during the years when the run-off in the glacier-streams has been greater than 1.358 times the run-off in Eidselv, the surplus is accounted for by above average additions from the glacier, and vice versa in cases where the run-off has been lower. In this way the deviations from the average decrease of the glacier volume have been found.

He came to the result that of the meteorological factors only summer temperatures and precipitations in the form of snow can be used for comparison with the changes in the glacier mass. The computed variation in the glacier mass generally follows the variations in the temperature, but it is also clear that in a few cases a large amount of solid precipitation has brought about an increase in the glacier mass in spite of a high temperature. This was the case, for instance, from 1901 to 1907. Otherwise there are irregularities which may be ascribed to variations from year to year in other meteorological factors, and to uncertainty in estimating snow precipitation in single years. The advance and decay of the glacier tongues took place fairly regular four years after the computed increase or diminution of the bulk of the upper ice-field, Jostedalsbreen itself. It must, therefore, be the magnitude of the glacier volume which is the predominant factor determining the length of the tongues, and not a greater or smaller melting of the glacier tongues during the years in question. The glacier volumes corresponding to the same position of the glacier tongues must therefore have been of the same size.

In a later paper Rogstad (1951) has studied the melting on Jostedalsbreen compared with the temperature up to September 1950. He tries to estimate the amount of the various meteorological factors that are of importance for the melting of the ice and snow on the glacier, viz.

1. Convection from the air when its temperature is above 0° C.
2. Radiation.
3. Condensations of the humidity of the air.
4. Precipitation in the form of warm rain.
5. The earth's heat.

No. 4 and 5 must be considered to be quite insignificant on Jostedalsbreen. Radiation and condensation, on the other hand, have a considerable effect. Convection depends on the wind.

Rogstad has computed the magnitude of the effects of factors 1, 2 and 3 under three special conditions.

One of the results of his computations is that the total melting of the glacier from 1900 to 1950 is 115.3 m and in an entire precipitation of 93.25 m or an average respectively of 2.306 m and 1.865 m.

In a letter of 7/9 1957 Mr. Rogstad has made the following supplementary remark to his calculations:

"When I had found that the mass of the glacier had shrunk 16 metres from 1900 to 1940, I subtracted the corresponding mass of water, 16 m times the area of the glacier (259 sq.km or 4144 million cubic metres) from the run-off in Loen and Olden: 40,564-4,144 = 36,420 million cubic metres. The proportion between this figure, and the discharge into Hornindal lake is 1·211. In accordance with this proportion I subsequently calculated the variation of the mass of the glacier. In this way the small inaccuracies for single years in the first computation have been eliminated. The computation shows, for single years, a quite insignificant divergence from the first computation. This latest computation could not, however, be made until the shrinking of the glacier mass from 1900 to 1940 had been determined. (sign.) Olaf Rogstad."

Mr. R. Søgnen, Director of the Hydrological Department of Norges vassdrags- og elektrisitetsvesen has, by the same method as that used by Rogstad, computed the variations of the volume of Svartisen in northern Norway.

He has communicated the result of his investigation in a letter of 13/9 1957 to the authors. It is contained in the following table:

Year	Variation in level of water	Year	Variation in level of water
1931	1.3 m	1939	1.9 m
32	—0.3 »	40	0.1 »
33	2.6 »	41	0.1 »
34	1.9 »	42	0
35	—0.5 »	43	—0.4 »
36	3.4 »	44	—0.5 »
37	4.0 »	45	1.6 »
38	0.8 »	46	—1.6 »
		47	1.3 »

Positive figures indicate reduction of the glacier volume, and negative figures (—) an increase.

These figures must be considered as preliminary.

Fig. 10. Austerdalsbreen, an outlet glacier of Jostedalsbreen.
(Photo: Widerøes Flyveselskap A/S. 1947.)

As stated in the chapter on Areas and number of glaciers, Amund Helland has published a topographical-statistical description of Norway entitled "Norges Land og Folk", where each county is described separately. This large work also includes an account of the country's glaciers, the first of its kind, giving i. a. the areas of the glaciers described. There are 11 counties which have glaciers within their boundaries. The descriptions of these counties were published between 1898 and 1921.

For large parts of the country, Helland had to use old maps (the so-called amtskarter with no contour lines, scale 1 : 200 000. For this reason the figures quoted for glacier areas are in many cases inaccurate. Nor are all glaciers shown on these maps.

Since the publication of Helland's work the surveying of Norway has proceeded apace. On the basis of the most recent available material we have drawn up a table showing areas of each glacier in Norway.

It might be of interest to the study of glacier variations in different parts of Norway to compare the result of Helland's area computations with our own. We have therefore included below a table comparing these figures.

Not all of Helland's calculations of glacier areas are included in the table below, only those for which the maps at his disposal were sufficiently accurate to allow a significant comparison of this kind in demonstrating glacier variations.

Helland has also computed glacier areas for each separate herred. Olav Liestøl has done the same. It might be of interest to compare Helland's figures for the glacierized parts of the districts with Liestøl's, in

Name of Glacier	Lat. N. Long. E.	Helland Surveyed year	Helland Area sq.km	Liestøl Surveyed year	Liestøl Area sq.km	Retreat sq.km	Retreat per cent
Øksfjordjøkulen .	70° 10′—22° 00′	1891—02	50.8	1945 F.	36.6	14.2	27.9
Ålfotbreen	61° 45′— 5° 40′	1863—71	138.1	1945 F.	68.4	69.7	50.5
Jostedalsbreen ..	61° 40′— 7° 00′	1863—71	1252.0	1945 F.	815.0	437.0	34.9
Fresvikbreen ...	61° 05′— 6° 40′	1863—71	24.7	1947	16.7	8.0	32.4
Hardangerjøkulen	60° 32′— 7° 25′	1845—66	122.0	1955 F.	78.2	43.8	35.9
Folgefonni	60° 05′— 6° 20′	1845—66	264.0	1932—53	225.0	39.0	14.8

order to get an idea of glacier variations in the separate districts. But a comparison of this nature cannot be undertaken for the following reasons: in the case of several districts Helland has no figures for glacier areas. Furthermore in recent years considerable changes have been made in district boundaries, and the boundaries between the counties Oppland and Sogn og Fjordane have not yet been settled.

Short-term oscilliations

Rekstad (1925) has compiled statistics showing the duration of the short-term oscillations for western Norway. In the span of years from 1743 to 1873 Nigardsbreen, an out-flow glacier of Jostedalsbreen, had in all 7 oscillations; the mean duration was 18½ years. The duration of the oscillations of Bondhusbreen, an out-flow glacier of Folgefonni, in the period from 1865 to 1905, was 19 to 19½ years. During the span of time from 1900 to 1928 the duration of average oscillations in the case of 15 glaciers in western Norway was 15 to 22 years. The advances lasted for 7 years, and the retreat for 11 years. Both in the case of short-term and long-term variations, the duration of the advance is considerably shorter than the period of shrinking.

Glacier fluctuations in different parts of Norway

Our country has a great extent from south to north, and the central highlands divide southern Norway into two parts, Østlandet and Vestlandet, with different climatic conditions. But even in Vestlandet there may be divergencies — the glaciers of Folgefonni may in some periods behave differently from Jostedalsbreen.

In so far as the variations of the Svartisen glaciers in northern Norway are known they seem as a rule to be contemporaneous with the variations of the Jostedalsbreen. However, the first were retreating during the years 1922 and 1923, while the glaciers of western Norway were advancing strongly. Other glaciers in northern Norway have also in some years reacted differently from the glaciers of southern Norway. The Okstindan glaciers were advancing during the years 1908—11, and Frostisen and Meraftesbreen from 1906 to 1911. The glaciers of both these regions were retreating during the period from 1911 to 1934. The glaciers of southern Norway retreated strongly in the years 1906—11.

The variations of the glaciers in the central districts of the country have differed somewhat from those of Vestlandet and Svartisen, as far as can be inferred from our knowledge of conditions in the Jotunheimen area.

During the years when measurements were made in Jotunheimen, from 1903 to 1912, the glaciers of this region kept pace with the variations of the glaciers in western Norway. Measurements in Jotunheimen were resumed in 1934, and the variations after this year show some difference from those of Jostedalsbreen. In Jotunheimen the glaciers shrank considerably about the year 1940, but in 1943 they were fairly stationary, and a few were advancing. Later on they have all been retreating, although with decreasing force in more recent years.

Fluctuations of the Spitsbergen glaciers

All the large glaciers of Spitsbergen end in fjords and the sea. The first reliable maps of some of these glaciers were published in the first half of the last century. But it was not till the beginning of 20th century (1906) when the modern systematic Norwegian mapping of Spitsbergen was started and maps to the scale of 1: 100 000 were issued, that we got a new basis for the study of glacier variations in Spitsbergen.

In the approximately 50 years for which such maps are available these glaciers have, generally speaking, decreased. Nevertheless some glaciers in Spitsbergen are behaving in an entirely abnormal manner, a fact that has been known during the last hundred years. In the middle of the general retreat they suddenly show a tremendous advance.

The relatively small glaciers ending on land have to some extent also been mapped in the last 50—60 years. These too have retreated in this period and some of them have even disappeared.

The constant retreat of some large Spitsbergen glaciers during the last 50 years appears in a convincing manner from the following table.

It appears from this table that the extent of the retreat is very different for the different glaciers. Some of them, such as Hornbreen, Hambergbreen, Samarinbreen, Nathorstbreen and Recherchebreen, show a sharp decrease while the shrinking of others is more moderate. The factors that are most responsible for variations in the size of the glaciers ending in the sea are the climatic conditions and the temperature of the seawater. Less important factors are the areas of the glaciers and the depth of the sea at the front of the glaciers. The larger the glacier and the greater the depth of the sea, the more important are the variations. Especially if the depth is so great that the ice tongue is floating, the variations will be considerable.

Table showing the figures of the retreat of some glaciers ending in the sea.

Name	Latitude	Year	Decrease		Number of years	Decrease per annum (average)	
			Area sq.km	Length m		Area sq.km	Length m
Samarinbreen	77° 0′	1918—1936	3.1	1800	18	0.17	100
Hornbreen	77° 0′	1918—1936	10.0	3200	18	0.55	178
Hornbreen	77° 0′	1936—1938	3.0	300	2	1.50	150
Hornbreen	77° 0′	1938—1957	30.0	5500	19	1.58	290
Hambergbreen ...	77° 0′	1938—1957	15.0	5500	19	0.79	290
Recherchebreen ..	77° 25′	1838—1895	6.9	1900	57	0.12	33
Recherchebreen ..	77° 25′	1895—1898	1.1	380	3	0.37	127
Recherchebreen ..	77° 25′	1898—1918	0.5	170	20	0.025	8
Nathorstbreen	77° 25′	1898—1920	11.0	2000	22	0.50	130
Nathorstbreen	77° 25′	1920—1924	1.5	500	4	0.38	125
Fridtjovbreen	77° 50′	1898—1911	0.8	700	13	0.06	54
Fridtjovbreen	77° 50′	1920—1936	1.3	700	16	0.08	44
Fridtjovbreen	77° 50′	1911—1920	0.5	330	9	0.055	37
Andrébreen	79° 20′	1907—1936	0.9	300	29	0.03	10
Fjerdebreen	79° 25′	1907—1936	0.6	300	29	0.02	10
Sjettebreen	79° 25′	1907—1936	3.6	800	29	0.12	27
Waggonwaybreen	79° 30′	1839—1906	0.6	300	67	0.009	4.5
Waggonwaybreen	79° 30′	1906—1936	0.9	500	30	0.03	17
Smeerenburgbreen	79° 35′	1906—1936	1.5	600	30	0.05	20

In Spitsbergen, too, studies have been made on the material balance of some glaciers. Here we shall mention the research work carried out on Fjortende Julibreen (79° N) situated on the west coast of Vestspitsbergen. This work was done by a Norwegian-Swedish expedition in 1934 led by H. U. Sverdrup and Hans W: son Ahlmann.

During the winter 1933—34 the total accumulation on the glacier amounted to about 79 million tons, the total ablation to about 113 million tons. The loss by calving is now insignificant. The glacier thus had an ablation which was 34 million tons or 43 pct. larger than the accumulation. These figures show clearly the same result as the figures in the table, viz. a general shrinking of the glaciers.

We will now mention two glaciers that have advanced during the period of general retreat: Bråsvellbreen and Sefstrømbreen.

Up to 1937—38 this coast formed a fairly straight line from Kapp Mohn westwards where the eastern glacier cap of Nordaustlandet ended in the sea with an ice cliff and no individual glacier existed on this coast. Suddenly in the time 1937—38 the eastern part of this ice cliff made an immence advance of 20 km into the sea, which to a great extent was covered by calf-ice.

The table below shows the variations of Sefstrømbreen and Bråsvellbreen.

Name	Latitude	Year	Variation		Number of years	Variation pro anno (average)	
			Area sq.km	Length m		Area sq.km	Length m
Sefstrømbreen	78° 40′	1882—1896	+ 34.7	+ 5200	14	+ 2.48	+ 370
		1896—1908	— 9.6	— 1400	12	— 0.80	— 117
		1908—1910	— 5.8	— 1000	2	— 2.90	— 500
		1910—1924	— 8.6	— 1700	14	— 0.61	— 120
		1924—1928	— 1.0	— 200	4	— 0.25	— 50
Bråsvellbreen	79° 20′	1937—1938	+ 600	+ 20000	1	+ 600	+ 20000

The abnormal behaviour of some of the glaciers is due to the fact that they store up snow in the upper sections at the same time as the ice is melting away further down. As a result they eventually become so steep that the ice slips down and the glacier makes a tremendous lunge forward independent of any amelioration in the climate. On such occassions the speed of the glacier may attain as much as 30 inches per day.

According to the present observations the glaciers of Spitsbergen have on the whole in the last 150 years diminished. This decrease was less important up to the end of the 19th century, but later on it has continued at a brisker pace. When the shrinking started the glaciers had their greatest extension after the end of the glacial epoch.

The tremendous shrinkage of the glaciers in Spitsbergen is naturally due to the improvement in the climate, and this has been more marked here than anywhere else in the world. The increase in the sea temperature too in recent years has played an important part in this connection.

Fluctuations of the climate and its effect upon the regime of the glaciers

The notion climate is defined as the mean weather conditions after a smoothing over 30 years and the climate fluctuations as the variations of these 30 year means. The variations are referred to a normal period provisionally fixed for the years 1901—1930.

Since regular meteorological observations were started in Norway in 1866, it has been possible to study the correspondance between climatic conditions and glacier variations. The great decrease in the snow fields and glaciers that has taken place in recent years has been accompanied by a pronounced rise in air temperature. The glaciers obviously provide very sensitive registrations of the climate.

Th. Hesselberg and B. J. Birkeland of Meteorologisk institutt have studied the variations in the climate of Norway from the years for which observation material was available up to the year 1940. The results of their studies are given in four papers.

From Hesselberg and Birkeland (1956, p. 4) we quote the following information on the climatic variations up to the period 1911—1940:

"During the 200 years that have elapsed since meteorological observations began in Norway there have been incessant climatic variations. The changes that took place before 1860 are, however, smaller than those occurring later and the largest variations took place in the nineteenthirtieths. The changes were greatest in the winter and the autumn, smaller for the spring and smallest for the summer. The largest variation took place in January and the smallest ones' in July, the month for the yearly maximum and minimum temperature in Norway. The variations were greater in the northern parts of the country than in the southern parts and they were greatest in Spitsbergen. Further they were larger in the interior of the country than along the coasts.

From the eighteensixtieths the 30-year means of the atmospheric pressure began to rise at Ponta Delgado and at the same time the Icelandic Low became deeper and moved northwards, with the result that the dominating southern air currents from the southwest over NW-Europe augmented in force. In the neighbourhood of Norway the atmospheric pressure had fallen more over the sea than over land and the result was an additional air current from SSE, in force about 20 % of the mean southern stream.

This was confirmed by the wind statistics, which showed an increase in the frequency of southern winds. In Oslo the frequency of southern winds augmented by about 25 %, while the winds from north became less frequent by about 20 %. At the same time the frequency of winds from the east increased a little, while the number of winds from the west diminished. The wind statistics for Oslo thus indicate an additional stream of air from SSE.

The increasing air current from SSE brought milder and more humid air from more southern latitudes, and gives a direct explanation of the fact that the temperature rose all over the country and that the humidity and the precipitation augmented over great parts of Norway.

On the average for the whole country the mean annual temperature rose about 0.6° C. The rise of temperature was smallest at the southwestern stations and augmented towards the east and north. For Oslo it was 0.5°, in Skudenes 0.2°, in Bergen 0.4°, in Finnmark 1.0° and in Spitsbergen about 2° C.

The rise in temperature seems on the whole not large but it is sufficient to elevate the annual isotherms 110 m or to push them 200—300 km further to the north.

On the average the vapour pressure increased by 0.4 mbar, corresponding to a 5 % augmentation of the water vapour in the air. At the same time the relative humidity increased by 1.5 percent, but the rise is not valid for all stations.

The explanation of this fact is simple enough. The augmenting air currents from the south brought warmer air with a greater content of water vapour. On the way north the air is cooled and thus gets a higher relative humidity. The greatest increase in relative humidity we found on the eastern slopes of the central mountain ridge, where the air was cooled during its ascent. On the other side of the mountain ridge where the additional air current descends and the air is warmed, there was no increase or even a decrease in relative humidity.

As an augmenting air current from the south brings more water vapour in over Norway, we must expect an increase of the precipitation over the country as a whole. The observations showed that this increase was about 10 % in the eastern part of the country and on the eastern and southern slopes of the central mountain ridge, while the precipitation decreased on the western and northern slopes of the ridge, i. e. on the leeward side of the increasing winds from SSE.

We thus see that there are close relations between the long-term variations of the different meteorological elements and that these relations are easily explained by physical laws."

Since regular meteorological observations were started in Norway two hundred years ago, it has been possible to study the correspondence between climatic conditions and glacier variations. The pronounced rise in air temperature has been accompanied by a great decline in the snowfields and the glaciers in later years.

The glaciers obviously provide very sensitive registration of the climate.

The rise in temperature up to 1938 has been investigated by Th. Hesselberg and B. J. Birkeland (1940). Using a continuous smoothing of 30 years they have arrived at the existence of long-term periodical variations in the air temperature.

For Oslo the result is as follows:

Winter, increase in temperature of 1.9° C, beginning with the period 1836—65.
Spring, increase of 1° C, from the period 1839—68.
Summer, no apparent long-term variation, but a slight increase beginning with the period 1902—31.
Autumn, increase of 0.7° C, beginning with the period 1868—97.

For the whole year, an increase of 0.65° C from 1869—98 to 1909—38, and of 0.25°C from 1899—1928 to 1909—38.

For all 25 stations selected conditions have been found analogous to those prevailing for Oslo, except in the extreme southwest of Norway, where no change could be found. The most pronounced increase in temperature is found in the interior of the country, and in the north.

Using a ten-year smoothing it is possible to show what conditions have been during recent years. It appears that the amelioration in climate has been much more rapid in more recent years than before.

From the period 1899—1908 to the period 1929—38 the temperature has risen considerably everywhere in Norway. Most pronounced is the increase in the northern parts of the country. To illustrate this, Hesselberg and Birkeland have selected three stations:

	Year	Winter	Spring	Summer	Autumn
Oslo	0.38°	1.66°	0.90°	0.14°	0.79°
Sørvaranger	1.98°	3.57°	1.01°	1.53°	2.02°
Spitsbergen	2.47°	5.07°	1.99°	0.21°	2.34°

The figures for Spitsbergen, where an increase of nearly 2.5° for the whole year, and of as much as 5° for the winter may be noted, are most striking.

The shrinking of our glaciers has kept pace with the increase in temperature, and this in spite of the fact that precipitation has also been on the increase, especially during the winter, over the whole country, except for the central highlands, and the inner parts of western Norway. In these parts the Jotunheimen glaciers are situated.

In 1956 Hesselberg and Birkeland published the results of their studies of the long-term variations of the climate of Norway up to 1950.

The result of these studies may be summarized as follows:

The meteorological conditions in 1940—50 have changed essentially from the preceding decade. The general fall of atmospheric pressure over Northern Europe together with a rising pressure at the Azores has been replaced by a rising pressure in Northern Europe and a falling pressure at the Azores. This change in atmospheric pressure has caused the additional winds from the south to be replaced by augmenting winds from the north, which is evidently a direct cause of the fact that a rise in temperature has been replaced by sinking temperature, initiated by the extremely cold winters 1940—1942.

The fall of the air temperature in 1940—50 has also provoked a noticeable change in the strong decrease of the glaciers in the foregoing years.

Hesselberg and Birkeland (1956, p. 14), have a table of the recent 5 years means of the air temperature departures at meteorological stations in Svalbard and Finnmark, viz.:

	1935—39	1946—50	1947—51	1948—52
Spitsbergen	2.30°	1.74°	1.60°	1.44°
Bjørnøya	2.26°	1.26°	0.94°	1.10°
Karasjok	1.50°	1.02°	0.70°	0.72°

As can be seen from this table the mean annual temperatures for Spitsbergen, Bjørnøya and Finnmark are so much lower than before the war, that it seems justified to say that the recent fall in temperature extends to the Arctic regions.

This fall of temperature is not great, but its reality is confirmed by the fact that it is found at all the stations that have been examined.

Further we find a decrease of precipitation on the windward (western) side of the additional northern winds of the central mountain ridge and a decrease on the leeward side. At the windward stations on the west coast the mean precipitation has increased by up to 12 % and in Trøndelag by up to 15 %, while the amount of precipitation has decreased by up to 11 % at the stations in the eastern and southern parts of the country that lie on the leeward side for the additional winds.

Concerning future climate variations the authors make the following observation in their last paper (1956, p. 17): "Before we know more about the force which determines the variations of the general circulations it is not advisable to say anything about the future climate variations. We know that a complete change was initiated through the three cold winters 1940—42, but we do not know if the development will continue in that direction or if it is only of temporary character."

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BENEFITS DERIVED FROM THE GLACIERS

Glaciers and water-power

The predominant source of power in Norway is water-power, and it is significant that at present more than 99 % of the energy produced in Norwegian power-stations is hydroelectric.

Our resources of water power are valued at about 10—12 million kW; of this 2.9 million kW (1958) all year capacity have been developed. Some of the rivers that provide this power have affluents from glaciers rivers. A good deal has been written about the bearing of this fact upon the flow of water, especially in dry summers. Mr. Olaf Rogstad has elucidated this question in three papers (1943, 1948, 1951). He has examined the flow of two rivers, Fykanåga, originating from the glacier Svartisen in northern Norway, providing water to the Glomfjord power plant, and Glåma, which receives affluents from the glaciers in Jotunheimen, furnishing water for a series of power plants.

Fykanåga (Rogstad 1943, pp. 129—141 and pp. 154—155, 1949, p. 19) has a total area of precipitation of 288 sq.km; of this 90 sq.km, or 31.3 % of the whole area, is covered by glaciers. The computed effect of the melt-water during the period from 1914 to 1940 amounted to 5.4 % of the average flow, of which here practically all can be used. The shrinking of the glacier has produced an addtional 5800 kW.

Mr. Reinhardt Søgnen, Director of Hydrological Department of Norges Vassdrags- og elektrisitetsvesen, has been kind enough to communicate to us the following supplement to Rogstad's report on Fykanåga.

"A comparison between the discharge of the glacial river Fykanåga and the glacier-free neighbouring river Sundsfjordselven, in connection with measurements of precipitation in the district, indicate that the glacier during the period 1930 to 1947, has supplied a mean of about 85 million cubic metres of water annually. This corresponds to a depth of water of 0.9 to 1 m. The mean annual discharge at lake Fykan was 920 million cubic metres or 29.2 cubic metres per second; of this Svartisen glacier has contributed 2.7 cubic metres per second. Mr. Olaf Rogstad found, for the period 1913 to 1940, a mean annual melting of 54 million cubic metres, that is a water depth of 0.6 m. The summer temperature during this period was 0.75° C above normal (stations Glomfjord and Bodø).

During the period 1930 to 1947 the summer temperature was 1.2° C above normal. So far, the melting was probably greater in the latter period. It seems, however, that the amount of snow in the spring time is a concurrent cause, as the melting of the glacier may be rather great after winters poor in snow, even if the surplus in temperature is small — and vice versa. According to our investigations the glacier has decreased in volume in 12 of these 17 years, while it has been stationary or increasing in 5 years."

The catchment area of the river Glåma, the largest in Norway, comprises an area of 41,500 sq.km. The glaciers of this district cover in all 520 sq.km, or 1.2 % of the whole. The additional water from the glaciers amounted to an average of 1.17 % of the "useful" quantity of water during periods of low water, corresponding to an addition of about 2800 kW — as an average for the years 1901 to 1948.

Another effect must be taken into consideration beside the variations in the bulk of the glaciers. During the winter the glaciated areas have a greater discharge than the ice-free fields. No accurate basis for computing the amount has been found. Rogstad says that the hydrological department of Norges Vassdrags- og elektrisitetsvesen supposes that it may be about one litre per sec. per sq.km. This would mean an increase of 7.1 million cubic metres in the "useful" amount of water in Glåma, as an annual average, or additional water power amounting to about 400 kW.

For the Glomfjord power plant in Fykanåga this winter flow has no considerable influences, the amount of water stored being very large compared with the annual afflux.

This discharge from the glaciers during the winter is due to the fact that some water has been retained, and leaks out gradually. Some ice will probably also melt at the bottom of the glacier.

Summarizing his calculation upon the influence of glaciers on the water power, Rogstad states the following (1943, p. 142): "However, the existence of a glacier in the area of catchment of a river will no doubt tend to smoothe the distribution of the flow of water upon the various years, and further, this fact will bring about an augmentation of the regulated flow, which might otherwise be obtained. In years of small precipitation the glacier will altogether decrease, and this will bring about an increase of the low water discharge, which the precipitation alone would have occasioned in these years. In years with great precipitation the glacier will all in all increase, as part of the precipitation will remain as snow and ice on the glacier. This will tend to diminish the large discharge which the great precipitation would have occasioned, if the whole snowfall had melted and come into the river during the said years.

In rivers rising in high mountains, lacking glaciers, but having during some summers overlying snow-fields, which melt off in other years, there will, of course, be a certain smoothing of the run-off from one year to another. But, if several warm and dry years follow in succession, surplus snow will remain for the last years. Therefore, in a succession of dry years the glaciers will have a marked influence upon the amount of the regulated flow of water, which may be obtained in the river, as was the case in Nordland county from 1924 to 1938."

In a later paper Rogstad (1949, p. 20) puts his point of view on this question in the following way:

"It is of course difficult to draw any general conclusions regarding the influence of the glaciers upon our water power as a whole, based upon the computations here published. Only a few of our rivers, with any considerable water power, however, have tributaries from glaciers of any importance. Where the glaciers have the greatest effect will be where the ice-fields are extensive in relation to the precipitation areas and where it is not possible to construct large reservoirs. —— But such rivers are rather insignificant in Norway. The disappearance of all our glaciers would have little effect on our water power resources.

I have come to the conclusion that even though the glaciers have a favourable influence upon the water power of the rivers, and specially in warm and dry summers, it is a gross exaggeration to say that the disappearance of the glaciers would be a catastrophe. In my opinion it would be more correct to say, that the effect upon our water power would on the whole be slight."

So much for Mr. Rogstad. The conditions during exceptionally hot and dry summers must, however, be taken into more consideration. In the summer of 1947 eastern Norway had no rain at all for about a hundred days and the temperature was high. Brooks and rivers dried up, the ground water level sank, wells were empty and forest and vegetation suffered. But at the same time Otta and Sjoa rivers, affluents to Glåma, were in flood. The rivers spring from glaciers in the Jotunheimen mountains. In this way the power plants along the lower Glåma got water enogh in spite of the catastrophic drought.

Traffic across some glaciers

FOLGEFONNI

BY JOHANNES NORVIK

Folgefonni is situated on the peninsula between Åkrafjorden, Kvinnheradsfjorden and Hardangerfjorden. It has an area of 225 sq.km, and is the third largest of the Norwegian glaciers. Its greatest N—S length is 34 km, and its E—W width 16 km. Two narrow gulches, Blådalen and Kvitnedalen, divide it into three parts. The northern part has a height of 1654 m, the middle part rises to just over 1600 m, and the southern, the highest, 1661 m. They are all typical glacier caps with many out-flow

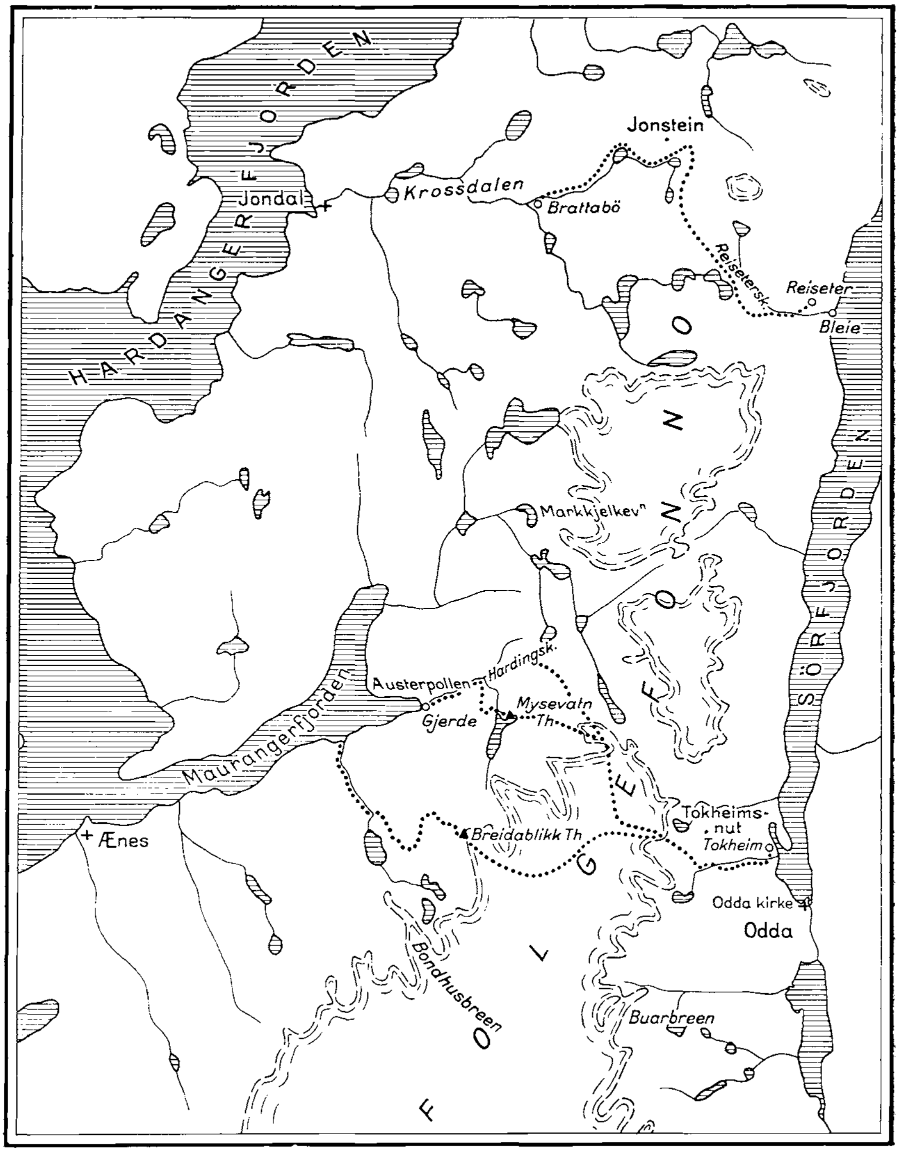

Fig. 11. Map of routes across Folgefonni.

glaciers. The mountain on which Folgefonni is situated slopes abruptly down to Sørfjorden, a southgoing branch of Hardangerfjorden, and the surrounding valleys. The height of these cliffs is 1300—1400 m. Only two of the glaciers are fairly large valley glaciers rising to moderate altitude, Bondhusbreen reaching 310 m and Buarbreen 426 m above sea level. The glacier margin reaches the top of the cliffs and has many small glaciers ending in considerable heights. Many of these break off (calve), forming regenerated glaciers.

It is a world of mountains and ice-fields with farms only situated along the seashore. Into this peninsula Maurangerfjorden makes a deep cut. Nature herself has here created a short cut between the outer and inner Hardangerfjorden, and from time out of mind, up to the introduction of the steamship, people have crossed the peninsula by this neck of land instead of sailing or rowing around it to the north. Tracks led from old from the inner part of Mauranger to Sørfjorden across Folgefonni.

Jonas Ramus states in his Norriges Beskrivelse (1715, p. 133) that travelling on Folgefonni was forbidden from St. Bartolomew (Aug. 24th) to Holyrood-Day (May 3rd) because of dangerous crevasses in the glaciers. The necessity of issuing such instructions is proof that crossings of glacier were common in summer time.

Very often young people from Hardanger crossed Folgefonni in order to hear the sermons in Ænes church, while on the other hand people from Mauranger came to the church in Odda to attend the services held there. And the farms Nå and Kvestad in Hardanger hired pastures on the Mauranger side along Markjelkevatn.

The famous dean in Hardanger and Voss Niels Hertzberg (1759—1841) very often travelled across Folgefonni to visit his brother, P. H. Hertzberg, who was parson at Kvinnherad in Sunnhordland. Forbes crossed Folgefonni in 1851.

The most used and oldest track led from Austrepollen in Mauranger up through Hardangerskardet over Folgefonni and down to Tokheim farm near Odda. It was a comparatively safe route, even in misty weather, as here Folgefonni was more free from crevasses than elsewhere.

At the northern end of Folgefonni there was also a very old track, still more used than the more southern one through Hardangerskardet. This northern road began at Jondal and ran up Krossdalen, across the mountains and down Reiseterskardet to Reiseter and Bleie in Vikebygd district of Sørfjorden. According to an old legend the Holy Crucifix in the church of Røldal was carried this way. Certain it is that the track became a much-used pilgrim road with a "selehus" or hostel at the upper end of Krossdalen. Near Jondal church there is still a barrow from heathen times called Austmannhaugen. "Austmann" were people from eastern Norway. The road to Røldal and farther eastwards was also called Austmannvegen. Austmann-names generally indicate traffic arteries. The name Reiseter is also very old, dating back to the Viking Age or earlier. The first part of it may be reid, i. e. riding and road, as the road over the mountains begins there. The finding of a Spanish coin on the road might also be seen as proof of the volume of traffic along it. The track was further used for droves of cattle and horses until steamship took over the transport.

Nowadays there are no perennial snow-fields along this track, but in former days there were. Sexe and Olafsen say that the fields north of this track are a continuation of Folgefonni, divided only by Reiseterskardet.

Regular tourist traffic began in the district about 1840—1850, with guides available for crossings of Folgefonni. In the ninethieths riding-tracks were built from east and west up to the rim of the glacier. A little earlier travelling across the ice-cap by sledges, drawn by horses or reindeer came into use. At the rim of Folgefonni tourist huts were built by Mysevatn, where the oldest track is, and further south by the track from Bondhusbreen, the Breidablik hut was erected. From there the track runs near Bondhusbreen. A trip over the peninsula can be made in about nine hours, the crossing of Folgefonni proper taking about two hours.

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JOSTEDALSBREEN

BY JOHANNES NORVIK

A glance at the maps of Jostedalsbreen shows it as a long and comparatively narrow mountainous region between the Sognefjord and Sunnmøre in western Norway. Here the annual precipitation is very high, about 2000 millimetres, and as the mountains go far above the snow line, to 2000 metres or more, this mountain ridge is consequently a snowy waste, formed like an oblong shield. But into this scutcheon nature has cut deep fissures, valleys with or without lakes, on both sides. From the valleys on the western side of the snow-fields the distance to some of the valleys on the eastern side is often very short.

These incisions are on the western side, and beginning from the north they are: Strynsvatn, Loenvatn, Oldenvatn, Stardalen and Jølstervatn. In the east we see Rauddalen, Styggevatn, Krundalen, Veitestrandsvatn and the Fjærlandsfjord. Between these cuts Jostedalsbreen crossing was comparatively easy, and anyway so much shorter. Anyone travelling from Jostedalen to the eastern farms in Olden in Nordfjord had to undertake a walk or ride of about 30 kilometres. If he wanted to avoid the snow-field, he had to ride or walk down to the sea, as in ancient times there were no roads for wheeled traffic in this part of the country. The route to Lusterfjorden, a branch of Sognefjorden, could only be used in summer time (from St. John's day to Martinmas), according to the parson in Jostedal, Mathias Foss, about 1750. The other route along the river to Gaupne, on the same branch of Sognefjorden, he described as "cumbrous, difficult and dangerous". Having reached the sea one had to row west to Vadheim, if one wanted to take the shortest possible route, then cross over-land and continue through valleys and over passes involving all sorts of inconveniences, and often dangers. By the time the traveller had reached Olden he had covered a distance of 340 kilometres. Even after roads for wheeled traffic had been made in many valleys this route was too cumbersome.

It is therefore evident that the track across the snow waste must be very old, almost as old as the first settlement in the mountain valleys. In Jostedalen the temperature is generally too low to raise grain with any success. In the lower and more fertile valleys of Nordfjord, the barley and oats are always sure to ripen. So the people from Jostedalen had to buy their grain there and carry it across the bre, on their own backs, on horseback or on sledges most of the way. As barter they brought all sorts of household and farming tools. From the west they also are reported to have brought herrings, and they might therefore be supposed to have brought other sorts of fish and also salt.

The first settlers in Jostedalen must have arrived omparatively late, as no archeological remains, no pagan mounds or graves have been found. The colonists were therefore Christians and are recorded to have had a church in 1323. Shortly afterwards the Black Plague struck the country,

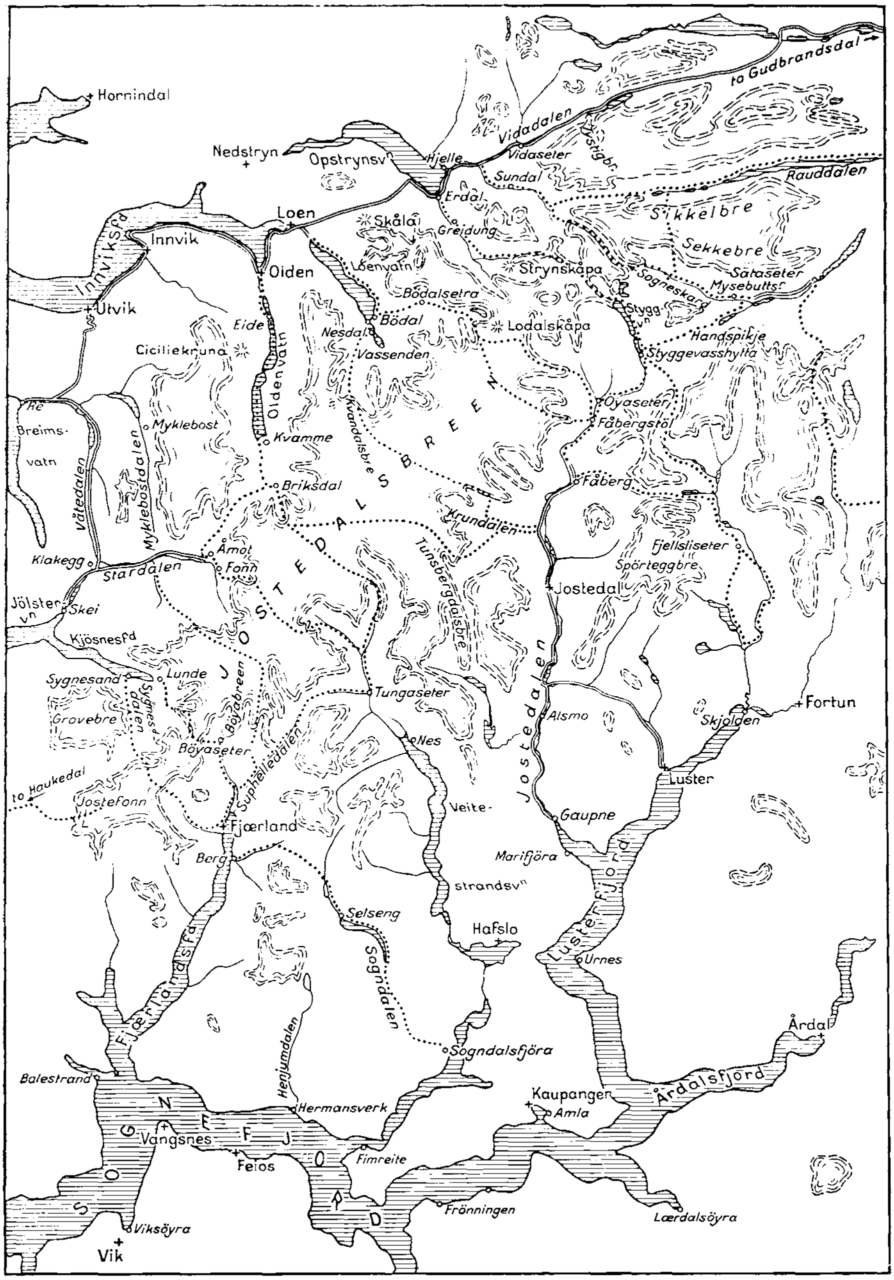

Fig. 12. Map of routes across Jostedalsbreen.

so violently that in mountainous regions abandoned farms from that time still exist. Legend relates that the whole population of Jostedal save a young girl perished, and that the valley was repeopled from Nordfjord across the bre. There are many indications that this is true. Thus the dialect in Jostedalen is the same as the patois in Nordfjord and wholly different from that spoken elsewhere in Sogn. Lars Hess Bing says that poor people from Nordfjord began clearing the deserted farms in Jostedalen "according to Royal encouragement and merciful exemption from taxation" (L. H. Bing: Beskrivelse etc. 1796, p. 313). Repeopling must have taken place about 1550, and the traffic grew as the new population increased in number and wealth.

The most used track connections east and west, beginning from the north, are:

1. From Strynsvatn to Skåre farm in Hjelldal, through Vidadal, past Vidaseter, along the mountain valley of Vassvenddal to Grotli and down to the Otta river in Sjåk, Gudbrandsdalen. The road here was built in the eighteennineties, and for many miles runs at a considerable altitude, the highest point reached being 1 148 m above sea-level. Kraft says (1829, Vol. IV, p. 909) that travellers avoid the great snow-field on this route. It is to be doubted whether this has always been the case. Tradition relates that Jostedalsbreen once extended into the Sunnmøre mountains. In 1900 Tystigbreen reached right down into Vidadalen, its lower end lying at 1 138 m. This road can only be used in summer-time, the mountains being too weather-beaten, snowy and misty in winter.

2 a. From Strynsvatn past the farm of Sundal, a branch of Hjelldal, north of the Sogneskardet, up on Kampferhamrane, the elevation there being about the same as in track 1, 1 150 m. But here the track very soon descends at a very steep gradient, to the Leirvatn lakes in Rauddalen, then along Rauddalsvatn, 900 m above sea level, and down to Sjåk. Slingsby says that this track only skirted Jostedalsbreen in 1891, but Rauddalsbreen reached down to the upper Leirvatn (Helland, 1913, III, pp. 115—116). In 1838 a man perished in a crevasse here (Eide, T. O., 1955, p. 36). Naumann used this track in 1822 and also speaks of Rauddalsbreen, saying that it came down transversally to the valley and that the crossing of it was consequently short. This was a very ancient route from the east of Norway to the coastal district of the west. Here droves of cattle and horses were brought over to Gudbrandsdalen and this route was much used by pedlars and the like. In Sverre's Saga (Sverre, King of Norway 1150—1202) there is an account of a military force dispatched across the mountains by the famous Bishop Nicolás in 1179. It seems to have been a very usual thing at that time to make this crossing. The guerilla band boasted of their feat, but their boasts were surely based on the fact that they had succeeded in killing some of the King's adherents in Olden.

As most of this passage only climbs to 900 m, and snow measurements have shown the amount of snow to be comparatively low, plans for building a road capable of taking wheeled traffic and of being kept open all the year round have been discussed. It would be necessary for this purpose to blast a tunnel under Kampferhamrane. These rise up like a wall and the tunnel wold be short.

The old working track is still visible. T. O. Eide mentions the possibility that Kampferhamrane might be a corruption of Kaupferdhamrane, literally the Mercantile Trade Crags. In this case this track may be one of the oldest of its kind.

2 b. The Sundal—Sogneskardet route branched off from the abovementioned one. The name Sogneskardet indicates that it was a usable track as far as Jostedalen. But the next and more southern one was far more well-trodden.

3. From Strynsvatn past Greidung farm in Erdal, going up south of Strynskåpa, either down to Styggevatn or farther west and more direct down to Fåbergstøl. Jens Kraft says that the passage across Jostedalsbreen proper is about 25 km (1829, vol. 4, pp. 883 and 910). Slingsby calls this track "the horse and cattle pass". It "is undoubtedly the best known of all ...... When there is a wedding in Nordfjord, the usually solemn-faced swains of Jostedalen cross over this pass in great force to join in the festivities of the sunny west, and the light-hearted sons of Stryn cross over it in a like manner to dance at the wedding of an eastern belle". (Slingsby, The Justedal revisited, 1891.) Old tales say that a whole wedding procession once made its way to Oppstryn church, as there was no church in Jostedalen at that time, that is to say before 1660. Matthias Foss says that the people travel along this route "every year", the distance over the nevée being only 14 km. (As we see the figures are not in accordance with those of Kraft.) The only time for crossing is between Easter and Michaelmass. He tells of carrying corn, herrings and grain back to the home valley. Corn is here barley, used for the brewing of ale. Cattle and horses were driven over there (M. Foss, 1802—03, pp. 18—21).

4. From Bødal farm in Loen a track led up to the nevée south of Lodalskåpa and over the Fåbergstøl. According to a Royal Resolution (Order in Council) of Sept. 20th 1828 there were guides appointed to escort travellers — also in winter time (Kraft, 1829, vol. 4, p. 922).

5. A track from Nesdal in Loen to Krundal in Jostedalen, "undoubtedly a very ancient pass", says Slingsby, (cit. paper, p. 38), but the way up or down Kvandalsbreen is somewhat difficult, because of the shrinking of the glacier, he points out.

6. Matthias Foss speaks of a track from Kvamme farm in Olden to Jostedalen. But this track was not much used, as it was the most difficult and the most dangerous (Op. cit., p. 19). Helland says that according

to other sources, it was frequented as late as near Christmas-time, men from Jostedalen coming to Kvamme to buy grain, carrying it back on their own backs (Op. cit., Part A, p. 135). From Kvamme to Bergset in Krundal the distance is 28 km (Foss).

7. From Olden to Tungaseter in Jostedalen runs a track mostly used by tourists.

8. From Åmot in Stardal to the same Tungaseter — also much used.

9. From Lunde farm in Kjøsnesfjord, a branch of Jølstervatn, a track led to Bøyaseter at the southern end of the Bøyabreen glacier. "It is strange to think that the only recognised pass over the southern part of Jostedalsbreen seems to have been from time immemorial that of the Lundeskar." (Slingsby, op. cit., p. 28.)

The track is very steep down from the nevée (1450 m above sea level) to the west, and down the Lundeskard, it is even dangerous, though not so perilous nowadays as in former times. Den Norske Turistforening has introduced some improvements providing the track with bolts and wire to assist people in ascending or descending. On the eastern side there is also a carriage road from Fjærlandsfjorden up to Bøyaseter. At the upper end of Bøyadalen there is a place called Jølstrabotn, yet another indication that this passage has been much used.

10 a. From Sygnesand in Kjøsnesfjorden, a little west of Lunde, a track led up Sygnesanddalen over Jostefonn (1600 m above sea level), and down to another Jølsterbotn in upper Mundalsdal, and from there farther down to Mundal farm at Fjærlandsfjorden.

10 b. A branch of this track began in Haukedal in Førde, led up Grønningdalen, along Sygneelven, over Jostefonn and down to the same Jølsterbotn. Here, too, the names Sygnesand and Sygnaelv west of the snow-field prove the tracks to be old and much-used.

Very often people who have crossed Høgebreen, as the nevée is often called, were ferried over Fjærlandsfjorden and continued their journey over the mountains to Sogndalsvatn and along Sogndalselven down to Sogndalsfjorden. When cattle and horses were driven along such tracks the forage was gratis, and as the drivers always found seters (dairy farms) on their way, they too fared very cheaply.

People at that time were seldom deterred from long journeys in the mountains and life in the open. So brought men from Jostedalen butter, tallow and meat on their pack-horses all the way to the town of Røros. Matthias Foss mentions this trade (1750) and computes the distance to be 32 Norwegian miles (362 km). The people went thither almost every year, he says. Farmers from upper Gudbrandsdalen made their way along the same track to Jostedalen and down to the sea, with long strings of pack-horses and drivers with all sorts of wares. They returned with iron, salt and, in bad years, barley. This track was the shortest from Sjåk to the sea (viz. on the way to Bergen).

Wild animals, such as bear and ermine, also found their way over Høgebreen. When new snow hid the crevasses people crossing the glacier were always extremely cautions. But if they found the tracks of ermine they felt sure. For this little animal never looses its way on the snow-field, going straight from valley to valley. If he comes to a concealed fissure he instinctively senses it, and, having rounded the dangerous place he continues straight on as before. (Hoprekstad, 1937, p. 25.)

When modern roads were built the traffic on the old tracks gradually decreased, but droves of cattle and horses used them up to the eighteen-nineties. From then Jostedalsbreen has melted down considerably, and Knut Fægri says that driving cattle over it is impossible nowadays (Fægri, 1936, p. 16).

The tracks of old were never quite forgotten. When the old traffic decreased a new one, that of tourists on foot, grew up in the eighteen-seventies. The grand old man among tourists, Charles Cecil Slingsby, found on his rambles many old cairns, proofs of how much these tracks were used. And nowadays tourists cross Jostedalsbreen every summer by the hundreds, using the cairns built up by forgotten generations and, in the north, especially Lodalskåpa as their landmark.

On the whole comparatively few disasters have occurred among the thousands who have crossed this glacier cap. The best time for crossing is before St. John's Day. In recent times crevasses have grown wider and more difficult to traverse. And when wanderers ran into fog or snow-storms, lives were not infrequently lost. Foss speaks of the necessity of having people acquainted with the glacier to lead parties crossing. Nowadays there are mountain guides at the disposal of the tourists in most of the hotels and tourists huts. And walkers are warned by weather-forecasts and hotel managers. So the tourists run no risk on glacier traverses, provided they exercise due care.

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THE GLACIERS OF JOTUNHEIMEN

BY LARS SULHEIM

Information on the traffic over the glaciers in Jotunheimen has been provided by the mountain guide, Lars Sulheim in a letter of Oct. 16th 1957 to Werenskiold. Dealing with our subject the letter runs:

"The districts near Gjende which are comprised within the boundaries of the district of Lom, belong to "Leirdalen and Bøverdalen commons". From this it is clear that the farms in Bøverdalen had the right to pasture and dairy farming in the western parts of the Gjende region. Good proof of this is afforded by the Hoftastulen and Glømsdalstulen seters in Storådalen. (These now abandoned seters belonged to the Hoft and Glømsdal farms in Bøverdalen.) Through Visdalen an old thoroughfare once passed; certain proof is afforded by the existence of

Hellstugu, a ruined hut in Visdalen half way between Bøverdalen and Gjende. The name probably means flagstone hut. But Sulheim is of another opinion, he thinks that the name means refuge for wayfarers. The track passed naturally through Urdadalen to Gjende, continuing over to Bygdin down to Valdres, Land, Hadeland and on to Oslo. For several seasons they had to take the cattle over other routes than this ordinary track. By Gjende verdure comes early in spring, therefore the cattle could manage to live here, while snow-fields were still lying in upper Visdalen and in the whole of Urdadalen. They then went with the cattle over Hellstugubreen and Memurubreen so that they came down to the western part of the tongue of Memurubreen and down into Storådalen. They mostly travelled over the glaciers during the night, when the snow was firm.

It was certainly not uncommon for cattle to be driven over the glaciers, when they went out in spring time or early summer at other places in the high fields as well. As a matter of fact, the people of the Skjåk district travelled across the eastern part of Hestbreen: they had at a very early time acquired a seter at Netto (in the upper Bøverdal). The name of the glacier is probably due to some incident or other connected with horses. Along this route, there are no longer any glaciers, but about 150 years ago, glaciers were no doubt lying here. The highest point on this route is about 2000 m above sea level.

Sometimes the route (to Gjende) went across Semmelbreen — between Semmeltind and Memurubreen. I have been told that a man lost his horse here.

None of the cattle tracks which have been mentioned here are now in use any longer. It may in fact be about 40 years since a horse passed through Urdadalen. When anybody travels with horses and cattle between Bøverdalen and Gjende, the route passes over Høgvaglen, where at path has been cleared. Here, and further along Langvatnet the snow is no longer such an obstacle as in former days."

FLATKJØLEN (DUOLPAJIEKNA)[1] AND LAPPFJELLET
BY JOHANNES NORVIK

This glacier is situated in the Sørfold district, Nordland county, 67°24′ N. and 5°15′ E. Its direction is west-east and it crosses the border with Sweden, where the name of the glacier is Rakokjiekna. It has a total length of 25 km and its area in Norway is 43.3 sq.km. This figure is calculated on the Norwegian map, scale 1: 100 000, which was surveyed 1906—1908. But since then the glacier has diminished considerably. It is very flat and its height above sea-level is 1100—1200 m. It is comparatively free from crevasses.

[1] Lappish name. (Duolpa means flat, jiekna glacier.)

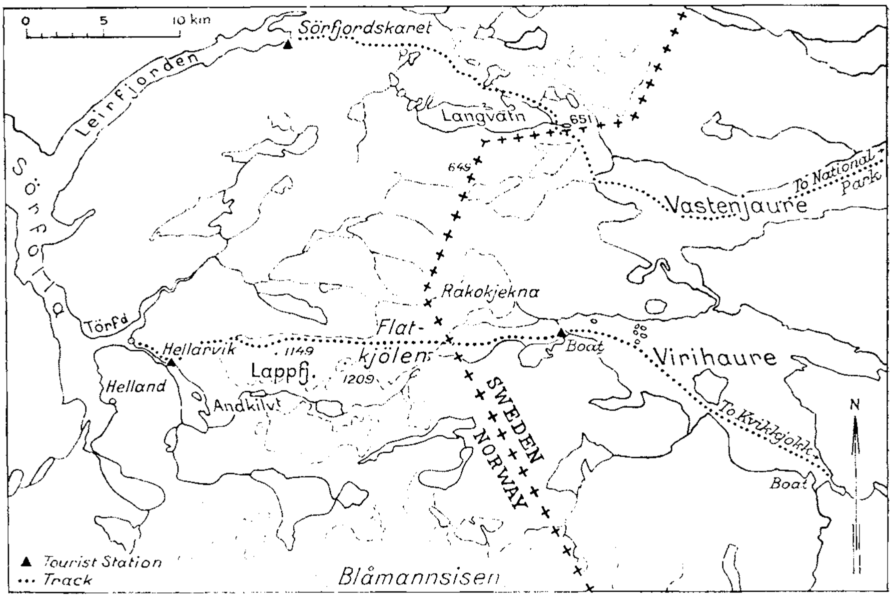

Fig. 13. Map of the route across Lappfjellet and Flatkjølen.

As a basis for the drawing of the accompanying map has been used gradteigkartene Sørfold, surveyed 1906—1908, Lunnajavrre, surveyed 1908 and published 1913, and also Turistkartan över Sverige, Blad 22. Scale 1 : 300 000. Sth. 1947.

The passes in the border mountains between Norway and Sweden, which are generally called Kjølen, dividing the Scandinavian Peninsula in two, have from old had a comparatively lively traffic. The sagas tell us of trading with the Lapps by Norwegian tax collectors, who must have used some of the numerous passes. For taxes were also collected east of the present border. Later on we learn that Swedish tax collectors found their way into Norway for the same purpose, taxing the Lapps. The famous vicar and author Petter Dass (1647—1708), describing these tax collectors, generally called birkarles or barkkarles, states that they were also traders and came from the far Bothnian Gulf, 600 km away. They bought fish and sold iron-ware. Petter Dass also speaks of trade with the Lapps. They came down from their mountains, on or about St. John's Day and sold their pelts and hides, reindeer meat and all sorts of handiwork, bartering their wares for fish and woven goods.

One of these old tracks over Kjølen is of special interest to this work because it crosses the comparatively large glacier, mentioned above.

It was mostly Lapps who wanted to reach the fjords in this district, Lapps who lived in the favourable regions around Virijaure and

Vastenjaure[1]. They found that the easiest way in summer was the one over Flatkjølen — Lappfjellet.

The Lapps used skis and special sledges, called pulk and kierris, a sort of toboggan. With reindeer as draught animals the journey was far easier than through the passes with pack animals. They could cross the glacier in one day; from the fjord to the Virijaure district was a hard trek, though it could be done in a single day.

In olden times the crossing of the glacier was considered quite dangerous. The great Swedish botanist Linné went there on the 16th July, 1732. He calls the glacier "a dazzling snowy waste", and "an icy mountain". He observed that the sides of the crevasses "exhibited many snowy strata above one another". On his way back to Sweden over the "icemountain", the journey was endangered by a thick mist. Happily the travellers discovered "the track of a reindeer, and of some kind of vehicle in which goods had probably been lately conveyed towards Norway".

In winter the Lapps preferred to cross the border a little east of Langvatnet[2], on the way from Vastenjaure in Sweden. They then had to go down to Leirfjord through the Sørfjordskaret, which is very steep. Moreover, as Langvatnet is only 609 m above sea-level, this track lies comparatively low down.

The Swedish botanist Wahlenberg travelled three times up and down over the glacier between Tørfjord and Virijaure. The march over the glacier "lasted some hours". In his report on the excursion he has a map which shows both tracks down to Sørfolden, over Flatkjølen and past Langvatnet to Leirfjord.

West of the mountain range the Norwegian Major Peter Schnitler in the 1740's investigated the lay of the borderline. He questioned witnesses concerning the line and problems in connection with it. He was in Sørfolden in 1743 at the farm Helland, where he was informed of an old fair in Tørfjord about Michaelmass (Sept. 29.). At such times the Lapps came over the border to barter reindeer meat and cheese and other articles for brandy, tobacco, salt, fish, liver-oil, powder, lead and woven goods. These Lapps had to cross the glacier.

Some time after 1700 the newly erected Lapp Mission commenced its activities, and the fair ceased to exist when Schnitler visited the district. In spring time the Swedish had to cross the glacier together with their reindeer in order to utilize the grazing grounds on the Norwegian side. After 3—4 months the pasture grew somewhat scanty in Sørfold, and the Lapps drove their reindeer back over "Jiskjølen". They lived mainly in the district of Virijaure. The shortest cut over to Sweden, however, was from Leirfjord to Vastenjaure, it was said.

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[1] Jaure or javvre, is the Lappish word for lake.

[2] Lappish Gukkejavvre.

According to Hülphers' description of Swedish Norrland from the 1790,s the minister of Kvickjock visited the Lapps in the Virijaure district in July, where he preached to them in Lappish on a hill called Arras, west of Virijaure. Norwegian Lapps, it is said, also came over to hear the sermons. It was believed that they came because they so seldom had the opportunity of hearing the gospel in their own language, and some of them at least must have crossed the glacier because it was the quickest way. In his ennumeration of the mountains west of the Lule Lappmark, Hülphers include Tulpajäkna (Duolpajiekna).

C. J. Pontoppidan also mentions Tulpageikna in the explanation to his map of North Norway, 1795, as the Snow Mountains north of the Almajalos, and mentions the possibilities of travelling through the passes in Kjølen, of which the most important is that from Rana in Norway to Piteå Lappmark, the one Petter Dass commented on. But in his list of passes used, Pontoppidan also includes the passes in Folden.

In 1883 Charles Rabot travelled in Nordland county and went over Flatkjølen in order to travel in Swedish Norrland among mountains and glaciers there. Like Linné before him, he found the crossing to be somewhat tiresome.

As had been case with many other glaciers, tourists also found Flatkjølen interesting.

As early as 1879 Chr. Tønsberg mentions in his guide book the track from Tørfjord or from Lappelv at Andkilvatnet to Virijaure and Alkavara Capek (north of Virihaure), 5 Norwegian miles. He has no comment on the glaciers en route (p. 417), but this track must have passed the glacier.

It was left to the people of Nordland themselves to press the claims of these remote districts as a hiker's el dorado.

In Toralv Hagen's handbook for travels in North Norway (1926) we find particulars about the Andkilvatn-Virijaure route. It takes 10-12 hours to reach this lake, but the walk over Lappfjellet-Flatkjølen proper lasts only 1/2 hour. Hagen contends that the walk is easy. A mountain guide is available at Hellarvik farm. The route Leirfjord-Sørfjordskar-Vastenjaure is also mentioned (pp. 113 and 114).

In 1925 Bodø og Omegns Turistforening published a handbook of a more local character, and here we find that the trip Megard in Tørfjord-Virijaure over Flatisen may be done in 8-9 hours. A guide is necessary over the glacier. The route Leirfjord-Gukkejaure-Vastenjaure is also mentioned (pp. 16—19).

Norwegian guide books refer to Swedish ones, and no wonder. In Norway there are so many districts where the population is spare and the scenery overwhelming.

In Sweden such views are mostly to be found in the northern part of the country. Some Swedish miles east of Flatkjølen there is a vast region laid out as a national park, thanks to its natural beauty. And a little more to the south we have Kvickjock, the paradise of Lappland. Hans Lidman says in "Norden rundt", 1947, that Virijaure is one of the most beautiful lakes in the Swedish mountain world (pp. 435-447).

Every summer consequently sees a steadily increasing stream of tourists arriving in the neighbourhood of Flatkjølen. In later years it has even been possible to reach Virijaure by planes. On Swedish tourist maps it will be seen that boats are used on Virijaure and Vastenjaure; huts for over-night accomodation and other amenities are marked, as well as the trails running into Norway. Swedish guide books give particulars as to pass-ports, how to obtain guides, and so on.

Among Norwegian publications we must mention Kristian Nissen's article on Nordland-Lappland in Den norske turistforenings årbok 1917. He deals with routes into Sweden, and especially the classical one over Flatkjølen. For a distance of several Norwegian miles ski or sledge may be used. Horses may be used to pull sledges (p. 170).

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Both show the tracks over the border, along Gukkajavrre or over Duolpajiegna.

Turistkartan över Sverige, Blad 22 (1:300 000). Stockh. 1947.

Utilization of ice from Norwegian glaciers

It may be assumed that no glacier in the world has any direct commercial value. In fact glaciers are generally hostile to trade.

But there are three glaciers in Norway from which not inconsiderable quantities of ice have been utilized for refrigerating purposes, viz. Folgefonni, Strupbreen, and Øksfjordjøkulen.

FOLGEFONNI

First of all a few words on the name of the glacier, as this has different forms in the works on the glacier. The form Folgefonnen is most frequently used in these works but on the map published 1951, issued by Norges Geografiske Oppmåling, a quite new form of name — Folgefonni — (from the old fonnin) is introduced. This form of the name is used in this work.

In Hordaland, western Norway, the word fonn means:

1) a heap of snow, a snowdrift, 2) a snow-field, 3) in other dialects it also means an avalanche. The first part of the name Folgefonn, folga — means a thin layer of snow, probably derived from the Old Norse verb fela (past partic. folginn) — to conceal. The English verb. filch is related. With the definitive article attached to the name it must in Old Norse be fonn-in, the Folgefonn. Hence the name Folgefonn-en in most of the bibliography. The people in Hardanger, north and west of the fonn, say Folgefonn-æ or only Folg-æ (Folgjæ). In Sunnhordland, west and south of the glacier, it is called Folgefonn-o or Folg-o.

Folgefonni is represented on three gradteigsmaps:

1. Folgefonni surveyed 1932—1942 and published 1951.
2. Skånevik, surveyed 1915—1920 and published 1923.
3. Fjæra, surveyed 1955. It has not been published, but will appear in a year or two.

Export of ice from Folgefonni took place, to our knowledge, for the first time from Bondhusbreen, an outflow glacier on the west side of Folgefonni. It flows in a E—W direction and ends about 300 m above sea-level, near the eastern shore of Bondhusvatn, a lake 1400 m long. Its outlet is at the western end, and a river, 3 km long, runs down to the Maurangerfjord by Sunndal farm.

The first available information on the topic is to be found in the daily newspaper "Morgenbladet", October 4th 1925, Christiania. The author, the famous Dean of Kinsarvik, Niels Hertzberg, had heard that in May that year a Scotsman named Growe came to Bergen in his schooner Albion in order to load it with ice from Folgefonni. Someone had advised him to fetch it from Bondhusbreen, and in June he dropped anchor at Sunndal, where he made a contract with the surrounding peasantry that they should bring him ice to the ship for 18 skillings a vog (a skilling was about halfpenny, a vog 40 lb. or, in moderne Norwegian currency and weight, about 60 øre for bringing 18 kilos of ice). Later, as the number of men bringing ice grew — they came from almost the whole parish of Kvinnherad — Captain Growe got the ice for 12 skillings (40 øre) a vog.

As there existed no road from Sunndal to the glacier, they had first to carry boats through a formidable 7.5 km long scree to Bondhusvatn.

The hardy and industrious men of Kvinnherad first hacked the ice loose and loaded their boats (the glacier was then nearer to the lake than now), and rowed it to the other end of the lake, and from there they carried it on their backs through the scree to Sunndal. Some of them carried 3 vogs, others 4 vogs on their drenched backs. In this way the Briton took onboard 5,000 vogs (90 tons), and would have got 2,000 more if a dispute had not arisen between the carriers and the owners of the farm, because the former trampled meadows and fields under foot. And this was the end of the new trade, it seemed, which had given the carriers a total earnings of Kr. 2,000 for loading the Albion. It was exported to Scotland where it was to be utilized for preserving salmon.

It is very strange that demands for this ice should first come from a foreign country. How could a Scottish firm be the first to be aware of the facilities for obtaining ice at a remote glacier in Norway? In a way it was not so remote. Dean Hertzberg wrote his article "Noget om Sneebræen Folgefond" in 1818. English anglers and hunters visited him and he advised them as to the best way of reaching Folgefonni. So it must be assumed that its glaciers were not quite unknown to many people in Scotland and England. Bergen was not far from Folgefonni, and some fish-exporter there must have known it, and had a notion of its possibilities.

The assumption that the above-mentioned quarrel would put an end to the ice trade in Mauranger proved unduly pessimistic. There must have been some export after 1822, as the firm of Johan Dahll in Kragerø found it worth while to build a road for vehicles from Sunndal to Bondhusvatn through the scree that had been the worst obstacle for fetching ice. The road, 3.5 km long, was built in 1863 and called Isveien. Th. S. Haukenæs, who in the eighteeneighties and nineties travelled about in western Norway in order to collect all sorts of dying traditions from olden times, visited Bondhusbreen and mentions Isveien in an account of the story of the export in 1822. Mockler-Ferryman relates the same particulars as Hertzberg and Haukenæs. "For some years", he says, "there was a fairly good trade done in ice, but after a while it fell off and eventually died out". (Haukenæs, 1888, p. 55 et seq.; Mockler-Ferryman, 1896, p. 59 et seq.; Vibe, 1896, p. 134; Helland, 1921, I, p. 83.) From Bondhusbreen the last load was presumably exported in 1863.

Ice was also exported from the eastern rim of Folgefonni. Dean Hertzberg contended that it was to be procured much more cheaply there, as it might be loaded on sledges in front of a glacier and brought comparatively easily to the sea. At Valaberg, high above Bleie farm in Sørfjorden, there is an outflow glacier called Støkken. Støkka means in the vernacular "to break off and fall out". The front of the glacier is vertical and breaks off in big blocks, which tumble down and form a regenerated glacier, the lower end of which Hertzberg estimates to be 1,500 Norwegian feet above sea-level (about the same number of English feet). The track from the glacier to Skiparvik, where the ice had to be loaded, he measured and found to be 4,064 feet. Thus conditions were far better than in Mauranger, and he believed a suitable price might be 6—8 skillings a vog. His parishioners all seemed to agree with this, and a Bergen merchant, Daniel Wiese, sent a ship on Hertzberg's advise to Skiparvik under captain Herlofsen's command. The man-drawn sledges proved capable of taking 9—10 vogs (160—180 kg), the horse-drawn ones 12—16 vogs (216—288 kg). And the workers could easily manage two trips a day. The peasants who could use their horses were thus able to earn kr. 6 to kr. 12 a day. But when the ship arrived the men broke their verbal agreement with the Dean (kr. 1.36 per 100 kg) and demanded a far higher rate (kr. 2.33 per 100 kg). The captain therefore took a cargo of only 36 tons and this was loaded in one and a half days. Robert Everest mentions this export in his "Journey through Norway", 1829, p. 232.

No export of ice from Folgefonni is recorded for the years immediately following. Some exchange of letters between a firm in Christiansand and Hertzberg in 1832 produced no results. But in 1834 an English schooner arrived, which in three and a half days loaded 9,000 vogs of ice. Her captain paid 8 skillings a vog for having the ice carried down. The head of the firm that had negotiated this was Consul A. Grieg of Bergen, and the captain's name was Robert Thomas. Vibe also tells of a load taken in 1834 (Vibe, 1896, p. 230). The parson of Ullensvang, Olaf Olafsen, who for many years lived in the same deanery as Hertzberg, and had an oportunity of studying his correspondance, has related this. Hertzberg computed the average earnings of the ice-carriers to be kr. 2 a load. The total earnings of the peasantry can be computed to be kr. 2,000. As the glacier was common ground, all paid-out money represented wages for labour (Olafsen, 1920, p. 23 et seq.). Captain Thomas paid a visit to the old Dean, who wrote about it in his traveller's book (see Hertzberg, Nils, 1929).

Olafsen has also collected some oral accounts from Bleie farm of expeditions that came to fetch ice. In the years 1855—1858 there were two English ships. The price this time was 8—12 skillings a vog. The peasants made a new road for the ice transport, called Klakaveien (Olafsen, 1920, pp. 23—26). In his book "Ullensvang" he mentions the ice export without giving any particulars.

But we know from other sources that ships must have come to Skiparvik from time to time. The Reverend Alfred Smith, who travelled in Hardanger in the eighteenfourties, has an informative little sentence in his "Sketches in Norway and Sweden", 1847, p. 15: ". . . the Norwegian ice which is sold in London is brought from this glacier". Another fact points in the same direction. Knut L. Måge relates in a letter to the author of this article the following, that in his boyhood Olav Larson Bleie, born 1830, planted early potatoes in order to sell them to the Englishmen when they came to fetch ice. The English visits must therefore have been more frequent than most people think.

Sir C. Anderson, Bt., who travelled in Norway in 1852, speaks in his "An Eight Weeks' Journal in Norway, etc." of the export of ice "some years since" (p. 51). All this indicates that ice must also have been exported in the '40s, and this is confirmed by a report from the lensmann (rural sheriff) for the years 1846—1850. It runs as follows: "As a rarity may be mentioned that in the year of 1846 7 loads of ice were fetched by English ships. It was brought down and loaded at Bleie farm. As a result, between kr. 8,000 and kr. 12,000 came into the parish. But as the bringing down of the ice, which involved a great deal of toil, took place in the middle of the warmest season in summer, the advantage was actually less than one might think ......" (Olav Kolltveit: For 100 år sidan, 1949, pp. 109—129.)

Måge relates that a Bergen firm, Th. Brown, got a load in 1851 of 4,300 vogs (approximately 77 tons). In 1852 the brig "Countess of Warwick" took 16,000 vogs (nearly 300 tons) and the brig "Mestley Parks" loaded 9,237 vogs (106 tons). The English, however, maintained that the Folgefonn-ice was too expensive, though they considered it to have a greater "specific frigidity" than the ice obtained in southern Norway (lake ice). In the last eighteenfifties the ice market was firm and in 1859 the Hardanger district had a positive run on ice. In 1862 S/S "Amicitia" of Rotterdam took a load in Skiparvik (Vibe, 1896, p. 230). There is a tradition at Bleie that S/S "Hero" took a load in the same year (Måge in a letter).

We hear little from the ice market later in the sixties, but that the demand for ice still existed is shown by the bold undertaking attempted by two Stavanger contractors. In 1874 they built a chute of timber from the glacier below Støkken to a storage house put up in Skiparvik. The length of the chute was about 2,500 metres, and its cost about kr. 16,000. The chute proved to present unforeseen difficulties and could not be used. The export from Skiparvik ceased presumably in 1874 or shortly after.

We have no information as to the total quantity of ice exported from the two glaciers, nor of the firms engaged in this trade. Our information about the years of shipment are also, as shown above, somewhat vague.

Fig. 14. The ice-chute from Støkken to Skiparvik.

That this business did not grow into a regular trade, great as the demand must have been, is due to the fact, indicated above, that it proved difficult to establish a firm agreement with the workers, as well as with the owners of the ground, on wages and rents. With regard to the demand for rents by the owners of the ground, who even threatened to stop the transport from Støkken in 1825, Olafsen relates that the Government decided that they could not forbid the transport; but they had a right to just compensation for damage inflicted on their ground.

We must assume that there were several export firms interested in this trade both in Norway and in Great Britain.

But what finally brought this unstable traffic to its end, was that in 1850—1860 methods for storing ice in sawdust or peat were invented. This made it easier and cheaper to cut ice on tarns and lakes near the sea in winter time, store it and send it to customers when needed. Glacier ice could not compete.

The export of fresh water ice gradually assumed large dimensions in south-eastern Norway. The greatest recorded export took place in 1906, when it was 495,000 tons to a value of kr. 1,597,400.

After that year the export decreased steadily on account of the growing use of ice produced by technical means. The export of fresh water ice from Norway is therefore now without any real importance.

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STRUPBREEN AND STRUPVATNET

BY ADOLF HOEL

Position and topography

The glacier Strupbreen is situated in Troms fylke on Lyngshalvøya at 69°50′ N. The glacier is to be found on the map-sheet Lyngen, scale 1 : 50 000. The map of Strupbreen included in this paper is based on the maps Lyngen, Balsfjord, Storfjord and Ullsfjord.

The name Strupbreen is derived from the Norwegian noun strupe[1], because the lowest part ends in a deep, narrow cleft.

In 1956 major Axel Printz, topographer of Norges geografiske oppmåling, field-checked the new topographical map of Lyngen (M 711, nr. 1634 III, scale 1 : 50 000). In this connection he has given the following information on Strupbreen:

"This glacier, situated in Lyngen herred between Jægervatnet to the west and Lyngenfjorden to the east (69°45′ N. and 19°50′ E.), commences in the black mountains which form the boundary between the districts of Karlsøy and Lyngen with Struptindane to the north and the sharp ridge separating Store Lenangstid (1696 m) and Tafeltind (1395 m) to the west.

The glacier, stretching east towards Lyngen, after a short distance splits into two arms, one of which — Koppangsbreane — runs southeast
The glacier, stretching east towards Lyngen, after a short distance
towards Koppangen, while the main glacier runs east-northeast. It flows down to the eastern end of Strupvatnet (506 m), and continues down towards Strupen, a broad bay in Lyngenfjorden, culminating about 330 m a.s.l. at the time the photo was taken (1953).

The glacier runs, as mentioned above, down to Strupvatnet, where it calves. The water-level in this lake varies greatly. In warm summers so much water is produced by the melting glacier ice that it forces a channel through the glacier, with the result that the water-level decreases appreciably. There is a difference of about 50 m between high and low water. The stream rushing through this channel carries calving ice all the way down to the fjord, and the ice is sometimes transported south as far as Lyngseidet".

The history of exploration

The first official general survey of the region was carried out in connection with the mapping of Troms fylke, that was completed in the years 1869—72. The scale was 1 : 200 000 and obviously a map performed in only three years of such a vast and mountainous district must be of poorer quality than maps of Southern Norway on the same scale.

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[1] Strupe means in English throut.

Fig. 15. Jeggevarre, the highest mountain on the Lyngen peninsula, with a little glacier cap on the top. (Photo: Widerøes Flyveselskap A/S.)

Yngvar Nielsen, Professor of geography at Universitetet i Christiania has given an account of the older oscillations of Strupbreen (Nielsen, 1896, p. 368). He visited this part of Norway in 1880, and relates that old peoples insisted that the glacier did not exist before 1740, being formed between that date and 1769.

Mention should also be made of the French geographer Charles Rabot, who made a journey to Strupbreen in the middle of the eighteen-nineties (Rabot 1900, pp. 108—110). He gives an exhaustive account of Strupvatnet, and declares that in natural beauty it exceeds the celebrated Märjelen Zee in Switzerland, which is dammed by a glacier. His chief sources were Hastings and Slingsby. He also mentions the oscillations of Strupbreen. During the period 1885—1895 Strupbreen was retreating. In the middle of 1885 it stretched all the way to the level ground near the sea (10 m above sea level). But after this year it began to retreat and "to-day (1896)", says Rabot, "it comes to an end on the rim of the mountain, sending blocks of ice down to the level ground, where it forms a regenerated glacier".

A. Helland, the author of the well-known work "Norges Land og Folk", at the end of the eighteennineties was working at his description of Troms fylke, which was published in 1899.

In 1898 he visited Lyngseidet, where he met Slingsby, who gave him a great deal of information about Lyngsalpene. Helland himself did not personally visit these mountains. In his description of the county he has given a comprehensive account of these mountain areas, including Strupbreen and Strupvatnet. The following is an extract os his account (Norges Land og Folk, Vol. 19, part 1, pp. 57—58).

"Among the high mountains of Lyngen lie glaciers that run down towards the sea. One of these glaciers, Strupbreen, which lies north of Lyngseidet, stretches down into a cwm-shaped valley and runs so far down that it lies only 10 m above the sea. In Strupen on the stretch between Jægervatnet and Strupen two Englishmen, climbing in Lyngen in 1898, came across a lake about 3 km long, not marked on the map, which is dammed by the glacier. When they made their way to Strupvatnet a few days later, the lake had disappeared; the ice floes were lying on dry land and there was hardly anything left of the lake."

Strupbreen and Strupvatnet have also been described by Olav Liestøl, in a paper "Glacier-dammed lakes in Norway", 1956. This paper contains a sketch-map, plotted from air photographs taken on July 15th, 1953, scale 1 : 50 000. It is the first map ever published of this glacier region. Liestøl has computed the area of the glacier to 14.0 sq.km. He has estimated the volume of the drained water of the lake to be about 12 mill. m^3.

A paper by Kristian Gleditsch deserves a special mention. 33 pages deal with Lyngsalpene and all the ascents made in the eighteennineties.

Extremely interesting is the author's determination of the height of Jiek'kevarri. In 1957 he landed on the summit of this mountain in a helicopter and was able to make an exact determination of the height (1832.7 m).

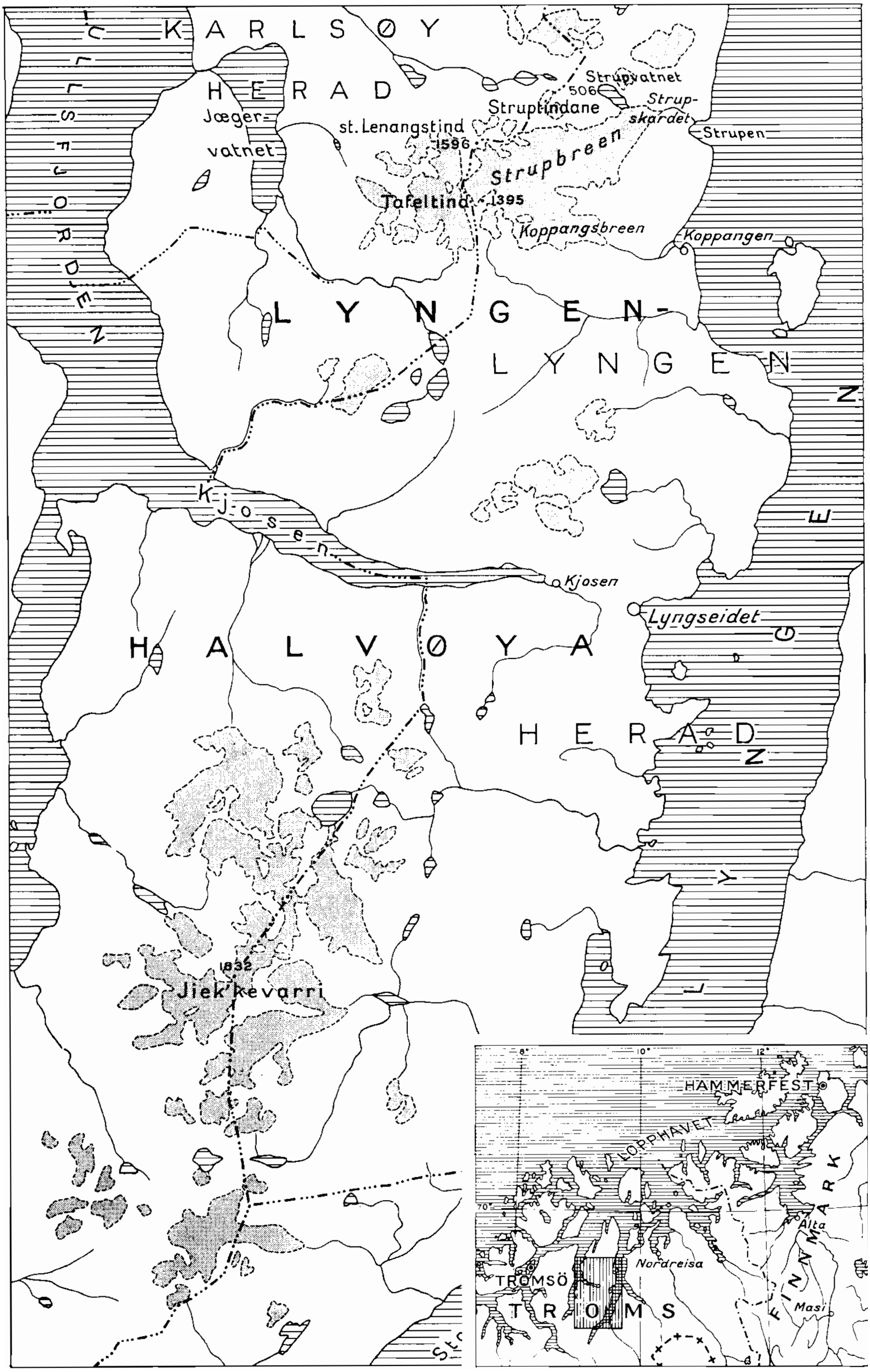
The article by Gleditsch contains 15 pages of notes and among these we find numerous references to bibliography. I have therefore not considered it necessary to refer to all the articles in "Alpine Journal" that deal with ascents made by the English climbers.

The first exploration of Lyngsalpene

The Norwegian climber Josef Caspari was the first man to undertake protracted tours of Lyngsalpene with a view to climb Jiek'kevarri. Two of his tours were made in 1896 and two in 1897. All of them proved unsuccessful. His attempts are described in Den Norske Turistforenings Aarbog for 1896 and 1899.

British climbers in the eighteennineties opened up Lyngsalpene as a climbers el dorado. These pioneers had already made a name with their climbs in southern Norway. It was the prospect of conquering Jiek'kevarri, at that time regarded as the highest peak in northern Norway, that attracted them to Lyngsalpene. This mountain is the highest and most dominant on Lyngenhalvøya.

The actual height of this peak is 1832.7 m, and there are in fact only six mountains in northern Norway that are higher. The highest in this part of Norway is Oksskolten (1915 m), south of Ranafjorden.



Figs. 16 and 17. Maps showing the glaciers of Lyngenhalvøya.
Inserted map shows the location.

In 1897 Jiek'kevarri was climbed by G. Hastings alone. (Alpine Journal, Vol. 19, p. 65.) In 1898 three Englishmen climbed in Lyngsalpene. These were G. Hastings, W. C. Slingsby and W. F. Hasket Smith. J. Caspari joined them on two of their trips, at their invitation. The party was also accompanied by the guide E. Monsen Hogrenning from Nordfjord.

Caspari (1899, pp. 50—55) gives a lively account of the trip, and of the wild and jagged mountain world, as well as a description of the remarkable lake Strupvatnet. The glacier front formed a perpendicular wall running sheer down into the lake, where it calved. The icebergs floated on the lake.

Later that year, after Caspari had parted company with his British companions, he made another visit to the lake, on August 3rd, with Karenus Kristoffer Thin (Caspari, pp. 58—59). On this occasion they discovered to their amazement that the lake been almost drained, and that many pieces of calf ice were lying on dry land.

In a letter Hastings told Caspari that on August 19th 1897 he had looked down on the lake from Rendalstind, from a height of 4200 feet, and discovered that on this occasion the water level was the same as it had been when they first visited the lake on July 17th. Whether this observation was correct is not certain, as the distance down to the lake is very considerable, but if it is correct it should mean that the lake had been filled with water in 16 days. Caspari had no explanation of the way in which the lake had emptied itself. On July 3rd-4th Hastings and Hogrenning once again climbed Jiek'kevarri.

An attempt of export of ice from Strupbreen

The export of ice from Öksfjordjökulen was known all over northern Norway. The excellent results of this trade encouraged Tromsö businessmen in 1882 to attempt to obtain ice from Strupbreen, which was considered to be favourably situated for this purpose, its front at that time being situated near the shore of Lyngen.

The author has contacted the following men in the Lyngen district in order to obtain information on the extract of ice from Strupbreen:

A. Solbakken, chairman of Lyngen municipal council, I. Rivertz, sheriff of Lyngen, H. Kristoffersen, sub-postmaster and freighter, Koppangen in Lyngen, J. H. Giæver, businessman, Tromsö and O. K. Giæver, businessman, Lyngseidet. Below is an abstract of the information received from these men.

Attempts to export ice from Strupbreen were made in 1882 by two Tromsö-men, R. Killengren and P. Kjerschow. There was level ground from the shore up to 10 m elevation and about 150 m long up to the front of Strupbreen. The firm engaged in this project built a quay as well as a store-house and a trolley track connecting the quay and the glacier front. H. Kristoffersen gives the following account of this absortive enterprise.

When construction work had been completed, an avalanche from the upper part of the glacier destroyed the plant and swept the buildings into the sea. This catastrophe put an end to all further attempts to extract ice. However, the Giævers have another explanation of the failure of this attempt.

The extract of ice was abondoned because the ice was contaminated by sand, gravel and earth particles. This made the ice unusable for the purpose. The store-house and the trolley track were pulled down and removed to another place (Jøvik in Lyngen).

The most probable explanation of these two conflicting accidents must be that the avalanche of ice had occurred before the plant was built.

However, ice was collected on a small scale from this glacier in another manner and by other people. This ice emanated from the outlet of Strupvatnet during the outbursts of the lake.

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ØKSFJORDJØKULEN

BY ADOLF HOEL

History of exploration

The other glacier in Norway whose ice has been of commercial value is Øksfjordjøkulen, which is situated in the counties of Finnmark and Troms at approximately 70°7′ N. in Jøkulfjorden.

This glacier is marked on gradteigskart Bergsfjord, Nr. S. 4, scale 1 : 100 000. It was surveyed by Norges Geografiske Oppmåling in the years 1891—1902, and the map was published in 1907.

This glacier posesses several peculiar features, and might well be described as one of the strangest glaciers in the world. Until recently only a few scanty pieces of information had been recorded in literature on the subject of this glacier, but during the last few years Hoel has corresponded with people living in the vicinity of the glacier and collected a great deal of information about it. It might therefore be of interest to give an account of the glacier based on printed and written sources.

The most important descriptions of Øksfjordjøkulen are to be found in the following works:

The first printed account of Øksfjordjøkulen is that of the celebrated German geologist Leopold von Buch, who travelled through this part of Norway in 1807. His account of his journey, entitled "Reise durch Norwegen und Lappland", was printed in 1810. He mentions Øksfjordjøkulen and Jøkulfjorden, giving various details on the calving of the glacier.

The famous Scottish geologist Archibald Geikie journeyed extensively in Western and Northern Norway in 1865. His observations from these journeys were published in "Geological Sketches at home and abroad", London, 1882, where he also deals with Øksfjordjøkulen. He describes the glacier, its calving an the formation of icebergs, and he also includes and excellent drawing of jøkulen, which is reproduced on p. 112 of the present publication.

The next author to deal with Øksfjordjøkulen was Thos. von Bayer whose book "Ueber den Polarkreis" was published in 1889. He made his journey in the summeer of 1881. He has an excellent account of the calving of the glacier, and the formation of icebergs, as well as a drawing of the glacier which resembles Archibald Geikie's.

The first person to reach the actual glacier plateau was the Englishman G. Hastings, accompanied by the Norwegian mountain guide E. Hogrenning. The ascent took place on August 16th, 1898, and was made from the head of Jøkulfjorden. They reached a height of 3,300 ft., which is about 200 m below the highest point of the glacier. (Alpine journal, vol. XIX, London 1899, p. 363.)

The Norwegian doctor Just Thoner made a journey in Northern

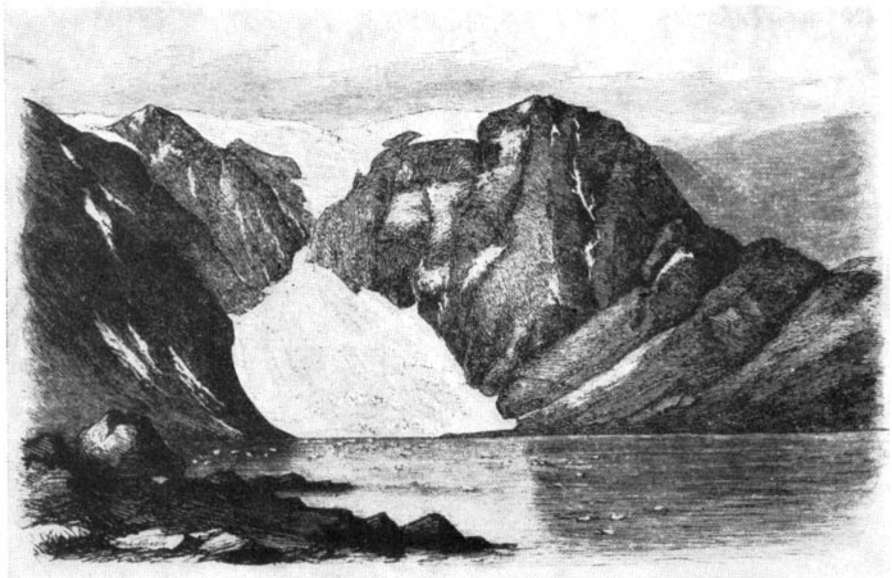

Fig. 18. View of Jøkulfjord glacier. Sketch by Archibald Geikie.

Norway in 1900 during which he visited Øksfjordjøkulen. He has described this journey in the Aarbog of Den norske Turistforening, 1906, pp. 71—88, while Øksfjordjøkulen is dealt with on p. 72. This is an ordinary tourist description based on older sources.

Amund Helland is responsible for the first comprehensive description of Øksfjordjøkulen based on older sources and on-the-spot information. This account is to be found in "Norges Land og Folk", Tromsø Amt, I, 1899, p. 57 and Finmarkens Amt, I, 1905, pp. 118—119.

With regard to Øksfjordjøkulen we have as mentioned above, received valuable information from people living in the vicinity of this glacier. The Tromsø og Omegn Tourist Association and the Alta og Omegn Tourist Association have supplied us with the names of persons acquainted with this glacier and the export of ice from it. The particulars we have received from Mr. O. G. Thomassen, farmer at Jøkulfjorden, are especially detailed. He lives only 6 km from the glacier and was the leading man in collecting ice for export and therefore he knows Øksfjordjøkulen better than anyone else.

Among others who have provided us with photographs and other material, we are especially indebted to E. Eriksen, chairman of the Kvænangen district council, Øivind Johansen, guide, Skjervøy and doctor Hans Eng, Burfjord.

Description of the glacier

The surface of the glacier is gently curved like a shell. It is a typical glacier cap. It is 10 km long from east to west and its width from north to south is 6 km. Its area is 36 sq.km. Its greatest height is approximately 1200 m.

From this glacier cap — Øvrebreen — many glacier tongues run down into the adjacent valleys. The largest branch is Jøkulfjordbreen. It terminates at the head of the 15 km long Jøkulfjorden in Troms. This glacier is a so-called "fall-jøkul". It terminates in a pointed tongue on the upper portion of a steep mountain wall 650 m high. From this point the ice crashes down and is crushed. The pieces of ice form a cone-shaped regenerated glacier down by the inner end of Jøkulfjorden — Nedrebreen. It towers up towards the upper glacier. This is the only glacier in Norway that reaches the sea.

Other big calves leap over Nedrebreen into the fjord. They drift away from the end of the fjord. Occasionally pieces of ice are carried out as far as the island of Spildra which is about 19 km from the glacier, and they have even been known to reach Rødøy in Kvænangenfjorden which is situated 30 km from the glacier. But as a rule they seldom move beyond the limits of Jøkulfjorden during the summer.

Boats on Spildra are in constant danger unless they are hauled up high and dry. As soon as they hear the noise of the glacier calving the people living on the north coast of Spildra run down to the boats and haul them up.

Down by the sea, at the head of Jøkulfjorden and beneath the upper glacier, there is a cone of ice which towers up towards the pointed tongue of the upper glacier formed down by the sea. The top of this ice cone probably reaches about 200 m above the fjord. From the sea and straight up towards the apex of the cone, the distance is 450 m. The angle of the slope is about 40 degrees. The distance from the apex of the cone to the lowest point of the glacier tongue varies at the moment from 50 to 100 m according to the season of the year.

The upper glacier calves all the year round, but the largest calves always occur in spring.

Beneath the apex of the upper glacier a waterfall emerges, which is frequently very strong in the summer months, but dry in winter. It disappears between the top of the cone and the mountain, where there is a large hole.

The square section of the hole referred to between the lower cone and the mountain side varies naturally according to the mean temperatures of the spring and the summer. It is generally at its largest at the end of August, when it may attain a dimension of about 200 sq.m. It is sealed up in winter probably by snowdrifts, but is opened up by the waterfall in spring. Thomassen is the only person still alive to have climbed up to the hole, three times in all and in summer.

In 1937, while working on the ice in July, Thomassen noticed that the waterfall beneath the upper glacier suddenly stopped, and did not

8

re-commence for almost exactly an hour. When it did it flowed with tremendous force, and with such a volume of water that all the men collecting ice had to make their escape as quickly as they could, to save their lives.

Smaller calves disappear in the hole between the top of the cone and the mountainside, and reach the sea beneath the base of the cone. The ice thus produced sometimes fills the entire inner bay of Jøkulfjorden with ground ice, that is to say lumps of ice seldom weighing more than half a kilo. But calves disappearing in this way may sometimes weigh several tons at least, without filling up the hole behind the apex. The innermost bay is often entirely filled in this way.

At the very head of Jøkulfjorden, just in front of Nedrebreen, there is a pool[1], i. e. a lagoon-like formation separated from the fjord by a bar consisting of stones of every size, ranging from grains of sand to large slabs of rock. In all probability the original bar marks the greatest extent of Nedrebreen. Subsequently it must have been considerably changed as a result of loose material, especially large stones, being cast up on it during calving.

When calving is at its intensest stone blocks weighing as much as 50 tons and more may be hurled up on to the bar. The channel leading into the pool was altered in the winter of 1928 as a result of a rock being forced out of the pool and into the middle of the channel. Another stone, with a diameter of about 8—10 m lying in the entrance channel, was moved some 30—40 m out, and can now be seen, in its new position, sticking up above the water. To-day it is called Kvitøya.

The water in the pool freezes up every winter, but occasionally calved blocks make holes in the ice.

Quite frequently fish are killed when calving takes place, though apart from occasional shoals of billet there are seldom many fish in the pool, but sometimes hundreds of dead fish can be seen on such occasions. Seal, too, sometimes enter the pool, but these animals have an uncanny knack of making good their escape during calving.

The width of the pool by the glacier is 300 m, and its length is approximately the same. Its depth is 12 fathoms, and the inlet is 12 feet deep at spring flood tide.

Calving of the glacier

Calving has taken place from Øvrebreen and Nedrebreen. When the latter calves it may split in its entire width (300 m) and at an altitude of 150 m. An ice-block of this size may remain standing in the pool for weeks. It naturally breaks into numerous pieces as it falls, but icebergs weighing several thousand tons may be formed on such

[1] Norwegian — poll.

occasions. When calving takes place from Nedrebreen ice and water are thrown up over the bar. Smaller portions of Nedrebreen, too, sometimes break off in the form of lesser calves.

Owing to the general rise in temperature especially in the last 40—50 years Nedrebreen has gradually shrunk, and calving ceased in 1936. As a consequence in 1937 it was necessary to blast ice out of the glacier, and to make use of ice-chutes, as mentioned in the section dealing with the export of ice.

Calved ice from Øvrebreen may reach the sea in one of two ways, either by passing through the huge hole in Nedrebreen, where the pieces are further reduced by crushing, or else — when calving results in really large blocks of several hundred tons — the ice is hurled straight onto Nedrebreen and slides down it into the pool. But it is never hurled right across the bar and into the actual fjord beyond.

Owing to frictional electricity strong bluish flashes of light are sometimes to be seen as the masses of ice slide across the cone.

When calving occurs on a large scale, water and ice may come pouring out of the pool as though from a handbasin which is being emptied. On these occasions water and ice are hurled across the bar forming the edge of the pool, but there is always some ice left in the pool. The water flows back into the pool with a powerful undertow. When large blocks are calved some slabs never touch the rocky slope at all, but simply tumble straight down onto the lower cone of ice and slide into the sea without any appreciable reduction in size. Other blocks are ground to powder; this happens when there is a frost, which makes the ice brittle and occurs when most of the calving takes place. The ice dust is very light and fine as powder, so fine in fact that it makes its way through people's clothing. Even if the sun is shining the cloud of ice-dust will make it as dark as night. In mild spells there is less dust and the fragments of ice falling into the sea are on the average larger.

When the calved pieces tumble down into the hole, they are ground against rock and boulders, emerging as small lumps. The large blocks of ice that tumble down are nearly always rounded in shape, the largest having a diameter of about 20 m.

The sound of calving can be heard like a lound peal of thunder. When the wind is in the right quarter this can be heard as far as Burfjord, an arm of Alteidfjorden situated some 50 km from the glacier.

Sometimes pieces of rock are to be found lying on the ice floes. These may have tumbled down from Nedrebreen and been sealed up inside the ice floes when ice calved from Øvrebreen falls down on top of them. Stone and rock may also be propelled on to the ice from the bottom of the pool, and remain lying on top of an ice floe.

Not infrequently accidents occur during calving. Those who are familiar with the behaviour of the glacier can gauge when calving is about to take place, and are thus able to take the necessary precautions. Nevertheless many accidents have taken place. No statistics are available, and only isolated instances are recorded, such as when people catching seal or fishing for herring have had their boats smashed to smithereens by falling blocks of ice. Considerable damage has also been sustained by boats entering the pool to fetch ice, and many dramatic situations have arisen in this narrow fjord lagoon at such times.

Fluctuations of the glacier

The central part of the Øksfjordjøkulen has hardly decreased in height above sea-level. But the tongues running from the jøkul down towards Skalsavatnet and in other directions have decreased considerably, while the branch running down towards Jøkulfjorden does not appear to have dimininshed.

In the olden days the apex of the cone and the apex of the glacier were almost joined together. The reason why the cone has decreased is the general rise in air temperature, especially in the last 60 years. The cone has never disappeared entirely. The decrease took place especially in the period from 1932 to 1937, but not subsequently. It seems to be incapable of further decrease, owing to the fact that it is constantly being replenished from the upper glacier. The commercial exploitation of ice which has been carried on for a number of years has had no effect whatever on the decrease in the cone.

Export of ice

At how early a date fishermen and above all fish merchants started to procure supplies of ice from this glacier is rather difficult to decide, but from 1920 on this practice became increasingly widespread, as larger ocean-going vessels gradually operated farther from the coast and into the Arctic Ocean for their catches, and of necessity had to carry supplies of ice. The requirements of the fish merchants rose correspondingly, as they found larger markets abroad for their fresh fish, especially flounder, salmon and halibut. From 1925 onwards there was usually a large fleet of vessels lying at anchor during the summer months waiting for the glacier to calve. When this took place there was as a rule enough ice for all comers, as thousands of tons usually broke off at a time. From 1930 on and right up to the time of the second world war demands were so great that the inhabitants of Jøkulfjorden had to form an "Ice association" in order to ensure that the boats had sufficient labour to assist in loading the ice. This association received a concession in 1933 for regulating the supply of ice.

In the last mentioned period a fairly large fleet of freight vessels, was engaged every summer solely in transporting ice for sale to the fishing districts all the way from Vardø in Finnmark and down the coast of the southern part of Nordland county.

Up to the year 1937 the ice that was used commercially was simply collected from the sea after ice had calved from the ice cone. These blocks were often several hundred tons in weight, and were frequently stuck to the bottom of the bay. Other blocks were comparatively small. This ice, in fact, originally came from the large glacier, and remained lying, under considerable pressure, on the cone, which in turn calved into the sea. Since 1937 no larger-scale calving of ice from the cone has taken place.

During the period 1937 to 1949 ice was collected in the following way. Charges were blown in the cone from the sea, and the ice collected in iron-covered ice-chutes, which were 21 inches wide and 9 inches deep. These were pushed further and further into the ice, as blasting proceeded. Eventually these chutes might be as much as 150 m long. They were laid on a dog-leg. In order to reduce the speed of the ice in the chute, bolts were, where necessary, placed in the bottom of the chute. It was possible to load as much as 30 tons in one hour from a chute. This work was extremely dangerous, owing to the rocks that were liable to fall down with the ice calving from the large glacier, etc.

The reason why this activity ceased in 1949 was that the authorities built a refrigeration plant, set up cold-storage plants, etc., with the result that the sale of ice ceased.

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THE RESULT OF HOEL'S AND WERENSKIOLD'S INVESTIGATIONS IN JOTUNHEIMEN 1927—1948

(Based in part on work carried out in the field by A. Koller, B. Luncke and W. Solheim.)

General information on Jotunheimen

SITUATION

The glaciers which are the subject of this investigation are situated in the Jotunheimen mountains, which form the highest mountain massif in Norway and North Europe. The loftiest peak in this range is Galdhøpiggen, 2469 m. The Jotunheimen mountains are bounded by Gudbrandsdalen, Sogn and Valdres, but these boundaries can only be given approximately, as it is, for instance, difficult to lay down any natural delineation towards the west. The boundaries might be given as between 61° 20′ and 61° 50′ Lat N, and between 7° 40′ and 9° Long E.

On this basis this area measures from north to south 55 km and from east to west 70 km and the area can be estimated at approximately 2500 sq.km.

EARLY HISTORY

A century ago Jotunheimen was known only to the inhabitants of the districts which bordered on this great range. There were saeters and heardman's and reindeer hunter's huts up there, lakes well stocked with fish, and pastures and hunting grounds which had been used as long as people had lived in the adjoining regions. The knowledge which the rural population had acquired of the mountains from time immemorial was not recorded in written documents, and was therefore not available to the outside world. It was not until visitors from further afield came to these mountains in 1813 and 1820 that a knowledge of this wild range became spread abroad.

The first person to set out to explore the Norwegian mountain realm was a doctor and botanist, subsequently Professor at the University of Christiania, Christen Smith. After visiting mountain and glacier region in West Norway in 1812, he started in the following year to explore Jotunheimen. The fruit of his investigations made him more familar with the topography of Jotunheimen than any other person, apart from local dalesmen.

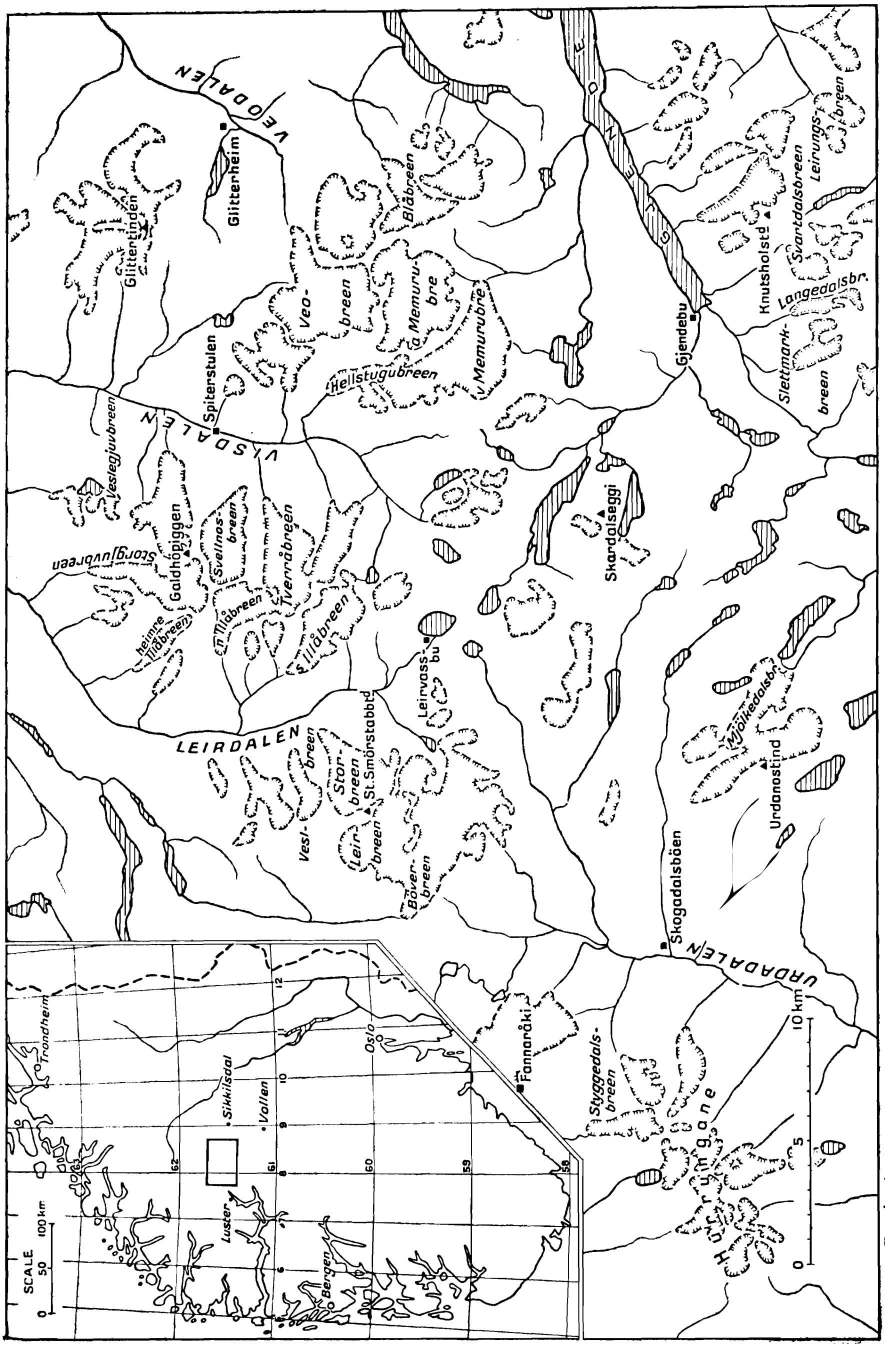


Fig. 19. Map of Jotunheimen.

In 1820 two young men, Chr. P. B. Boeck, a student of medicine, and B. M. Keilhau, a student of geology, set out to explore the Jotunheimen mountains. Both subsequently became Professors at the University of Christiania in their respective subjects.

Their journey in Jotunheimen was without comparison the most important ever undertaken in these mountains, and for this reason these two are generally accepted as the "discoverers" of Jotunheimen.

It was Keilhau who familiarized the people of Norway with the geography of Jotunheimen, through the medium of an article in Budstikken (at that time the most important scientific publication in Norway) on September 21st, 1820. This was entitled "Nogle Efterretninger om et hidtil ubekjendt Stykke af det sønden-fjeldske Norge" (Some information of a hitherto unknown part of South Norway). The contents of this article provided so many surprises for learned and scientific circles that it would be difficult to gauge its actual impact.

The first Norwegian University was founded in 1811 in Christiania (re-spelled Kristiania in the late 19th century and re-named Oslo in 1925), three years before the 400 year long union with Denmark was dissolved. The teaching staff of the newly founded university consisted mainly of Norwegians educated at the University of Copenhagen.

The scientific researchers at the new institute of learning regarded it as an important task to explore the geography and natural resources of their country. Last in the list of regions to be investigated came the mountain areas, with Jotunheimen bringing up the rear. In North Norway, too, there were a number of little known and almost inaccessible regions, primarily the tract of country situated between Ofotfjorden and Tysfjorden, which was not thoroughly explored until 1906 by Hoel. (See Adolf Hoel: Glaciers between Ofotfjorden and Tysfjorden, p. 252.) It was referred to as the "dark spot" in the topography of North Norway.

PLACE-NAMES IN JOTUNHEIMEN

Origin of the name Jotunheimen

Keilhau, in his paper "Om de Skandinaviske Formationer anden Suite" — Magazin for Naturvidenskaberne, Vol. 1, Christiania 1823, p. 110—153, says that we miss an intergrating name for the mountains in question. In a note (p. 133) the editor of this magazin, Professor Gregers Fougner Lundh, tells that Keilhau at an earlier occasion had proposed the name Jotunfjeldene, a name which is becoming to the object.

In his article "Einige Bemerkungen auf Ausflügen in die Norwegischen Schneegefielde" Isis von Oken, Jena 1822, C. F. Naumann gives the information that Keilhau and Boeck had proposed the name Jotun Field", "inded a suggestive name, for the Jotuns are for the Nordic mythology what the Titans and Giants were for the Greek one". (Cfr. German Riesengebirge.)

In his article "Hurungerne", — Mag. Nat. Vol. 1, Christiania 1923, V, P V, Lundh also speaks of de "kolossale Jotunfjelde".

The poet and mountain rambler A. O. Vinje is the first who has introduced the name that now is used: Jotunheimen (the home of the giants). We find this name in his little story "Fjøllstaven min", III, — Nyhedsbl. Nytaarsudg., 1862, pp. 26—36.

Further information of the name of Jotunheimen is found in the following paper: Lars Ekre, Opplysningar til stadnamn fra Midt-Jotunheimen og tilgrensande bygder. Oslo 1960. Pp. 58—64.

Some remarks upon the names of the glaciers in Jotunheimen

From ancient times several trails have lead through the Jotunheimen mountains (see p. 92). Glaciers which were well visible from these trails have clearly been named by travellers.

More remote glaciers, known only to reindeer hunters, have been named by these. And, lastly, some glaciers have been "christened" by tourists in modern times.

A great many glaciers are named after the rivers issuing from them. For instance, Storgjuvbreen and Veslgjuvbreen are named after the rivers Storgjuva and Veslgjuva, which run through the narrow gorges; Storgjuv and Veslgjuv — meaning the "Great" and "Little" gorge. The Illå glaciers are named after two rivers, Illå, meaning a "bad river" — i. e. hard to cross.

The Hellstugu river and glacier derive their names from a hut built of stone slabs.

The Memuru river issues from the Memuru glaciers. The syllable "me" means "middle". The last compound clearly derives from the same Old Germanic root (mer-) as Norw. dial.vb. mara "to rub, to exert friction accompanied by pressure". Slettemark means "flat field". Langedal — "long valley". Svartdal — "black valley".

There has obviously been some confusion as to the names of two glaciers on the eastern part of the Galdhø massif: Styggbreen and Svellnosbreen. Stygg means "ugly" and Svellnos the "ice-covered nose". There is also a peak named Stygghø in the neighbour, but it is not ugly at all, neither is the glacier. The Svellnos glacier was ugly, steep and full of crevasses.

As mentioned above many glaciers are called after adjoining rivers, Norwegian river names have been collected and explained by Oluf Rygh in Norske Elvenavn Kr.a. 1904.

SURVEYING

The most important basis for the study of glaciers is, as mentioned above, topographical maps, and for this reason we shall now include some remarks on the development of mapping in the Jotunheimen mountains, with special reference to the glaciers which have been the object of our investigations, viz. those which belong to the Galdhøpiggen area, and run down to the Visdal and Leirdal.

The first trace of any cartographical knowledge of this part of Norway is found on a map by Isaac van Geelkerck, from about 1650, discovered by Mr. Kristian Nissen, in the archives of Norges Geografiske Oppmåling, Oslo. Mr. Nissen has been so kind as to supply the following information:

> "Isaac van Geelkerck was a Dutchman by birth: he served as a military engineer in Norway from 1646 to 1657. Several of Geelkerck's maps of the whole of Southern Norway, or parts thereof, have been found in the collection of Norwegian maps, of the Norwegian Topographical Survey. On a couple of these, some lakes in the eastern parts of the Jotunheimen area are represented, with their old names: Gjende, Sjodalsvatn, Bygdin, Vinstervatn. The names are easely recognisable for instance, Gond, now Gjende. Obviously, Geelkerck has not personally visited these parts of Norway, but he has got accounts of the lakes and their names from persons living in the neighbourhood."

The following is an extract from an article in Den norske turistforenings årbok (the Year-book of the Norwegian Touring Club) for 1948, written by Major Per Tang, late topographer of Norges Geografiske Oppmåling.

The mapping of the Jotunheimen mountains commenced at the end of the 1820's. The first land-surveyor in this district was Captain in the Corps of Engineers, Th. Broch, who in 1826, 1827 and 1836 carried out a number of triangulations through the high mountain-areas between Gudbrandsdalen, Sogn and Valdres. This was the first time that triangulation was carried out in Norway with a theodolite. He also measured a number of heights with a mercury barometer. Thus the foundation was laid for a survey of these mountains.

The first surveyor to work in the area between Valdres and Gudbrandsdalen was the well-known topographer and draughtsman of the first "Amtskart" (county map), Captain N. A. Ramm, from 1830 to 1831. In 1842 Captain (later General) F. P. L. Næser continued this work. But the bulk of the work in the mountains was carried out by Lieutenant (later General and Cabinet Minister) H. N. Storm Wergeland in 1841, 1842 and 1843. He both triangulated and plotted the district all the way from Vangsmjøsi in the south to the Møre og Romsdal county boundary in the north, i. e. half Vang, part of Vågå, the greater part of Lom and Skjåk, and parts of Luster. His survey work embraces a total of about 4600 sq.km. His sketches, to a scale of 1 : 100 000, contained no heights, but nevertheless his work may be said to constitute an outstanding achievement, when we consider that these high mountains comprise Norway's loftiest, bleakest and remotest mountain areas.

The results of Ramm's, Næser's and Wergeland's work on Jotunheimen can be found in "Kart over Christians Amt" (Map of the county of Christian), now Oppland fylke, middle sheet, published in 1849, and northern sheet, published in 1851. The scale, as in the case of all county maps, was 1 : 200 000.

In the 1860's the work of mapping was extended to that portion of Jotunheimen which is situated in Inner Sogn. Major F. C. Sejersted carried out triangulation work here between 1863 and 1865. From now on topographers were equipped with instruments for measuring heights, though for a long time the basis upon which these heights were determined was rather inaccurate. It was not until 1888 that precise levelling was carried out in Jotunheimen.

Captain A. Magnus was the first person to approach the Jotunheimen mountains from the Sogn side. The bulk of the Jotunheimen mountains in the county of Sogn, however, was surveyed by Captain Henrik Lund in 1867 and 1868, employing survey methods and not sketching. The result of the surveys undertaken in Inner Sogn are to be found in "Amtskart over Nordre Bergenhus" (County map of Nordre Bergenhus, now Sogn og Fjordane fylke, sheet II, which was published in 1874, and sheet IV, available from 1880).

These triangulators and surveyors were the pioneers of mapping in the Jotunheimen mountains.

In 1867 it was decided that Norges Geografiske Oppmåling, apart from the county maps, should also issue maps to a scale of 1 : 100 000 with equidistant 100 ft[1] contours, the so-called rektangelkart (rectangular maps). The first officer to undertake surveys for a map of this kind in Jotunheimen was Captain (later Colonel) J. N. Hertzberg, who mapped the central parts of Jotunheimen in the years 1871—1876. He was the first surveyor to work on Galdhøpiggen. The result of this work is to be found in the map-sheet "Galdhøpiggen" (1880).

Lieutenant (later Lieutenant-Colonel) D. Tønnesen surveyed the Tyin—Bygdin area in 1887, while in the same year Lieutenant (later Lieutenant-Colonel) Th. Prytz surveyed the district between Gjende and Vinstra. The result of this work is the map-sheet "Bygdin", which was published in 1891.

With the intention of carrying out entirely new mapping of the Jotunheimen mountains, the Survey started a fresh triangulation in 1898. This was effected in the years 1898 to 1904 and 1912 to 1934 by as many as fifteen triangulators. During the latter period the astronomer H. Jelstrup made astronomic observations on Galdhøpiggen in order to

[1] One Norwegian foot is 31.374 cm, while the British foot is 30.4797 cm.

determine longitude and latitude. In the years 1921, 1924 and 1929 three lines of levelling were carried out in Jotunheimen.

On the basis of the latest triangulations the bulk of the Jotunheimen mountains have been surveyed afresh by a number of topographers. The area with which we are concerned, the district around Galdhøpiggen, has thus been surveyed three times: by Wergeland in the 1840's, by J. N. Hertzberg in the 1870's and by H. J. Hertzberg in 1931.

The result of the most recent survey work in Jotunheimen is to be found in the so-called gradteigskart, which are to the same scale 1 : 100 000 (L) as the above mentioned rektangelkart, viz. Gjende (1938), Lærdal (1943), Vågå (1946), Lom (1948), Skjåk (1951) and Sygnefjell (1951).

The maps to a scale of 1 : 50 000: Aust-Jotunheimen (1933), Midt-Jotunheimen (1935), Vest-Jotunheimen (1939), deserve special mention.

The survey work of Norges Geografiske Oppmåling in Jotunheimen has continued for close on a century, and the result has been good maps, which, as far as most of this mountain group is concerned, satisfy the requirements of our age.

Generally speaking, maps serve a great many different purposes of a practical, economic, technical, touristic or scientific nature. As far as mountain country is concerned, however, technical, touristic and scientific considerations naturally occupy a more important position.

The above-mentioned circumstances must be taken into account in choosing the most suitable method of surveying. The old method of mapping the Jotunheimen mountains was by the so-called plane table survey.

Mapping in high mountains may be seriously hampered by adverse meteorological conditions: strong wind or storms, snow or rain, fog or low-lying clouds place serious obstacles in the way of survey work, and as a rule human habitations are few and far between, roads are scarce, and the country is very rugged.

Apart from the Galdhøpiggen area the new maps have been worked out on the basis of terrestrial photogrammetry. This method, which was used for the first time in the 1910 survey, was well suited to Jotunheimen, where a new survey was started in 1931.

At the same time maps are being published to a scale of 1 : 50 000. These give a far larger range of topographical details and names than maps to the scale of 1 : 100 000.

The three above-mentioned map-sheets to a scale of 1 : 50 000 together cover an area of 2700 sq.km, and are based on 900 photograms. They are a direct reproduction of the original maps. Incidentally the Jotunheimen maps are the first topographical maps in Norway to be issued in this way, conforming with the principles for high mountain cartography which are in use all over the world.

The method of surveying for these maps, and the reproduction of details, bear testimony nevertheless to a development which shows an increasing consideration for the scientific importance of the maps. The first two sheets, Aust- and Midt-Jotunheimen, show no glacier limits; nor are crevasses and falls of ice included in the glacier area. On the other hand these morphological details, which are of such importance, at any rate for glaciology, have been included in the last sheet to be published, Vest-Jotunheimen.

Photographs taken on the ground can never include every part of the terrain. Consequently in map construction a number of gaps occur, which have to be filled in after a subsequent inspection on the ground. Previously this was done by plane-table surveying. But in the area covered by the map of Vest-Jotunheimen this supplementary method of surveying has also been carried out by means of aerial photogrammetric survey, and in fact so efficiently that this sheet shows perfectly homogeneous lines, achieved by purely optical and mechanical means.

The names on the original map in the most striking group of mountains, Hurrungane, have been engraved on a special copperplate to prevent the contour-lines being obscured by the names. This is a further proof of the importance which survey to-day attaches to the representation of the orographical forms in maps of mountain areas.

As the morphological details are printed in different ways on these maps, they must be used with a certain degree of caution for scientific investigation.

But it may be said that we here have a cartographic work which gives a good working basis especially for the geographical and geological investigation of this important area.

As far as actual glaciology is concerned, the value of these maps is rather limited. Detailed investigation of the movements of glaciers, the formation of crevasses, moraines, etc., will always demand maps of still larger scale. However, photogrammetric maps to a scale of 1 : 50 000 give a comprehensive and very accurate survey of the ice areas, and at the same time, provide a basis for comparison with older maps. The comparative table given below shows the area of some of the largest and best known glacial areas in the central Jotunheimen mountains, computed from the new photogrammetric maps and from older surveys from the 1870's.

Areas according to new and old maps.

Name of glacier	From 1934 Sq.km	From 1874 Sq.km
Austre Memurubre	10.2	10.3
Vestre »	9.2	9.2
Storgjuvbreen	5.0	5.0
Glitterbreen	5.7	7.1

The value of a comparison of this kind is above all conditioned by the accuracy of the glacier's boundary as shown on the older maps. It appears that during some of the surveys in Jotunheimen, the precaution was taken of obtaining a reliable basis for estimating variations in the glaciers. (Topographic maps of Norway, p. 79.)

An article by the late Erling Bjørstad (1939), formerly chief of the Topographic Section of the Survey, deals with the problems of surveying mountain regions.

Co-operation between scientists, especially geologists and glaciologists, and the Geographical Survey, would undoubtedly help to make good the shortcomings still existing in our mountain maps, and to lay down once and for all the principles which should govern our mountain surveys.

GLACIER TYPES AND MORAINES

Most of the Jotunheimen glaciers are of the alpine type.

The glaciers of Jotunheimen may, with rare exceptions, be considered as separate entities, each tongue draining its own snowfield, surrounded by steep rocky walls, and separated from neighbouring snowfields by ridges. It may happen that two glaciers drain the same snowfield in opposite directions, thus Hellstugubreen runs northwards, Vestre Memurubre southwards from the same field, at a height of about 2000 m, forming a grand highway of snow and ice between two ranges of splendid peaks. It is not, however, difficult to assign the proper parts of the snowfield to each glacier.

Cirque glaciers and hanging glaciers are common.

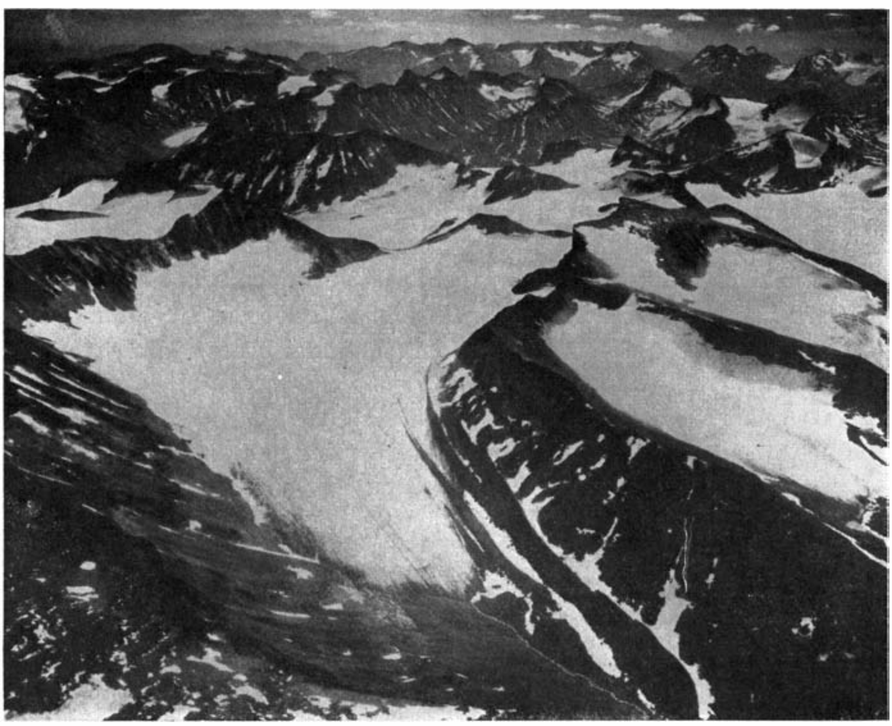
The glaciers of Jotunheimen are small compared with those of the western and northern parts of Norway. Large icefields of the Jostedal type, with many glaciers draining the same ice caps, are not found here. The largest is Smørstabbreen.

The entire area of the Jotunheimen glaciers is approximately 320 sq.km.

Practically all glaciers in Jotunheimen are surrounded by great semi-circular end-moraines, 8 to 10 in number, one behind the other, at the very front of the ice. The outermost moraine is always the largest, and forms a distinct boundary between the grassbound and mossy ground outside, and a waste of naked stones and rocks inside, with some tufts of hardy grass and a few alpine plants, especially the *Oxyria digyna*. The outermost moraine is generally composite, formed by two distinct walls. It was deposited during the great advance of the glaciers in the first half of the 18th century.

The moraine ridges continue in grand sweeping curves on both sides of the ice tongue, high above the present surface, and can be followed

Fig. 20. Vestre (in the foreground) and Austre Memurubre. Glittertind to the left in the background. (Photo: B. Lunke, Norsk Polarinstitutt, Aug. 1955.)



Fif. 21. Nordre Illåbre. (Photo: B. Luncke, Norsk Polarinstitutt, Aug. 1955.)

along the margins. Around the upper parts of the glaciers, a belt of naked, bleak, grey boulders and rocks — as opposed to the almost black colour of the lichen-covered rock above — presents a conspicuous line, marking the recent extent of the snowfields.

PREVIOUS GLACIOLOGICAL INVESTIGATIONS IN JOTUNHEIMEN

As mentioned above (p. 18) P. A. Øyen is the pioneer of glacial research in Jotunheimen. He began his work in 1891 and visited Jotunheimen later in the years 1892, 1901, 1902 and 1909.

His studies include the volume of water and deposits brought down by these, the temperature of the air and of the glacial rivers, but above all he concentrated on investigations into the variation in the glaciers. In order to do this he built cairns at suitable places in front of the glacier tongues, and the distances to the ice were measured with steel tapes, along a fixed direction indicated by a secondary cairn. The cairns were marked by letters or crosses, cut into a rock, so that they could easily be identified. He placed his cairns so that the line would reach the ice at the most projecting point of the glacier and in the middle of the front. But as a result of tremendous melting in recent years, the glaciers have retreated so much that the lines of direction laid down by Mr. Øyen have become unsuitable and in some cases, for instance in Bøverbreen, the line fixed by Mr. Øyen does not even meet the glacier at all. If the line hits the glacier to the side of the tongue, the measured retreat will be too great. For these reasons measurements must be taken along other lines of direction.

Cairns were built in front of 28 glaciers, viz.: Steindalsbreen, Leirungsbreen, Svartdalsbreen, Langedalsbreen, Slettemarkbreen, Austre Memurubre, Vestre Memurubre, Glitterbreen, Veobreen, Hellstugubreen, Tverråbreen, Svellnosbreen, Styggebreen, Veslgjuvbreen, Storgjuvbreen, Heimre Illåbre, Nordre Illåbre, Søre Illåbre, Veslbreen, Storbreen, Bøverbreen, Leirtjørnbreen,[1] Sandelvbreen, Maradalsbreen, Gjertvassbreen, Styggedalsbreen, Skagastølsbreen, Ringsbreen.

A number of the cairns were built by Øyen, but most of them were erected on his instructions by mountain guides of Den norske turistforening (the Norwegian Touring Club) in this part of Norway. During the years when Øyen visited Jotunheimen, he usually carried out remeasurements, though most of this work was also executed by mountain guides.

The great majority of these cairns are carefully described in Øyen's publications, but in some cases we have no descriptions. (See Werenskiold 1956.)

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[1] Leirbreen on the maps.

Measurements were made once a year, usually towards the end of August. Table pp. 204 and 205 shows the results of these measurements (the average for all glaciers is shown as a curve in fig. 53).

Øyen's glacier investigations were subsidized by the Norwegian Touring Club from 1901 to 1908, by Fridtjof Nansen's Fund from 1900 to 1911, and by Videnskabsselskabet (the Society of Sciences) in Oslo in 1912. Subsequently he failed to obtain funds to enable him to continue his investigations, which as a result were brought to a stop.

In 1933 Werenskiold resumed the work, which continued til 1948. After this year Norsk Polarinstitutt took over the survey and further investigation of the glaciers. Werenskiold measured 10—15 glaciers. He found most of Øyen's cairns intact, but he had to erect new ones in most places — the distance had increased so much that it became inconvenient to make the measurements from Øyen's cairns — owing to the retreat of the glaciers.

All glaciers have retreated considerably since Øyen began his observations.

Unfortunately, an advance which most probably occurred in the 20's could not be recorded.

J. B. Rekstad's work in Jotunheimen is dealt with in the chapter on the History of Glacier Research in Norway (p. 14).

Hans W:son Ahlmann, Professor of Geography, Stockholm, also deserves a special mention. He mapped and investigated glaciers in the Hurrung group, western Jotunheimen, in the years 1919—20, 1922—26, concluding in 1939. The Styggedal glacier was chiefly studied, especially as to variations, but the Skagastøl- and Midtmaradal glaciers were also mapped 1919—20.

Styggedalsbreen advanced some metres in the years 1921—24, about 5.15 m in the middle of the front.

These glaciers are outside the area covered by our investigations.

INTRODUCTION AND DESCIPTION OF THE GLACIERS INVESTIGATED

Every year, from 1906, Norwegians have carried out mapping work and natural history investigations in Svalbard. This research was started by Major Gunnar Isachsen, who was in charge of the expeditions from 1906 to 1910. From 1911 on the expeditions were under the leadership of Adolf Hoel. In 1906 and 1907 this was the result of private enterprise, but from 1909 the Norwegian State made a contribution to this work. As the years passed, the State contribution gradually increased, and from 1928 this work was organised entirely as a state undertaking, under the name of Norges Svalbard- og Ishavs-undersøkelser (Norwegian explorations in Svalbard and the Polar Seas). In 1948 this name was altered to Norsk Polarinstitutt.

For a number of years three topographers of this institute, the engineers Alfred Koller, B. Luncke and W. Solheim, had taken part in the survey work in Svalbard. They had a great deal of experience in the surveying of glacier and mountain areas, and had acquired an extensive knowledge of the problems connected with the study of glaciers.

Moreover, Alfred Koller had during the years 1907 to 1912 participated in the work of measuring the glacier flow and the ablation of Lilliehöökbreen in Spitsbergen.

In 1927 no money was granted for expeditions to Svalbard, and for this reason the three topographers mentioned above were in a position to undertake other work.

Adolf Hoel and W. Werenskiold thereupon agreed to take advantage of these circumstances to initiate comprehensive investigation of the glaciers in Jotunheimen, with the assistance of the above mentioned three topographers.

During the German occupation it was likewise impossible to undertake any expedition to the Arctic, and Koller and Solheim were therefore employed in the work of surveying glaciers in Jotunheimen.

There are now several tourist stations in Jotunheimen, some privately owned, some belonging to The Norwegian Tourist Club. From these stations all glaciers in this region can be reached in a day's walk.

The authors decided that Hellstugubreen, Tverråbreen and Svellnosbreen in Visdalen in the eastern part of the Jotunheimen mountains, south of Galdhøpiggen, would prove eminently suitable for survey and other investigations.

The primary reason for choosing these three glaciers was that they are easily accessible.

From Røysheim in Lom a mountain track leads up to the *seter* and tourist station, Spiterstulen in Visdalen, 1103 m. above sea level. In the first summers, all our instruments and other equipment had to be carried by pack-horses, but later on the track was gradually improved, so that it became possible to run a motor car straight up to Spiterstulen. Moreover, the proprietor of Spiterstulen, the well-known mountain guide Lars Sulheim, proved exceedingly helpful in providing us with the necessary assistance for the work.

The distance from Spiterstulen to Tverråbreen and Svellnosbreen is 2.5 km and to Hellstugubreen 4 km. The country around these glaciers is also well suited for all sorts of survey work which would have to be undertaken for glacier investigations, e. g. triangulation and surveying with tachymeters, and it also proved comparatively easy to find suitable observation points for terrestrial photogrammetry, for fixing the position

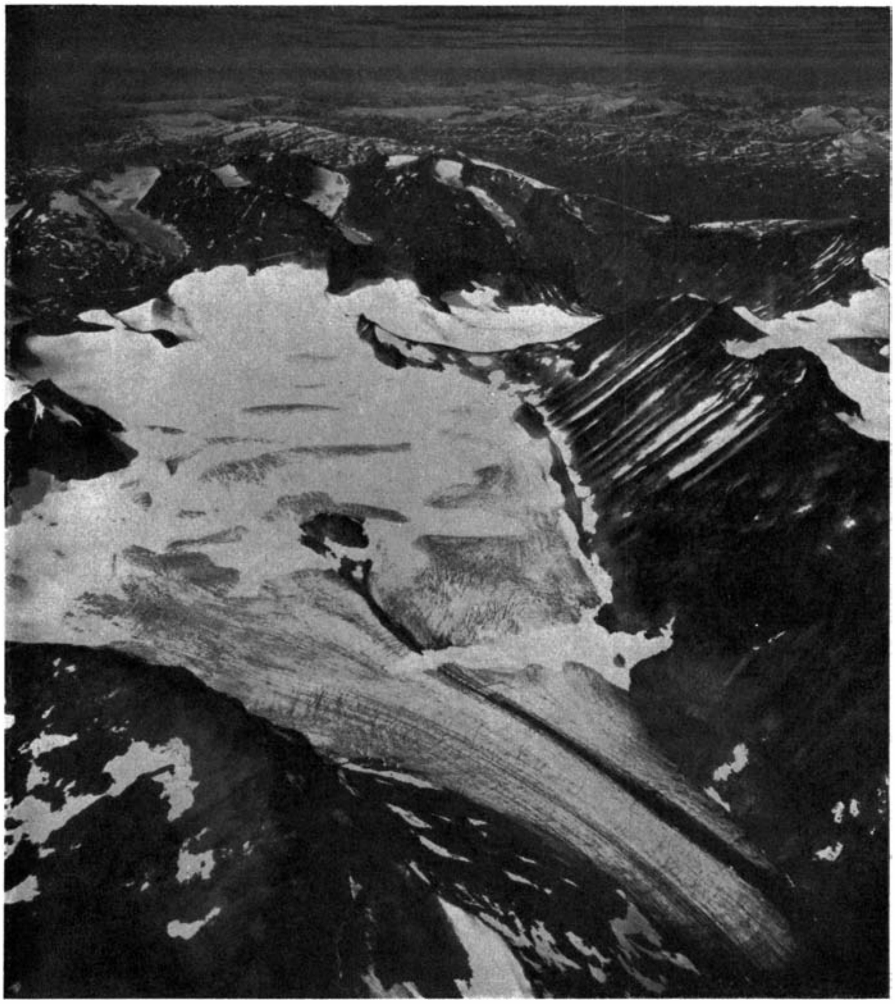

Fig. 22. Tverråbreen. (Photo: B. Luncke, Norsk Polarinstitutt, Aug. 1955.)

of points on the glaciers. Both Hellstugubreen and Tverråbreen have moderate slopes and are comparatively free from crevasses. It is, therefore, easy to move about on these glaciers. Svellnosbreen is not quite so accessible as the other two, and is considerably more crevassed. Consequently the only survey work that was undertaken on this glacier was for the purpose of studying its variations.

The prevailing precipitation winds on these glaciers are from the NE and SE. The dimensions and height above sea-level are, according to The Geographical Survey of Norway's map Midt-Jotunheimen (1934), scale 1 : 50 000.

Fig. 23. Svellnosbreen with Galdhøpiggen to the left. Hestbreene and the northern part of Jostedalsbreen in the background. (Photo: B. Luncke, Norsk Polarinstitutt, Aug. 1955.)

Name of glacier	Length km	Area in sq.km	Height above sea-level of the front in m	Height above sea-level of upper end in m
Hellstugubreen	3.83	4.30	1424	1965
Tverråbreen	4.83	6.81	1362	2220
Svellnosbreen	4.00	5.00	1412	2100

The net ice area of Tverråbreen is 6.8 sq.km (1927).

The gross ice area of Hellstugubreen is 4.30 sq.km, that of a nunatak 0.04, the net area is thus 4.26 sq.km.

The drainage area of Hellstugubreen is 11.00 sq.km.

INSTRUMENTS EMPLOYED FOR THE TOPOGRAPHICAL SURVEY

Bought year	Firm	Theodolites no.	Magnification	Diameter in cm		Reading to	
				Hor. circle	Vert. circle	Hor. circle	Vert. circle
1918	Sigurd Baalsrud, Oslo	535	24	13	9	1^c	1^c
1920	Otto Fennel Söhne Kassel	11904	17	13	10	1^c	1^c
1922	Sigurd Baalsrud, Oslo	901	28	15	14	10^{cc}	50^{cc}
1924	Carl Zeiss, Jena	15904	24	7.5	5.0	10^{cc}	10^{cc}
		Camera type	Camera Size cm	Objective type	Aperture		Focal length cm
1909	Gaumont, Paris Spido	7793	9x12	Zeiss Tessar	1 : 6.3		13.36
1918	C. P. Goerz, Berlin		13x18	Goerz Double Anastigmat	1 : 4.8		18.25
1923	Carl Zeiss, Jena photo-theodolite	19895	13x18	Ortho Protar	1 : 2.5		19.382

CHRONOLOGICAL RECORD OF WORK

1927

The main work of surveying the lower part of Tverråbreen and Svellnosbreen was carried out in 1927 from August 27th to September 6th by the engineers A. Koller, B. Luncke and W. Solheim, together with Adolf Hoel and W. Werenskiold, as well as a number of assistants. As mentioned above, they had their head quarters at Spiterstulen in Visdalen.

A basis, 870 metres long, was measured under the supervision of Mr. Koller. This measurement was carried out as an ordinary precision measurement, with the use of a 20 m steel measuring tape, sprung-weights and levelled stands, as well as thermometer readings. It was measured twice with a difference of seven mm in the first and second measurement.

By triangulation this basis was connected with 11 stations where various marks (bolts or holes drilled in the rock) were placed. The triangulation net was linked up with the net of the Geographical Survey of Norway. The co-ordination was carried out with more than the necessary number of checks, and as a result an opportunity was obtained of comparing the lengths computed on our basis and the lengths of the Survey. The agreement was so complete that no adjustment was necessary. The points of comparison are: the cairns on Galdhøpiggen, the Vestre Memurutind and the cairn on Stygghø. Koller took photograms from three bases and, in addition, orientated photograms were taken on three trigonometrical points for map construction.

The trigonometrical measurements were later worked up at the offices of Norges Svalbard- og Ishavs-undersøkelser, chiefly by Koller and Solheim. This involved 54 working days. The photogrammetric map construction work was carried out by Solheim. The Stereographic map office of Oslo was responsible for the stereo-photogrammetric construction, while the final drawing was made by Luncke.

The results of the surveys are to be found in two maps: 1) A map, to a scale of 1 : 2000, with a two-metre contour interval, of the tongues of Tverråbreen and Svellnosbreen, as well as the territory between them. This map is stereo-photogrammetrically constructed in its entirety, and covers an area of 1.97 sq.km. 2) A map to a scale of 1:10 000, with a 10-metre contour interval, comprising the entire catchment of Tverråbreen as well as the tongue of Svellnosbreen to a height of 1750 m above sea-level (9½ sq.km), has also been constructed on the basis of stereophotograms. 5.4 sq.kilometres have been constructed photogrammetrically. Altogether this amounts to an area of 15 sq.km.

1928

Meanwhile material was still lacking from certain parts of Tverråbreen, as well as from all the upper parts of Svellnosbreen which stretches to the very foot of Galdhøpiggen. In order to fill in these gaps Werenskiold went to Spiterstulen, together with an assistant, in the autumn of 1928.

The trigonometrical network was extended with observations from six new stations, where the necessary photograms were also taken. The glacier tongues were photographed again from the same stations as in the preceding year, and a number of moraines were plotted on the map with the help of tape measurements in the field.

Furthermore, a reconnaissance of the topography of Hellstugubreen was made, and two signals were placed at suitable spots for future survey.

The trigonometrical material gathered that summer was worked out by Solheim. No photogrammetric construction work, however, was carried out, as the picture material, owing to an unduly large amount of new snow in the mountains, showed too few details.

1929

Field work was continued by Koller and Werenskiold from August 6th to September 5th. Weather conditions were unfavourable. A stereo-photogrammetric survey was made of the tongues of Tverråbreen and Svellnosbreen from the same stations as in 1927. In addition, the lower part of Hellstugubreen was mapped stereo-photogrammetrically. Øyen's cairn in front of Svellnosbreen, erected in 1901, was linked up with the triangulation net, and the distance to the tongue of the glacier was measured. On top of the plateau, near Leirhø, Werenskiold built two cairns, from which photograms were taken.

The trigonometrical material collected in the summer was worked up by Koller. The stereo-photogrammetric construction was worked out on the stereo-autograph of the Geographical Survey of Norway by the Director of Stereografik A/S, Haaken Christensen, civil engineer, with the assistance of Luncke and Solheim. 0.32 sq.km of Tverråbreen and 1.67 sq.km of Hellstugubreen were constructed on a scale of 1 : 2000. Furthermore, a general topographical map was constructed photogrammetrically, to a scale of 1 : 10 000, with a ten-metre contour interval, of Hellstugubreen and its surroundings. The area covered was 3.9 sq.km.

1930

In the summer Werenskiold went up to Spiterstulen with an assistant. He carried out a number of trigonometrical observations and took photographs in order to complete the general map of Hellstugubreen. Six trigonometrical and photogrammetrical stations, at a height of over 2000 m, were made. The river course from Tverråbreen to Spiterstulen was measured by Werenskiold with a tachymeter.

The subsequent working up of the observations, trigonometric as well as photogrammetric, was carried out by Koller. The map of the catchment area of Hellstugubreen was now practically complete.

The map of Hellstugubreen was constructed to a scale of 1 : 10 000, with a 10-metre contour interval, and comprises an area of 7.6 sq.km., together with the stereo-photogrammetric map of 1929.

1931

In the summer Koller and Werenskiold carried out a mainly tachymetric survey of the tongue of Hellstugubreen and Tverråbreen, during the period from September 8th to 16th, to provide material for a map to a scale of 1 : 2000, and a 2-metre contour interval. On Tverråbreen they measured a distance up to 3½ km above the glacier front. The area covered was 3 sq.km. At Hellstugubreen, an area of 0.28 sq.km was surveyed with a tachymeter. A number of photograms of the upper part of Tverråbreen were also taken.

The subsequent work of trigonometrical calculation and map construction was carried out by Koller.

1932

From September 8th to 20th Solheim surveyed tachymetrically the tongue of Tverråbreen, covering an area of 0.40 sq.km and Hellstugubreen, covering an area of 0.33 sq.km. In addition, the front line of Svellnosbreen was also surveyed tachymetrically by Solheim.

1933

Before the First World War, as already mentioned, P. A. Øyen surveyed a number of glaciers in Jotunheimen. During the years from 1901—1912 he erected cairns in front of these glaciers, and measured the distance from the cairn to the glacier every year. His work, however, had to be discontinued in 1912 owing to lack of funds.

Werenskiold's aim in the summer of this year was to locate Øyen's cairns and to continue his survey. This work was carried out from the 6th to 14th August. Werenskiold succeeded in finding all the cairns in Leirdalen and Visdalen, nine glaciers in all.

The surveys were carried out in the same way as Øyen had done in his time, viz. with a measuring tape from the cairn to the glacier, along a line of direction fixed by a secondary cairn, and except where specified that the measurement was undertaken with a tachymeter, this is the method employed.

In this way these surveys have been resumed. The glaciers had meanwhile retreated as much as two hundred metres. This made it awkward to measure from Øyen's cairns, and it proved necessary to set up new survey cairns in the same line of direction, wherever this was possible. All these cairns have been described in a supplement, and photographs exist of most of them. These are to be found in the archives of the Norsk Polarinstitutt. Werenskiold surveyed the following glaciers:

Storgjuvbreen: Øyen's cairn could not be found, as it had been destroyed in a landslide in 1908. Two new cairns were erected and the usual survey undertaken.

At *Heimre Illåbre, Søre Illåbre, Nordre Illåbre, Storbreen* and *Veslbreen* in Leirdal, and *Veslgjuvbreen,* Øyen's cairns were replaced by new ones closer to the edge of the glacier. The Veslgjuvbre has a vertical front facing Gjuvvatn.

Furthermore the fronts of *Tverråbreen, Svellnosbreen and Hellstugubreen* were measured with a tachymeter.

1934

Werenskiold re-surveyed from the 7th to 14th August the following glaciers:

By the *Søre Illåbre, Heimre Illåbre, Storgjuvbreen* and the *Nordre Illåbre* a large W was painted in white paint on the new cairns which were erected in 1933 and 1934, so that there should be no confusion with other cairns.

On the Nordre Illåbre, Veslbreen and Veslgjuvbreen new cairns were placed in the line of direction.

Storbreen. It was impossible to follow the previous line of direction, as this had been rendered inaccessible by large brooks. The survey was carried out as well as possible in Øyen's line of direction.

All the glaciers had retreated since the year before. This applied most of all to Storbreen (22 m). Storgjuvbreen and Veslbreen had receded least (3 and 3.1 m, respectively).

The front-lines of Tverråbreen, Svellnosbreen and Hellstugubreen were measured with a tachymeter. Six photogrammetric stations were also taken from points which had been trigonometrically determined, in order to be able to construct a map of the upper portion of Svellnosbreen. In 1928 this glacier was also photographed, but the upper part of the glacier was, as mentioned above, covered with so much snow that no details for use in constructing a map were visible. However, during the two preceding years, there have been so many crevasses in the glacier that there have been enough salient points to make use of.

1935

In the course of this year work was carried out by Koller and Werenskiold. Koller's work lasted from the 19th August till the 2nd October on Svellnosbreen, and the tongue was surveyed from the front of the glacier and for a distance of 900 metres upwards. Similarly the moraines, as well as the glacial river, were mapped. The front portion of Tverråbreen was then mapped with the aid of 60 to 70 cross-sections taken athwart the glacier from the front and to a distance of 2½ km from it. The glacial stream and some of the ground on either side were also surveyed. The survey of Hellstugubreen, for a distance of 800 metres, was started on September 29th, and completed on October 2nd.

Werenskiold carried out a re-survey of a total of 6 glaciers during the period from 15th to 28th August. The following glaciers were involved:

The front line of *Storgjuvbreen* was surveyed with a tachymeter, as well as many points in a line running across the ice, and a number of moraines. The front line of *Heimre Illåbre* was surveyed with a tachymeter. The western portion is almost inaccessible, and was not surveyed. The moraines lying below the glacier were also included in this survey.

Veslgjuvbreen. Werenskiold attempted to measure the distance from the cairn to the edge of the glacier, but a great deal of new snow had fallen here during the previous week, and for this reason it was impsosible to decide where the glacier ended and the moraine began. The ice on Juvvatnet did not break up until the 9th of July this year, and not until July 10th in 1933 and 1934.

Veslbreen and *Storgjuvbreen.* There are a great many huge moraines stretching forward at least 750 metres in front of the present glacial fronts. A survey was made of these moraines and the glacial fronts with the tachymeter, and the distance from the marker cairn to the glacier was also measured.

Subsequently Werenskiold took a trip up *Veslbreen* to a height of approximately 1700 metres, in order to investigate conditions on the upper part of the glacier. The upper parts of Storbreen and Veslbreen are quite cut off from one another, and they behave rather differently with regard to advance and retreat.

Nordre and *Søre Illåbre* were measured with a steel tape.

Finally Werenskiold went up to the central peak of the Hestbrepiggene ridge, on which one of the Geographical Survey's trigonometrical beacons is situated. His object was to investigate the possibilities of making a glacier survey up here. Geitåbreen is the best for this purpose, as it is fairly regular, though somewhat small. It has receded considerably in recent years.

On the maps available a number of glaciers and snow fields are shown on the ridge of the so-called Hestbrepigg, approximately 2000 metres high, but now there are hardly any of these snow patches left. Instead large stretches of naked scree show where the snow once lay.

It is remarkable how much all the glaciers surveyed have retreated during the course of recent years.

Two of Illåbreene and Storbreen showed the greatest retreat: Nordre Illåbre 17.8 m, Søre Illåbre 13.5 m. Storgjuvbreen and Heimre Illåbre had remained practically stationary. These glaciers are situated in deep hollows facing north.

1936

In the course of this year Werenskiold worked alone with an assistant and was busy from 11th till 31st August.

The summer was cold and damp, especially in the western part of the Jotunheimen mountains. The following glaciers were re-surveyed:

Storgjuvbreen. The upper part of the glacier had a little snow on its west side beneath the Skarstind. The front of this glacier was measured with a tachymeter. The following glaciers were measured with the steel tape: Heimre Illåbre, Søre Illåbre, Nordre Illåbre, Veslbreen, Storbreen in Leirdalen, Vestre Memurubre, Austre Memurubre, Slettemarkbreen, Langedalsbreen, Svartdalsbreen, Leirtjønnbreen, Bøverbreen. At all these glaciers Øyen's cairns were found; at Leirungsbreen is was searched in vain.

Heimre Illåbre. On this glacier the lowest patches of snow were found, at a height of abt. 1865 m, lying at the foot of the mountain to the west, while the glacier itself was practically free from snow up to a height of 2035 m. Further up the old "firn" snow was lying up to a height of 2065 m, and above that height the glacier was covered by last year's snow. The distance from the cairn to the front of the glacier was measured with a tape.

Nordre Illåbre. Here there was a stripe of snow lying beneath Bukkehø.

Veslgjuvbreen. In order to fix the direction of the measurement a cairn was set up on the moraine, approximately 20 m behind the line of cairns standing in a little hollow in the moraine.

Veslbreen. The front of the glacier and a number of points in the moraine territory in front of it were determined by tachymeter measurements.

Søre Illåbre. A new cairn and a direction cairn, in the old line, were set up on the east side of the glacier. At the top of the measuring cairn a W was hewn into a block of stone.

Storbreen. Here moraines were plotted on the map constructed the preceding year.

Austre Memurubre. Øyen's cairns are situated on two huge stone blocks on a stony plateau lying on the east side of the glacial river. The distance between the two cairns is 63 m. A new cairn was built 383.1 m from the Øyen cairn which is situated nearest to the glacier.

Vestre Memurubre. Near the eastern edge a cairn was found, presumably one set up by Øyen, standing on a large stone in the moraine, and a direction cairn 43.1 m nearer the glacier. From it the distance was once more measured, across a broad stream. As measuring proved very difficult here, a new cairn was built farther down.

Slettemarkbreen. Øyen's two cairns were found, standing on each side of a glacial stream. A new cairn in the line of direction was built on a high moraine (from 1908).

Langedalsbreen. Here a tall cairn was found with a large slab on top, with a cross hewn into it (Øyen). The direction cairn was difficult to find but it was apparently a sharp stone on top of a large slab.

Svartdalsbreen. A cairn was standing on a high moraine heap centrally situated in front of the glacier. This was presumably Øyen's. A few stones lying a little farther forward show the direction line. A new cairn was erected in the same line.

Leirungsbreen. Here no cairn could be found.

Leirtjønnbreen.[1] Here a small cairn was found on a large stone, and 18 m from it a larger stone placed on top of another.

Bøverbreen. Here two cairns were found, one close to the river and another on a huge block close to the glacier, both on the east side. We built two new cairns in the direction line. The front of the glacier faces north. All the cairns are situated on the east side of the large stream. The glacier extends about 50 m farther forward, a little to the west of the direction line, but it is impossible to measure here, as there is a small lake right in front of the glacier.

1937

It was intended to extend glacier measurements in Jotunheimen during the summer of 1937 to include the measurements of ablation. This work was carried out by Koller.

Koller's work commenced on 27th July, and lasted until the 9th October.

In order to measure the rate of melting on Hellstugubreen 41 holes were drilled in the ice in 9 rows. Above the holes which had been drilled the glacier was heavily crevassed, so that it was difficult to place rows of holes here. For boring these holes an icedrill was used, of the same type that was constructed and used by the Swedish glacial expert Professor Axel Hamberg, during his glacier investigations from 1907 on. The icedrills are round wooden poles of ash or hickory equipped with a steel ferrule. The ferrule is shaped like a sharp mining drill with a cross-section of 33 mm. The wooden pole has a diameter of 26 mm. The set of drills which was first used consisted of 4 drills, 1.15, 2.15, 3.15 and 4.15 m long. The drills were intended for holes with a depth of 4 metres. The drills were rammed home with a sledge-hammer, and the ice-chips were swilled out with water. The following year the practice of only using 4.15 m drills was introduced and they were rammed home without the use of a sledge-hammer. In the holes that had been drilled ratan canes equipped with barbs and numbered discs were placed. The length of the ratan canes protruding above the ice was measured, as well as the depth of the holes. Ablation measurements were undertaken on a number of occasions during the summer and autumn.

The next thing that had to be done was to determine the place of every single cane. This was done by sighting from two trigonometrical

[1] Leirbreen on the maps.

points with the aid of a precision theodolite. As a check the lowest 24 points were also sighted from a third point.

The lowest portion of Hellstugubreen was surveyed with a tachymeter for a map to a scale of 1 : 2000.

Werenskiold's work commenced on 9th August, and lasted until 9th September. He carried out measurements on 15 glaciers viz:

Svartdalsbreen, Slettemarkbreen, Langedalsbreen. A snow-*field* had accumulated in front of the last mentioned glacier, and it was impossible to determine the distance between the vairn and the glacier.

Austre Memurubre. It proved difficult to reach the new cairn which had been placed the year before in the line of direction as a number of large streams now ran in front of the glacier.

Vestre Memurubre. Here so many cairns had been erected to mark the way for tourists, that it was difficult to decide which was Øyen's. The year before, however, a couple of his cairns were found, but it was practically impossible to take any measurements from them, as a number of large streams now flowed along the edge of the glacier, across the line of direction. Measurements were taken from a cairn marked W which had been set up the year before.

Blåtjørnholsbreen.[1] It was impossible to find Øyen's cairn at this glacier, and a new one was erected, 40.6 m from the glacier. 14 m nearer the glacier a smaller sighting cairn was built. — No subsequent measurements were made.

Veobreen. A new cairn was erected.

N. Illåbre and *S. Illåbre.*

Storgjuvbreen. The front of this glacier was surveyed with a tachymeter.

Heimre Illåbre. Here a small land-slide had removed the W cairn, but the actual foundations, consisting of a huge stone with letters painted on it, were still intact. As it was very difficult to take measurements from the W cairn, a new cairn was built in the same line of sight, 11.6 m closer to the cairn and marked WQ. The front of the glacier runs in a long tongue 40—50 metres off the line of direction, to the west of it, and down towards the stream. *Veslgjuvbreen* has sunk considerably all along its edge.

On August 22nd Werenskiold made his way across Sygnefjell to Bergen. On his return journey he travelled via Nordfjord, where he visited Olden and Loen to investigate possibilities of extending the investigations to cover new parts of the country.

With Krossbu as his base Werenskiold surveyed the front of *Leirtjønnbreen* with a tachymeter. He erected a new cairn in the line of direction from the year before, 45 m closer to the glacier.

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[1] Blåbreen on the maps.

Bøverbreen. Part of the front of this glacier was surveyed with a tachymeter.

Veslbreen had shrunk considerably, and the front of the glacier had broken up into huge blocks, separated by crevasses which went right down to the bottom. *Storbreen* had receded 25.5 m.

This summer Werenskiold did not get as far as the upper parts of any glacier, but could see at a considerable distance whether there was any snow left which had fallen that year. Moreover, he had various reports from people who had climbed to the mountain tops. It may be stated that in the eastern and central parts of Jotunheimen there was no snow this summer. There was either grey rock or blue glacial ice right to the summit, even on the highest peaks, such as Galdhøpiggen and Glittertind. The latter, seen from the south, appeared like a huge grey mound, but on the north side there may have been a little snow in the glacier cirques. The snow limit may be put at over 2500 m, while previously it has been assessed at 1800 m for these parts. The year before, the snow limit of the Søre Illåbre was approximately 2050 metres.

1938

The work undertaken in Jotunheimen in 1938 was carried out by Koller, Solheim and Werenskiold. This year the working programme was extended to include measurements of accumulation. For this purpose Koller drew up a series of instructions.

Snow measurements should be carried out at the time of year when all the winter snow has fallen and before melting has commenced. The depth of snow should be measured at all drill holes which could be found, as well as in one or two sweeps above the row of drilled holes, across or along the glacier and right up to the watershed.

In order to determine the specific weight of the snow, regular four-sided prisms should be cut out of the snow at suitable distances from one another, and having a cross section of 40 by 40 cm. Digging should continue right down until the glacier ice or the firn snow from the year before is encountered. The snow should be weighed for every metre or half-metre down the shaft thus sunk. In this way it should be possible to assess the varying density of a section, and to make a comparison between the density at various altitudes above sea-level. It is probable that in large parts of the glacier the density of the winter snow is the same, in which case the work should prove easy. Work would then consist simply in measuring the depth by sticking a tube vertically down to the ice or firn snow.

The tools necessary for work in the field are as follows: a snow shovel, a tennon-saw, tubes 4 m long, with a decimal scale, a large zinc tub for weighing the snow, a steeltape, and an aneroid barometer.

The mountain guide Lars Sulheim of Lom had told us the most favourable time for measuring the snow. The measurements were carried out by Koller and Solheim during the period from 25th April to 3rd May. The depth of snow was measured on Hellstugubreen and Tverråbreen. It was obvious that a great many violent gales had raged during the previous winter, as the convex portions of the glacier had been swept almost clean.

On Hellstugubreen the depth was measured at all the canes which could be found, 45 in all. The snow was also measured above the row of canes right up to the watershed, though here this was only undertaken along the middle of the glacier.

The depth of snow varied from ½ metre to 4 metres. There was most snow on the higher portions of the glacier and in the hollows, and least on the lower part of the glacier. At some spots the ice was only just covered by snow.

On Hellstugubreen the specific weight was determined at 4 drill-holes which are included in the 45 mentioned above.

On Tverråbreen the snow was measured in a total of 65 places, and the specific weight determined at one spot.

The table on p. 144 shows the results arrived at in determining the specific weight of the snow.

The usual autumn observations on the glaciers were carried out by Koller, Solheim and Werenskiold.

Koller, who worked in collaboration with Solheim up to 3rd August, carried out his investigations from 22nd July until 28th September.

Hellstugubreen. The work, as in previous years, consisted in re-boring the holes, measuring the ablation, and determining the position of the holes by trigonometrical cross-bearing. The ablation was very considerable that summer. The holes which had been drilled the autumn before down to a depth of 3 to 4 metres, were in some places only a few decimetres in depth, and at one spot only 20 cm. In the first week the melting was so strong, that constant care had to be taken in drilling, to see that none of the holes disappeared. At one spot an ablation of 40 cm in 6 days was recorded. Together with Koller, Solheim took a number of stereo-photograms from four of the old stand-lines on the lower portion of Hellstugubreen, Tverråbreen and Svellnosbreen for a map to a scale of 1 : 2000, as in previous years.

Werenskiold's work on glaciers in Jotunheimen lasted from 6th August to 6th September, with one or two short interludes. Thus at the end of August he made a trip to Jostedalen to investigate the possibilities of including Nigardsbreen in our investigations. Conditions are excellent here, and this glacier is easily reached.

In Jotunheimen the following fourteen glaciers were measured:

Hellstugubreen.

At drill-hole 7, 25/4	Area sq.dm	Depth dm	No. of litres	Weight in kilos	Specific weight	Water content of snow mm
	36.0	6.0	216.0	87.15	0.4035	242

Just above the ice there was a layer of coarse crystalline snow, 30 dm depth.

At drill-hole 19, 27/5						
Upper layer	36.00	5.0	180.0	71.07	0.3948	198
Middle layer	36.00	5.0	180.0	80.25	0.4458	223
Lower layer	36.00	3.0	108.0	42.98	0.3979	119
		13.0	468.0	194.30	0.4152	540

At drill-hole 31, 28/4						
Upper layer	17.45	10.0	174.5	65.05	0.3728	372
Middle layer	18.50	10.0	185.0	82.45	0.4457	445
Lower layer	19.24	10.4	200.1	85.24	0.4260	443
		30.4	559.6	232.74	0.4149	1261

At drill-hole 34, 29/4						
Upper layer	16.20	10.1	163.6	63.20	0.3863	390
Middle layer	17.02	10.1	171.9	77.85	0.4529	457
Lower layer	17.84	3.2	57.0	24.89	0.4360	139
		22.4	392.5	165.94	0.4218	986

Tverråbreen.

At drill-hole 34, 3/5						
Upper layer	16.00	5.0	80.48	32.10	0.3988	200
Next to upper layer	12.20	5.0	81.00	34.82	0.4299	215
Next to bottom layer	16.69	5.0	166.90	80.03	0.4795	479
Bottom layer	17.07	2.3	39.31	16.26	0.4136	95
		22.3	367.69	163.21	0.4439	989

Coarse crystalline snow.

Langedalsbreen, Slettemarkbreen, Svartdalsbreen, Vestre Memurubre, Austre Memurubre, Bøverbreen, Leirtjønnbreen, Veslgjuvbreen, Storgjuvbreen, Heimre Illåbre, Nordre Illåbre, Søre Illåbre, and Storbreen.

The front of Storgjuvbreen was determined by means of a tachymetrical survey. With the exception of Langedalsbreen, which had been practically stationary during the last few years, all the glaciers had receded, varying from 44.1 m in the case of Storgjuvbreen in Leirdalen to 3.5 m in the case of Svartdalsbreen.

1939

Snow measurements were undertaken by Koller from 9th to 12th May on the same glaciers as in the previous years, but on a somewhat smaller scale, owing to the fact that one of his assistants was unable to join him. The result of the measurements can be seen in the table below.

Hellstugubreen.

At drill-hole 19, 10/5	Area sq.dm	Depth dm	No. of litres	Weight in kilos	Specific weight	Water content of snow mm
Upper layer	8.85	5.0	44.25	17.00	0.3842	192.1
Next to upper layer	9.155	5.0	45.78	19.92	0.4351	217.5
Next to bottom layer	9.533	5.0	47.67	20.48	0.4296	214.8
Lower layer	9.765	5.0	48.825	22.48	0.4604	230.2
		20.0	186.525	79.88	0.4273	854.6

Accumulation at drill-hole 19 855 mm.

At drill-hole 22, 11/5						
Upper layer	9.00	5.0	45.00	17.08	0.3796	189.8
Middle layer	8.85	5.0	44.25	19.46	0.4398	219.9
Lower layer	8.85	5.0	44.25	19.70	0.4452	222.6
		15.00	133.50	56.24	0.4215	632.3

Accumulation at drill-hole 22 630 mm.

Tverråbreen.

Upper layer	9.00	5.00	45.00	17.56	0.3902	195.1
Lower layer	8.85	5.00	44.25	18.84	0.4258	212.9
		10.00	89.25	36.40	0.4080	408.0

Accumulation 410 mm.

The usual autumn observations were carried out by Koller and Werenskiold.

Koller worked from 29th July to 20th September, and made the usual surveys on Hellstugubreen as in previous years. The rate of melting and movement of the glacier were measured, and the lowest portion was surveyed with a tachymeter for a projected map to a scale of 1 : 2000. At the end of August, with a tachymeter, he made a map of Spiterstulen and part of the surrounding country. This map was to a scale of 1 : 1000, with a 1-metre contour line. This map was made for the meteorological station which was established at Spiterstulen at the end of August. Werenskiold's work continued from 29th August, and comprised the following 15 glaciers: Svartdalsbreen, Slettemarkbreen, Langedalsbreen, Vestre Memurubre, Austre Memurubre, Veobreen, Vesljuvbreen, Storjuvbreen, Nordre Illåbre, Søre Illåbre, Storbreen and Veslbreen in Leirdalen, Bøverbreen, Leirtjønnbreen and Heimre Illåbre.

But it proved impossible to carry out the measurements on all of them. On *Veobreen* Werenskiold's cairn had been swept away by the glacial stream. A cairn was built more or less in the line of direction, 16.7 m from the edge of the glacier. Øyen's three cairns are probably still standing, and it would not have been difficult to connect all four cairns by a tachymetric survey, but Werenskiold was unable to carry out one that summer. The year before there was snow lying along the edge of the glacier, but an approximate measurement was undertaken. Consequently the result — an advance of 4.7 m — is uncertain.

Vestre Memurubre had now shrunk so much, that a raging river had appeared, running along the front of the glacier, and it was no longer possible to make measurements along the old line of direction. Up to this summer, the river from Austre Memurubre had always disappeared under the snout of Vestre Memurubre, making the ascent to this glacier easy. Now only a bridge remained, about 10 metres broad, separated from the glacier by a crevasse, and it became difficult to cross from the south — in the opposite direction it was easier. But this old route, from Memurubu to Spiterstulen, will soon be rendered impassable.

Heimre Illåbre was measured by an Englishman, Mr. David Linton. According to his measurements, the glacier had advanced 0.3 m, but it is probable that this figure is inaccurate. Apart from these measurements of the glacier Werenskiold, in the course of three days, surveyed with a tachymeter the front line and the moraines at *Slettemarkbreen.* All glaciers, with the possible exception of Veslbreen and Heimre Illåbre, had retreated. The greatest retreat was 30 m (Austre Memurubre), and the smallest 9.2 m (Leirtjønnbreen).

Measuring the flow of water in the Hellstuguå

At the suggestion of Hoel and Werenskiold, made to the Hydrographic Division of The Norwegian Department of Water Cources and Electricity (Norges vassdrags- og elektrisitetsvesen), a limnigraph was set up that summer on the spot where the river flows from Hellstugubreen. The head of the Hydrographic Division, Chief-Engineer J. Aastad, planned the measurements on the understanding that the cost of setting up the limnigraph and the carrying out of the measurements would be covered by Vassdragsvesenet's contribution to glacier research. Assistant Chief-Engineer, Halvdan Klæboe, set up the limnigraph, and inspected it regularly every summer. Apart from a few interruptions the apparatus functioned until September 1946. See p. 208.

Meteorological observations at Spiterstulen

Our investigations this year were extended to include meteorological observations at Spiterstulen. These were carried out by the Meteorological Institute at the suggestion of Hoel and Werenskiold. The guide Eiliv Sulheim was to undertake the observations. The station functioned during the summer and autumn months from 1939 to 1942. It was swept away by an avalanche in the spring of 1943.

1940

This year no measurements of snow depths were undertaken.

The measurements of glaciers in the autumn of 1940 were carried out by Koller, Solheim and Werenskiold.

Koller's work lasted from 4th August till 16th September.

Melting conditions this year were abnormal compared with previous years. The weather had been unusually warm from the middle of June till the middle of July, but later on it became colder, and snow fell in the higher parts of the Jotunheimen mountains. The colder spell continued throughout the time when work was being carried out.

The same work was undertaken this year as in previous years. Apart from the observations and the work of measuring on Hellstugubreen, Koller recorded all the readings on the water-level gauge in the Hellstugu river.

From 2nd to 9th September Koller had the assistance of Solheim, who had been working on Storbreen and Veslbreen in Leirdalen. Solheim carried out tachymeter readings on Hellstugubreen from three stations, so that the lower portion of the glacier could be mapped to a scale of 1 : 2000. He also helped Koller in his work by taking theodolite bearings from one station to a number of drill-holes on the glacier.

On Tverråbreen he made a photogrammetrical survey from a base at the front, and a number of points on the glacier were also surveyed with a tachymeter. From 20th to 29th August Solheim carried out survey work on Storbreen and Veslbreen in Leirdalen, and Werenskiold also took part in this work. Solheim took photograms from three base-lines, and these were done in such a way that the material obtained could be used for constructing maps of these glaciers to a scale of 1 : 2000 and 1 : 10 000. A number of the moraines were surveyed from two tachymeter stations. And finally four cairns in front of the glacier were determined by tachymeter.

Werenskiold carried out the usual measurements from cairn to glacier on the same glaciers as in previous years. It was not possible to survey Austre Memurubre, as the ground in front of the glacier was a quagmire of clay and stone.

Seven glaciers were measured: Slettemarkbreen, Langedalsbreen, Svartdalsbreen, Storgjuvbreen, Veslgjuvbreen, Søre Illåbre, and Nordre Illåbre. All the glaciers had retreated, the greatest retreat recorded being that of Søre Illåbre, with 34.4 m, and the least being that of Veslgjuvbreen with 2 m.

1941

Snow measurements on Hellstugubreen and Tverråbreen were carried out by Solheim during the period from 1st to 6th May. There was little snow — approximately 1 m less than in previous years, and the specific weight of the snow was considerably less than in earlier years, so that the snow melted away quickly. Nor was there this year, as there had been in previous years, a coarse-grained layer of snow in immediate

Hellstugubreen.

At drill-hole 19, 1/5	Surface area	Depth dm	No. of litres	Weight in kilos	Specific weight	Water content mm
Upper layer. .	17.54	5.75	100.85	36.07	0.3577	205
Lower layer .	21.37	11.00	235.07	100.36	0.4269	469
		16.75	335.92	136.43	0.4032	674
		Accumulation at drill-hole 19 675 millimetres.				
At drill-hole 25, 2/5						
Upper layer. .	17.12	7.7	131.82	46.01	0.3490	268
Lower layer .	19.64	11.0	216.04	87.41	0.4046	450
		18.7	347.86	133.42	0.3817	718
		Accumulation at drill-hole 25 720 millimetres.				
At drill-hole 20, 3/5						
Upper layer. .	16.18	7.08	114.55	40.06	0.3497	247
Lower layer .	17.33	12.08	209.35	84.96	0.4058	490
		19.16	323.90	125.02	0.3850	737
		Accumulation at drill-hole 20 740 millimetres.				

Tverråbreen.

5/5	Surface area	Depth dm	No. of litres	Weight in kilos	Specific weight	Water content mm
Upper layer. .	18.144	5.73	103.97	33.90	0.3261	186
Lower layer .	18.474	7.78	143.73	56.84	0.3955	307
		13.51	247.70	90.74	0.3660	493
		Accumulation 495 millimetres.				

contact with the glacier ice. The same conditions prevailed on Tverråbreen.

On Hellstugubreen the snow was weighed at three drill-holes, and the depth of snow was measured practically all over the glacier. On Tverråbreen the snow was weighed and the depth of snow was recorded all over the glacier. The results of these weighings are shown in the table p. 148.

The usual summer and autumn measurements were carried out by Koller, Solheim and Werenskiold.

Koller's work in Jotunheimen lasted from July 11th to August 11th and from 11th to 13th September. In the intervals he carried out survey work on the Okstindbre in North Norway.

As Koller was thus absent from the Jotunheimen mountains for about a month, he had only time to carry out part of his customary work on Hellstugubreen. He recorded snow-melting, and carried out the first determination of the positions of canes, as well as a provisional re-drilling. The remainder of Koller's work was entrusted to Solheim who worked from 27th August to 13th September. He re-drilled 21 holes from a depth of 2½ to 3 m.

From two stand-lines Solheim took photograms for the mapping of the upper part of the glacier to the scale of 1 : 10 000, and a stand-line in front of the glacier front for measuring the front part to the scale of 1 : 2000. The front part of the glacier was also measured with a tachymeter. In all, observations were taken on Hellstugubreen from eleven stations. 36 photograms were taken.

On Tverråbreen Solheim took photograms in two standlines for maps to the scale of 1 : 2000. In addition, the front of the glacier was measured with a tachymeter. Observations were taken from five stations, and ten profiles of the glacier tongue were made. All the standlines were the same as those used in previous years.

Werenskiold's survey took place from 18th August to 3rd September. He measured 13 glaciers, viz. Storgjuvbreen, Veslgjuvbreen, Heimre Illåbre, Nordre Illåbre, Søre Illåbre, Svartdalsbreen, Langedalsbreen, Slettemarkbreen, Austre Memurubre, Veslbreen, Storbreen in Leirdalen, Leirtjønnbreen and Bøverbreen.

It turned out that all the glaciers measured had retreated, with the exception of Søre Illåbre, which had remained constant. The retreat was particularly great in the case of the five last-mentioned glaciers, being as much as 58.3 m for Bøverbreen.

In 1941, too, the limnigraph was in operation. Mr. H. Klæboe was up there on his annual inspection. In addition, limnigraph readings were taken by Koller, and before his arrival by Eiliv Sulheim of Spiterstulen.

According to a report from the Hydrographic Division, Vassdragsvesenet, the limnigraph was set up anew in July 1940, when the delivery pipe was changed. The zero point on the water gauge was at the same time lowered 7.5 cm. Furthermore, in the course of the summer two flow measurements were carried out which showed a flow of 0.25 and 0.9 cub.m per second. In March 1940 approximately 0.01 cub.m per second was recorded.

With these measurements, together with those previously undertaken, the water flow curve may be considered to have been completely determined up to approximately 2 cub.m per second. The higher measurements which remained were to be undertaken on a suitable occasion. The limnigraph was dismantled in September, 1940, and installed again in June, 1941. In the interim occasional readings of the water-level were undertaken by Lars Sulheim.

Assistant Chief-Engineer Mr. Klæboe, together with Mr. Solheim, determined the specific weight of the water in the Tverrå river, in order to determine the load of mud. The result of this measurement shows a mud content of 0.2 per cent by weight. The meteorological station of Spiterstulen functioned during the summer throughout the time when Spiterstulen was occupied.

In 1941 there was also an unusually strong ablation, approximately the same as in the previous year, and amounting at the lower canes to 3½ m. During the period from 11th to 15th July it reached as much as 11 cm per day on Hellstugubreen.

The marked retreat of the glacier also has the effect that the velocity is diminished from year to year. Koller has estimated the relationship between the mean velocity per day in one year and the mean velocity per day for the preceding year.

Maps			Scale
Tverråbreen and Svellnosbreen			
(supplementary map Midt-Jotunheimen) ..			1 : 10 000
Tverråbre	1927	(tongue of the glacier) ..	: 2 000
»	1929	—»—	»
»	1931	—»—	»
»	1932	—»—	»
»	1935	—»—	»
»	1938	—»—	»

Drawings have been completed for the following maps:

Maps			Scale
Hellstugubre			1 : 10 000
Hellstugubre	1929	(tongue of the glacier)	1 : 2 500
»	1931	—»—	»
»	1932	—»—	»
»	1935	—»—	»

1942

Accumulation measurements were carried out by Koller from 7th to 13th May. (See below chapter on accumulation measurements.) On the day of his arrival there was a considerable snowfall in the glacier area. As usual there were also this year a number of wind-swept areas in the middle and lower parts of Hellstugubreen. Canes nos. 5, 6, 9 and 10 were quite free of winter snow, and at 15, 16, 18 and 22 there was less than 0.5 m. Above the row 20 to 25 snow conditions were more even.

On Hellstugubreen the specific weight of snow was measured at canes 28 and 39, where the depth of snow was 1.24 and 1.34 m respectively. From cane 39, 8 depths were measured at equal distances in a line up to the watershed towards Vestre Memurubre. The depth of snow on the upper part of the glacier was even, apart from a small patch around cane 40. The average depth of the old winter snow was 1.30 m, and of the new snow 0.28 m.

At approximately the same height as cane 28 on Hellstugubreen the specific weight of the snow on Tverråbreen was determined. Here the old winter snow was 0.73 m, while the new snow was approximately of the same thickness as on Hellstugubreen. The depth was measured at 44 places, distributed among six sections on the lower, and in 22 places on the upper part of the glacier. Here, too, the depth of snow was fairly evenly distributed, apart from a section just above the great icefall, as well as a small area to the northwest of the nunataks.

The results of determining the specific weight of the snow are shown in the table p. 152.

The more or less wind-swept patches where the depth of snow was irregular were, both in the case of Hellstugubreen and Tverråbreen, small in comparison with the areas where the snow was distributed much more evenly. Furthermore, most of the snow which had been blown away was still lying on the glacier. Thus the snow from the convex parts of the glacier had to a large extent been blown down to the edge. It should, therefore, be possible to arrive at a reasonable mean value for the winter snow by using the *average depth* in the areas where the snow is more evenly distributed. The specific weight of the old snow was, on an average, for both glaciers 0.41, and of the new layer of snow 0.22. The depth of snow, expressed in terms of water was, for Hellstugubreen, 563 mm, and for Tverråbreen 641.

The summer and autumn work was carried out by Koller, Solheim and Werenskiold.

Koller carried out the usual measurements on *Hellstugubreen* from 19th July to 14th September. The first triangulation took place from 29th July to 1st August, and the second from 12th to 14th September. Koller

Hellstugubreen.

At drill-hole 28, 11/5	Area sq.dm	Depth dm	No. of litres	Weight in kilos	Specific weight	Water content mm
Upper layer	25.00	1.7	42.50	10.35	0.2435	41.4
Next to upper layer	9.00	2.6	23.40	10.66	0.4556	118.5
Next to lower layer	9.00	5.0	45.00	17.67	0.3927	196.4
Bottom layer	8.70	5.0	43.50	16.56	0.3807	190.4
		14.3	154.4	55.24	0.3823	546.7

Accumulation at drill-hole 28 545 mm.

At drill-hole 39, 12/5						
Upper layer	16.00	2.65	42.40	8.28	0.1953	51.8
Next to upper layer	9.00	3.50	31.50	14.02	0.4451	155.8
Next to lower layer	9.00	5.00	45.00	16.76	0.3724	186.2
Bottom layer	9.00	4.90	44.10	18.07	0.4098	200.8
		16.05	163.00	57.13	0.3705	594.6

Accumulation at drill-hole 39 595 mm.

Tverråbreen.

Weighing 13/5						
Upper layer	25.00	1.70	42.50	10.35	0.2435	41
Middle layer	9.00	2.50	22.50	10.17	0.4520	113
Bottom layer	8.85	4.80	42.48	16.58	0.3903	187
		9.00	107.48	37.10	0.3797	341

Accumulation 340 mm.

also made a tachymetric survey of the front line of Hellstugubreen. As usual he was in charge of the limnigraph.

Solheim worked on *Hellstugubreen* and *Tverråbreen* from 30th August to 14th September.

On Hellstugubreen a photogrammetric stand-line was taken with 12 photograms for a map, to a scale of 1 : 5000, covering the whole glacier, and a photogrammetric stand-line with 5 photograms, covering the front part of the glacier, for a map to a scale of 1 : 2000.

At Tverråbreen three photogrammetric stand-lines were taken, with 23 photograms for a map to a scale of 1 : 10 000.

For the purpose of surveying the lowest portion of the glacier tongue to a scale of 1 : 2000, 2 photogrammetric stand-lines were taken with 12 photograms. In addition the front line was measured tachymetrically.

At *Svellnosbreen* a photogrammetric stand-line was taken with 8 photograms, for a map to a scale of 1 : 10 000. Furthermore, a cairn on the Svellnosaksla ridge was trigonometrically determined.

Altogether measurements were taken at 15 stations and 8 photogrammetric stand-lines, with 60 photograms. In addition 5 other stations were trigonometrically determined, and finally a number of compass intersection points were plotted.

During the 16 days these measurements were carried out, Solheim had 7 days when the weather was suitable for surveying, while the rest of the time the weather was squally, with wind and rain.

Werenskiold surveyed the following glaciers: Austre Memurubre, Svartdalsbreen, Langedalsbreen, Slettemarkbreen, Veslgjuvbreen, Storgjuvbreen, Heimre Illåbre, Nordre Illåbre, Søre Illåbre, Storbreen, Veslbreen, Bøverbreen, and Leirtjønnbreen.

All glaciers had retreated: Austre Memurubre most (42 m), Veslgjuvbreen least (3 m).

The direction line in front of Vestre Memurubre was still inaccessible. On Slettemarkbreen the distance to the glacier could not be measured, because there was a deep pool of water in the line of direction.

There was no last winter snow on Austre Memurubre, except for a rim under the precipices in the cirques on the west side.

The same was also the case on *Slettemarkbreen* and *Hellstugubreen,* where towards the north there was sheer ice. *Semmelbreen,* to the north of Gjendebu, had also retreated considerably. The tarn in front of the glacier front was twice as long as it appeared on the map of Aust-Jotunheimen. Another little tarn had emerged a little farther east, right in the corner. The glacier "calves" into both tarns, and there are large floes of ice in them. There was no snow on the glacier, except for a white rim at the upper limit.

1943

Snow measurements in Jotunheimen were undertaken by Koller during the period from 31st May to 2nd June, three weeks later than usual. For this reason it might be supposed that the results would not be comparable with those recorded in the previous year, but this was not the case, as the weather in the following year was unusually cold, so that snow melting had not taken place to any great extent before snow measurements commenced. There were huge masses of snow on the glaciers, at least twice as much as in the previous year. There was in fact more snow in the mountains this summer than people could remember having seen for the previous 40 years. There had been avalanches all the way down Visdalen, some of them fairly large, on both sides of the valley, especially on the west side, causing extensive damage to the birch woods and entailing loss of human life.

At Spiterstulen a large avalanche had crashed down just south of the dwelling houses, sweeping the meteorological station and most of the fence round the fold into the river. When survey commenced there was still new snow lying on the glacier. It had fallen three weeks previously.

The snow was unusually compact, so that the work of sinking the measuring tube down to the ice proved very exhausting.

On Tverråbreen 48 measurements of the snow depth were carried out in 7 sections. The specific weight of the snow was determined at a spot approximately 200 m from the edge of the glacier. Here the depth of snow was 2.35 m. This year there were 2 clearly marked layers of ice in the winter snow. On Hellstugubreen the specific weight of the snow was measured between canes 22 and 23, where the thickness was 2.11 m.

The distribution of snow on both glaciers was the same as in previous years; the lower convex part of the glacier had been more or less swept clean, but the depth of the snow on the central and upper portions was fairly even. The mean depth of snow on Tverråbreen was 2.87 m, and on Hellstugubreen 2.71 m. The specific weight of the snow in the case of the former glacier was 0.525, which corresponds to a "water value" of 1492 mm, and for Hellstugubreen 0.536, corresponding to a "water value" of 1409 mm.

This year, too, autumn measurements were carried out by Koller, Solheim and Werenskiold. A characteristic feature of the glaciers this summer was that along the edge of the glaciers there were large snow drifts, which protected the ice against melting, and made it difficult to measure the actual edge of the front. This also resulted in the linear retreat of the glacier tongue being considerably less this year than in other years. There was also quite a heavy fall of snow on the 12th and 13th August, and the new snow remained lying for quite a number of days, right down to the birch woods. The large masses of snow made it difficult to locate the canes. The winter snow was still lying as low down as the canes in row 27 to 31, on the 17th August, and in row numbers 32 to 35 the depth of snow was 0.30 to 0.40 m, and in no. 40 it was 1.20 m. By the 30th August there were still 4 canes — nos. 31, 37, 38 and 40 — which had not yet emerged from the winter snow. Nos. 31 and 37 did not emerge from the snow until the 11th September.

Owing to the great quantity of snow it was impossible to carry out the early triangulation. The work of determining the positions of the holes could not be started before the 1st September, and was continued on the 3rd, 5th, 8th and 22nd of September.

This year, too, Koller took charge of the limnigraph reading. It was inspected by Mr. Klæboe on 10th September.

Solheim worked on Hellstugubreen and Tverråbreen from 29th August to 9th September.

For surveying Visdalen to a scale of 1 : 10 000 from Spiterstulen and past the Hellstugu river, he took 5 stand-lines. Observations were made at 5 stations, and 37 photograms were taken.

On Hellstugubreen 2 stand-lines were taken with 8 photograms, for a map of the front of the glacier to a scale of 1 : 2000. Apart from these stations, observations were made at 5 other trigonometrical stations, and in addition a number of fixed points were observed for use in constructing this map.

For the purpose of surveying Tverråbreen to a scale of 1 : 2000, 2 stand-lines were made, and observations taken at 4 stations with 13 photograms. A number of supplementary measurements were also carried out with a tachymeter.

Altogether measurements were taken at 23 stations and 9 photogrammetric stand-lines were made from 18 stations with 58 photograms.

During the period Solheim was staying at Spiterstulen — from 28th August to 10th September, 14 days in all — the weather was good enough for work to be carried out on 10 days. During the other days the weather was squally, with fog and rain.

Werenskiold re-surveyed 10 of the glaciers in Jotunheimen from 19th August to 11th September, with a period of absence from 1st to 8th September, when he was travelling in another part of the country.

He surveyed the following glaciers: Austre Memurubre, Vestre Memurubre, Svartdalsbreen, Slettemarkbreen, Langedalsbreen, Storgjuvbreen, Heimre Illåbre, Søre Illåbre, Norde Illåbre and Storbreen. The Memuru glaciers were still shrinking. Austre Memurubre had retreated 22.5 m and Vestre Memurubre 149.5 m in 5 years, or approximately 30 m per year. The other glaciers had also retreated, but only from 30 cm to 4 m.

For the first time since 1938 he succeeded in measuring Vestre Memurubre, where as already mentioned a large torrent had hitherto prevented measurement.

Four glaciers, measured during previous years, were not measured during this year. These were Veslbreen, in Leirdalen, where the cairn had disappeared, and in addition Tjønnbreen, Bøverbreen, and Veslgjuvbreen. There were large drifts of snow in front of these glaciers. There were also drifts in front of Svartdalsbreen, Slettemarkbreen, Langedalsbreen, Storbreen, Storgjuvbreen and Nordre Illåbre, which made it difficult to carry out measurements, and resulted in somewhat inaccurate readings being obtained for Svartdalsbreen and Langedalsbreen. In the case of the other glaciers it was possible to find the glacier edge.

This year, too, Koller was in charge of the limnigraph, and it was inspected by Mr. Klæboe, of the Hydrographic Division.

Computation and construction in 1942 and 1943.

During survey work in Jotunheimen in the autumn of 1942 the usual maps were made of the tongue of Tverråbreen and Hellstugubreen to a scale 1 : 2000, as well as maps of Tverråbreen to a scale of 1 : 10 000. In addition, supplementary surveys were made on Hellstugubreen to a scale of 1 : 5000. The work of computing these measurements was carried out in the autumn and winter of 1942.

The construction of the maps was undertaken by Askheim and Solheim on Norges Geografiske Oppmåling's (Geographical Survey of Norway) stereo-autograph, during the periods when it was not being used by the Survey.

The work of map construction was started at Christmas 1942, and continued in the Easter and summer months of 1943. During this time the following maps were made:

Glaciers	Scale	Area sq.km
Tverråbreen and Svellnosbreen	1 : 10 000	15.50
Tverråbreen	1 : 2000	0.52
Hellstugubreen, supplementary survey	1 : 5000	
Hellstugubreen	1 : 2000	0.50
Hellstugubreen, surveyed 1938	1 : 2000	0.42

The surveys undertaken in the autumn of 1943 included the tongues of Tverråbreen, Svellnosbreen and Hellstugubreen to a scale of 1 : 2000. Apart from these a survey map was constructed stereo-photogrammetrically of the area of Visdalen between Tverråbreen and Hellstugubreen, to a scale of 1 : 10 000.

The work of computing these measurements was carried out in the autumn and winter of 1943, and a constructional sheet was printed.

1944

This was the last year that Koller, Solheim and Werenskiold worked together in Jotunheimen.

The snow measuring was carried out by Koller from the 6th to 8th June. The reason why the snow measuring was commenced so late was that Spiterstulen had not been opened earlier, and it had, furthermore, proved very difficult to get hold of assistants. This year, too, the depth of snow on Hellstugubreen was very small on the convex part of the glacier. Below the row of canes nos. 8 to 13 there was practically no snow, except along the edge of the glacier. The snow only reached appreciable depth above row 20—28; and from row 32—36, and right up to the crest of the glacier, the depth was even greater than that previously recorded.

At point 34, 1690 m above sea-level, the specific weight of the snow was determined. The snow at this height was a good 2 m deep, and winter conditions prevailed, so that there had undoubtedly been no melting here even in the last few years.

The depth of snow was measured at the canes and measurements were continued from the last drill-hole (no. 41) along the middle of the glacier. Here a total of 8 measurements were made. At points 2, 3, 5 and 8 measurements were carried out in cross-section.

On Tverråbreen, below the ice-fall, measurements were made along a profile, approximately in the middle of the glacier, between the central moraine and the southern edge of the glacier. A number of cross-profiles were also made in both directions. On this glacier, too, there were only small quantities of snow down on the glacier tongue.

At a height of 1700 metres, the depth of snow was the same as at the same altitude on Hellstugubreen. Here the specific weight of the snow was determined. A cross-section was made through this point, and observations were then carried on from here along a lengthwise section towards the cairn on Bukkeholstind. Here 2 cross-profiles were taken. Survey continued up along the edge of the cliff in a northwesterly direction, until peak 2120 between Tverråbreen and N. Illåbre came into sight. Seven points were then taken on the section between the large lateral moraine and the nunatak. On the edge of the great ice-fall the snow had been completely blown away.

The measured specific weight of the snow was the same in the case of both glaciers, viz. 0.467, and the mean average depth of snow for the two glaciers could be put at 2.5 m. The water value of the winter snow would thus have been 1175 mm.

During the autumn Koller and Solheim carried out observations and measurements on Hellstugubreen and Tverråbreen, and Werenskiold measured the glaciers with a tape-line.

Koller worked from 28th July to 5th September. The ablation was measured in the usual way at the canes. The first trigonometrical determination of the position of the drill-holes was undertaken from 2nd to 4th August, and the second from 2nd to 5th September. Koller also surveyed tachymetrically the front line of Hellstugubreen, and took readings from the limnigraph. Mr. Klæboe from Vassdragsvesenet also paid a visit to the glaciers this year.

Solheim worked during the period from 30th August to 5th September. Photograms were taken from 5 stand-lines with 10 stations. In addition, tachymetrical surveys were made at 4 stations. Finally a trigonometrical point was taken on the Svellnostind. Altogether he carried out observations from 15 stations and took 30 photograms.

Measurements comprised the tongues of Hellstugubreen, Tverråbreen and Svellnosbreen for maps to a scale of 1 : 2000. In addition, supplementary measurements were made for the map of Visdalen (1 : 10 000).

The weather conditions were unfavourable for survey work throughout the period. During the eight days he spent at Spiterstulen there was only one day of good weather. On the other days there were long spells of rain and fog.

Werenskiold re-measured 13 glaciers from 8th to 24th August: Austre Memurubre, Vestre Memurubre, Svartdalsbreen, Slettemarkbreen, Langedalsbreen, Storgjuvbreen, Veslgjuvbreen, Heimre Illåbre, Nordre Illåbre, Storbreen, Leirtjønnbreen, and Bøverbreen.

It should be pointed out that the glaciers were measured 14 days later in 1943 than in 1944. Consequently the retreat recorded for the year under review was bound to be unduly large.

There was a fall of snow in the middle of August, and some of the snow remained lying on the glaciers.

Computation and construction work of the glacier measurements undertaken in 1943 and 1944.

Measurements made in 1943 comprised the tongues of Tverråbreen, Svellnosbreen, and Hellstugubreen to a scale of 1 : 2000. In addition, Visdalen between Tverråbreen and Hellstugubreen was stereo-photogrammetrically surveyed to a scale of 1 : 10 000.

The computation and construction were carried out in the autumn and winter of 1943—44 by Solheim.

The surveys made in 1944 also included the tongues of Hellstugubreen, Tverråbreen and Svellnosbreen, to a scale of 1 : 2000, as well as supplementary survey work with a tachymeter for the Visdalen map (scale 1 : 10 000). The necessary computations were carried out in the autumn of 1944 by Solheim.

The constructional work with the Survey's stereo-autograph was commenced in the Easter of 1944 and continued in the summer and Christmas. During this time the following stereo-photogrammetric material was worked out by Askheim and Solheim.

Name	Surveyed	Scale	Area sq.km
Tverråbreen	1943	1 : 2 000	0.56
Hellstugubreen	1943	1 : 2 000	0.54
Visdalen	1943	1 : 10 000	36.00
Tverråbreen	1944	1 : 2 000	0.56
Svellnosbreen	1944	1 : 2 000	0.18
Hellstugubreen	1944	1 : 2 000	0.56
Visdalen supplementary survey	1944	1 : 10 000	0.04

In connection with the construction work a certain amount of drawing for the printing of maps had been carried out.

1945

No snow accumulation measurements were carried out in this year.

As in previous years, Koller worked during the autumn on Hellstugubreen from August 13th to September 3rd. Apart from work on the glacier he also took readings from the limnigraph.

Ablation was determined at all points, and the holes drilled anew. Bearings were only taken from one of the trigonometrical points.

Nils Werenskiold measured the following glaciers: Storgjuvbreen, Veslgjuvbreen, Heimre Illåbre, S. Illåbre, N. Illåbre, Storbreen, Leirtjønnbreen, Bøverbreen, Svartdalsbreen, Slettemarkbreen, Langedalsbreen, Vestre Memurubre, from August 13th to August 30th.

1946

Koller, Nils and W. Werenskiold worked in the Jotunheimen mountains during the summer of this year. No snow measurements were made this year either.

Koller carried out his investigations from August 29th to September 19th.

Already at the beginning of July the rate of melting was very considerable. The Hellstugu river overflowed its banks, but subsequently the weather remained cool.

Profile no. 1 (points nos. 1, 2, and 3) had now practically reached the very front of the glacier, and had to be abandoned. Profile no. 2 (5, 6 and 7) had practically melted away. In profile no. 3 (8 to 13) cane no. 8 had been removed already the year before by some unknown person. Nos. 9, 10, 11 and 12 had also practically melted away. No points lying above them had melted, and in row no. 4 (points 20 to 25) the melting was comparatively small. The tremendous melting which commenced in July had thus mainly affected the lowest portion of the glacier tongue. The holes were drilled up, and the rate of melting measured at 28 points on the upper part of the glacier.

In order to determine the position of the canes, observations were taken from only one station. This was on 27th and 28th August. This year, too, Koller supervised the limnigraph which was inspected by Mr. Klæboe.

As Spiterstulen was closed on 21st September, there was no opportunity of undertaking a second triangulation of the holes.

Nils and W. Werenskiold, during the period from 20th to 29th August, carried out measurements on the following 12 glaciers:

Veslgjuvbreen was low and flat for about 50 m, and the surface had sunk deep down behind the moraine cover.

Heimre Illåbre was measured from cairn WQ to the edge of the glacier which here lay 1500 m above sea-level, on the line of direction, while the lowest point of the glacier lay a little lower, viz. at about 1480 m.

Søre Illåbre could not be measured on the line of direction which was interrupted by a raging torrent, but such measurements as could be made were taken.

Leirtjønnbreen. Here a stone was placed in the line of direction 189 m from cairn W and closer to the glacier.

Bøverbreen. As cairn W had fallen down, a new one was built, but unfortunately on the wrong spot. It should have been moved to the top of the mound approximately 10 m to the northeast. It was subsequently built in the right spot.

Storgjuvbreen. The distance from cairn W to the edge of the glacier was measured. But the glacier reached a little farther down to the southwest. The ground in front of the glacier is getting more and more difficult with every year, as huge boulders roll down from the mountain side. On the west side a moraine was lying above the ice, rather like a shelf up the mountain side, and stones and gravel were tumbling down every now and then.

Storbreen and *Vestre Memurubre* were surveyed by Nils Werenskiold. It was impossible to find the cairn in front of Austre Memurubre.

Svartdalsbreen, Slettemarkbreen and *Langedalsbreen* were the last glaciers to be measured this summer.

During the period from 1945 to 1946 the glaciers retreated a record distance, in fact farther than in any previous year of which we have any knowledge. Nordre and Søre Illåbre retreated over 30 m.

1947

Olav Liestøl, Nils and W. Werenskiold surveyed from 12th to 28th August moraines and glacier fronts at Slettemarkbreen and Svartdalsbreen, with a tachymeter. The regular measurements were made at Vestre Memurubre, Storbreen, Hellstugubreen, Storgjuvbreen, Leirbreen, Bøverbreen, Heimre Illåbre, N. Illåbre, S. Illåbre.

Vestre Memurubre. Vestre Memurubre and Langedalsbreen were surveyed by Liestøl and Nils Werenskiold. The latter glacier was measured from a small cairn on the west side of the stream, just opposite a large cairn with a stone on it.

Austre Memurubre. It was impossible to find the cairn. A new cairn was set up on a boulder to the west of the river on the northeast side of a moraine heap. The distance to the glacier was 30 m.

Storbreen was measured with a steel tape by Liestøl and Nils Werenskiold.

Storgjuvbreen was surveyed by W. Werenskiold. A new cairn was set up in the line of direction.

Leirtjønnbreen and *Bøverbreen* were surveyed by W. Werenskiold. By Bøverbreen a new cairn was set up in the line of direction on a mound.

Heimre Illåbre, Nordre Illåbre and *Søre Illåbre* were surveyed by W. Werenskiold. The lower portion of the glacier tongue consisted of dead ice covered with sand and gravel. *Veslgjuvbreen* was surveyed by Liestøl and Nils Werenskiold. The snout of *Hellstugubreen* was surveyed with a tachymeter by Liestøl.

The summer of 1947 was exceptionally warm, and moreover there was hardly any precipitation throughout the month of August. The result was that rivers and brooks dried up, except those that issued from glaciers. Snow-fields disappeared, and there was no snow on the glaciers. Springs which usually provided abundant water dried out. A survey of the climatic conditions in 1947 is to the found in the "Meteorologiske forhold i 1947" by B. J. Birkeland — Naturen, Bergen, 1948.

1948

Measurements were carried out by Liestøl on 14 glaciers during the period 12th—22nd August.

Bøverbreen. The line of direction cuts past the glacier and meets a heap of dead ice.

Leirtjønnbreen.

Storbreen. The line of direction now meets the side of the tongue of the glacier. The ice has probably been very thin where the line of direction met the glacier last year.

In addition, measurements were carried out on *Søre Illåbre, Nordre Illåbre, Heimre Illåbre, Storgjuvbreen, Veslgjuvbreen, Tverråbreen,* and *Vestre Memurubre.*

Austre Memurubre. Werenskiold discovered the old cairn W in front of the Austre Memurubre the day before Liestøl arrived. The last glaciers to be measured were *Svartdalsbreen, Langedalsbreen* and *Slettemarkbreen.*

The lowest part of Hellstugubreen was surveyed with a tachymeter. This year once more showed a very considerable retreat in the case of all glaciers, with the exception of Veslgjuvbreen, which had advanced a few metres. The retreat must to a large extent be attributed to the unusually warm autumn of the previous year. In the case of several of the glaciers it may be assumed that more than half the retreat measured took place at the end of August and September, 1947.

SUMMARY OF WORK

General summary

The work has consisted of:

1. Survey work (mapping)
   a. Maps to a scale of 1 : 10 000, with a 10-metre contour line, of:
      1. Hellstugubreen
      2. Tverråbreen
      3. Svellnosbreen
      4. Visdalen from Hellstugu river to Spiterstulen.
   b. Maps to a scale of 1 : 2000, with a 2-metre contour line, of the front portions of the glaciers, from the lower end of the glacier and up as far as about 1 km above the end of the glacier, for:
      1. Hellstugubreen
      2. Tverråbreen
      3. Svellnosbreen.
2. Measurement of the depth of winter snow and determination of the specific weight of snow on Hellstugubreen and Tverråbreen.
3. Measurement of the speed of Hellstugubreen (winter and summer speed).
4. Measurement of the ablation on Hellstugubreen.
5. Measurement of the annual changes in length of 10 to 15 glaciers in the central part of Jotunheimen.
6. Measurement of the flow of water in the Hellstuguå.
7. Meteorological observations near Spiterstulen.

For mapping the stereo-photogrammetric method has principally been used, and to a lesser extent tachymetry. For measuring the changes in length, use has principally been made of measuring tape, measurements having been made from fixed marks on the mountain side or cairns to the edge of the glacier. In the case of some glaciers, maps have been made over end-moraines and also to some extent of the front line with a tachymeter.

Work carried out in single years.

1927

Survey for maps of the front portions of Tverråbreen and Svellnosbreen and of the country between them. Furthermore for maps comprising the whole precipitation area of Tverråbreen as well as the foremost sections of Svellnosbreen up to a height of 1750 metres above sea-level.

1928

Supplementary survey of Tverråbreen and Svellnosbreen.

1929

Continued survey of the front portions of Tverråbreen and Svellnosbreen. Measurement of the front portion of Hellstugubreen and of the whole glacier with its surroundings.

1930

Complementary surveys for a map of the precipitation area of Hellstugubreen. Survey for a map showing the river course from Tverråbreen to Spiterstulen.

1931

Survey of the front portions of Tverråbreen and Hellstugubreen.

1932

Measurement of the tongues of Tverråbreen and Hellstugubreen and of the front line of Svellnosbreen.

1933

Determination of the changes in length during the years 1932 to 1933 of 9 glaciers in the central portion of Jotunheimen.

1934

Survey for a map showing the upper portion of the Svellnosbreen. Determination of changes in length of the same glaciers as above.

1935

Survey of the front portion, lateral moraines and glacial streams, of Svellnosbreen. Determination of the changes in length of 6 glaciers.

1936

Determination of variations in length of 15 glaciers.

1937

Survey of the snout of Hellstugubreen.

Determination of the speed and rate of melting of Hellstugubreen.

Measurement of changes in length of 15 glaciers.

Investigations of conditions on the glaciers of Nordfjord with a view to a study of these glaciers.

1938

Measurement of the thickness of snow and determination of the specific weight of snow on Hellstugubreen and Tverråbreen.

Determination of the speed and melting rate of Hellstugubreen.

Measurement of the front portions of Hellstugubreen, Tverråbreen and Svellnosbreen.

Measurement of changes in length of 14 glaciers.

1939

Measurement of the thickness of snow and determination of the specific weight of snow on Hellstugubreen and Tverråbreen.

Survey for a map showing the snout of Hellstugubreen.

Determination of the speed and rate of melting of Hellstugubreen.

Survey for a map to a scale of 1: 2000, with a 1-metre contour interval, of Spiterstulen.

Measurement of changes in length of 15 glaciers.

Setting up of a limnigraph on the stream running from Hellstugubreen, and measurement of the rate of flow of the water.

Meteorological observations started at Spiterstulen.

1940

Survey for a map showing the snouts of Hellstugubreen and Tverråbreen.

Measurements of the speed and rate of melting of Hellstugubreen.

Survey of Storbreen and Vetlebreen in Leirdal for maps to a scale of 1 : 2000 and 1 : 10 000.

Measurement of changes in length of 7 glaciers.

Measurement of the water flow in Hellstugubre stream.

Meteorological observations at Spiterstulen.

1941

Measurement of the depth of snow and determination of the specific weight of snow on Hellstugubreen and Tverråbreen.

Survey for a map showing the upper portion of Hellstugubreen, and a map showing the front part of the glacier.

Survey for a map showing the snout of Tverråbreen.

Measurement of the speed and rate of melting of Hellstugubreen.

Measurement of variations in length of 13 glaciers.

Measurement of the flow of water in the Helstugu stream.

Determination of the specific weight of water in the Tverrå stream.

Meteorological observations at Spiterstulen.

1942

Measurement of the depth of winter snow and determination of the specific weight of the snow on Hellstugubreen and Tverråbreen.

Survey for a map to a scale of 1: 5000 showing the whole of Hellstugubreen, and for a map showing the front portion of the same glacier.

Survey for a map of the whole of Tverråbreen and for a map showing the front portion of the same glacier.

Survey for a map to a scale of 1 : 10 000 of Svellnosbreen.

Measurement of the speed and rate of melting on Hellstugubreen.

Measurement of variations in length of 13 glaciers.

Measurement of the flow of water in the Hellstugu stream.

Meteorological observations on the Spiterstulen glacier.

1943

Measurement of the depth of snow and determination of the specific weight of the snow on Hellstugubreen and Tverråbreen.

A survey for a map to a scale of 1 : 10 000 of Visdalen from just above the Hellstugu stream to Spiterstulen.

Measurement of the speed and rate of melting on Hellstugubreen.

Measurement of changes in length of 10 glaciers.

Measurement of the flow of water in the Hellstugu stream.

Meteorological observations at Spiterstulen.

1944

Measurement of the depth of snow and determination of the specific weight of the snow on Hellstugubreen and Tverråbreen.

Survey for a map showing the front portions of Hellstugubreen, Tverråbreen and Svellnosbreen, as well as a supplementary survey for a map of Visdalen.

Measurement of the speed and rate of melting on Hellstugubreen.

Measurement of changes in length of 15 glaciers.

Measurement of the flow of water in the Hellstugu stream.

1945

Measurement of the speed and rate of melting on Hellstugubreen.

Measurement of the flow of water in the Hellstugu stream.

Measurement of changes in length of 12 glaciers.

1946

Measurement of the speed and rate of melting on Hellstugubreen.

Measurement of changes in length of 12 glaciers.

Measurement of the flow of water in the Hellstugu stream.

1947

Measurement of changes in length of 15 glaciers.

Measurement of the flow of water in the Hellstugu stream.

Moraine and glacier fronts of Slettemarkbreen and Svartdalsbreen were surveyed and plotted.

1948

Measurement of changes in length of 14 glaciers.

Summary of work in the field.

Year	Date	Those taking part in the work
1927	27th August—6th September	A. Hoel, A. Koller, B. Luncke, W. Solheim, W. Werenskiold
1928	21st August—5th September	W. Werenskiold
1929	6th August—5th September	A. Koller, W. Werenskiold
1930	21st August—5th September	W. Werenskiold
1931	8th August—16th September	A. Koller, W. Werenskiold
1932	8th August—20th September	W. Solheim
1933	6th August—14th August	W. Werenskiold
1934	7th August—14th August	W. Werenskiold
1935	19th August—12th October	A. Koller, W. Werenskiold
1936	11th August—31st August	W. Werenskiold
1937	27th July—9th October	A. Koller, W. Werenskiold
1938	25th April—3rd May, 22nd July—28th September	A. Koller, W. Solheim, W. Werenskiold
1939	9th April—12th May, 29th July—20th September	A. Koller W. Werenskiold
1940	4th August—16th September	A. Koller, W. Solheim, W. Werenskiold
1941	1st—7th May, 11th—13th September	A. Koller, W. Solheim, W. Werenskiold
1942	7th—13th May, 19th July—14th September	A. Koller, W. Solheim, W. Werenskiold
1943	31st May—2nd June	A. Koller, W. Solheim, W. Werenskiold
1944	6th—8th June	A. Koller, W. Solheim, W. Werenskiold
1945	13th August—3rd September	A. Koller, N. Werenskiold
1946	20th August—19th September	A. Koller, N. and W. Werenskiold
1947	12th August—28th August	O. Liestøl, N. and W. Werenskiold
1948	12th August—22nd August	O. Liestøl.

Summary of work on the various glaciers

Storgjuvbreen.

1933. Øyen's cairns from 1901 had been swept away by a landslide. A new cairn was built.

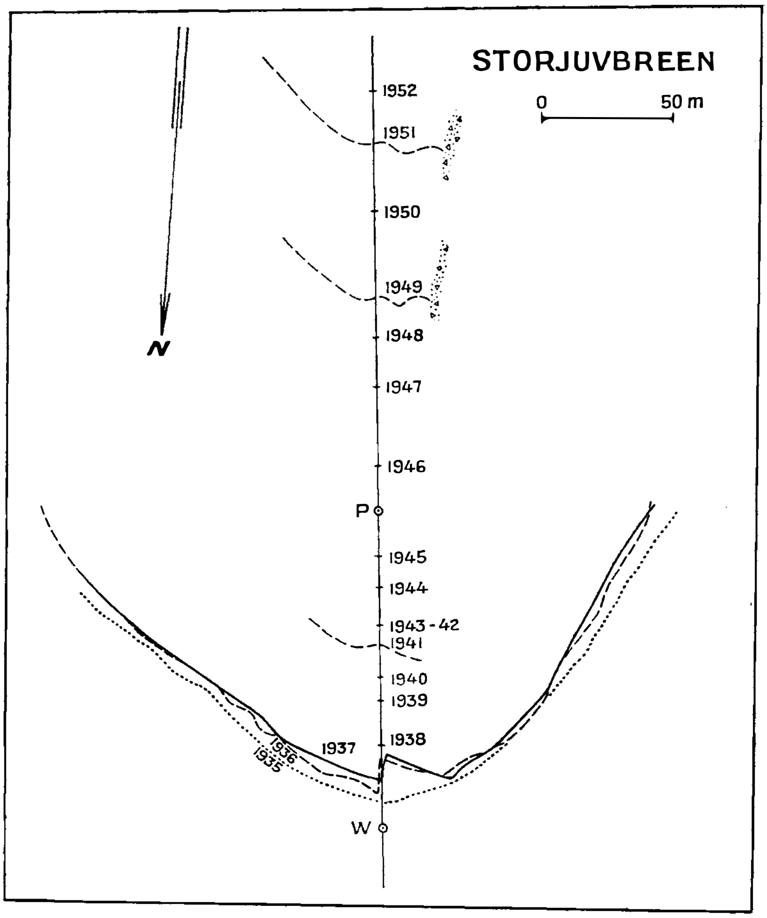


Fig. 24. Map of the frontal retreat of Storgjuvbreen. The line through W and P represents the direction along which measurements of the length of the glacier have been made.

1934. A large W was painted on the cairn.
1935. Front line was surveyed with a tachymeter.
1936. —»— —»—
1937. —»— —»—
1947. A new cairn was set up, 120 m from cairn marked W.
1948. This cairn had disappeared, swept away by the torrent, and another cairn was built, 69.5 m from W, in the same line of direction. Total retreat of glacier, 1933—52, 271.9 m.

Veslgjuvbreen.

1933. Øyen's two cairns were found (1901) and two new ones were built nearer the glacier, 98.5 m from Øyen's nearest.
1934. A white W was painted on the cairn.

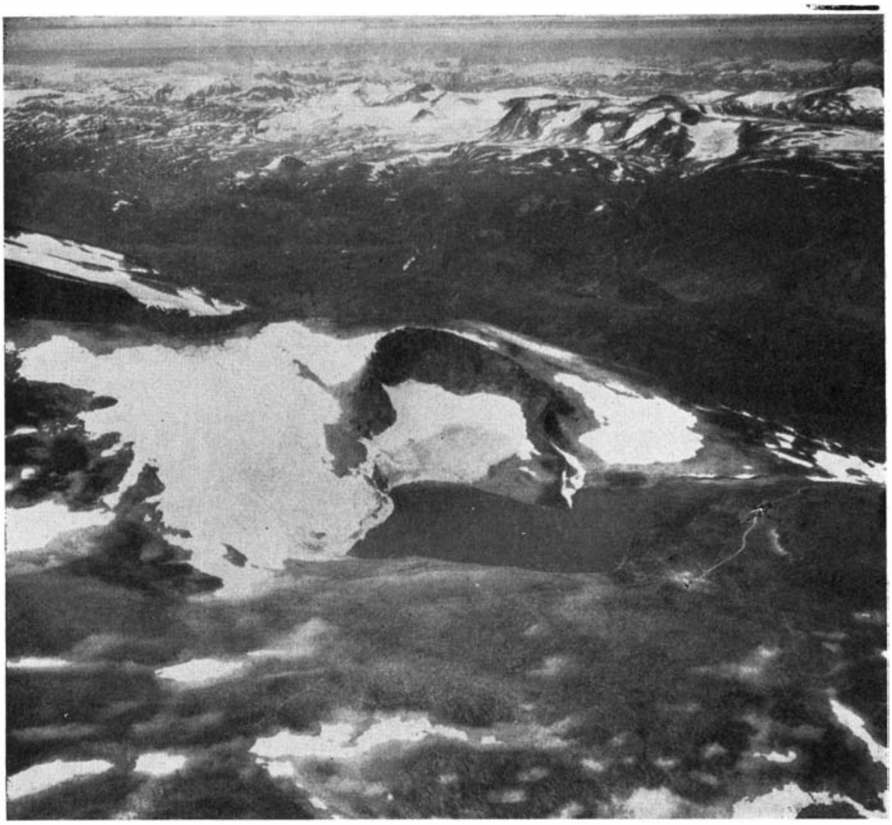


Fig. 25. Gjuvbreen and Gjuv-vatnet, Hestbreene in the background. (Photo: B. Luncke, Norsk Polarinstitutt, Aug. 1955.)

1936. A little cairn was built in the line of direction, 20 m behind the cairn W.
For several years measurement has been rendered inaccurate or impossible, owing to great heaps of snow at the glacier front.
Retreat 1901—54, 170.3 m.

Heimre Illåbre.

1933. Øyen's cairns, from 1903, were found, and a new one was built, 65 m nearer to the glacier.
1934. Painted a white W on the main cairn.
1935. Front line of glacier surveyed with a tachymeter.
1937. The cairn had been swept away by a landslide, but the foundation block with the W was intact. A new cairn was built in a more convenient place, 11.6 m nearer to the glacier, and marked WQ.
1939. The distance was measured by an Englishman, Mr. David Linton. He recorded an advance of 0.3 m. Total retreat 1903—54, 243.7 m.

Nordre Illåbre.

1933. Øyen's two cairns from 1902 were found, one marked with an A.
1934. A new cairn was built, 220 m from A, and marked with a white W. A cairn for the fixing of the line of direction was built, 20 m behind cairn W.
(1953. Another cairn was built, 73 m from W.)
Retreat 1902—54, 448.1 m.

Søre Illåbre.

1933. Øyen's cairns (1902) were found, one marked ARE. A new cairn was built, 198.8 m from ARE (ARE = Amund Rasmussen Elveseter.)
1934. This cairn was marked with a W.
Retreat 1902—54, 534 m.

Storbreen (in Leirdalen).

1933. Øyen's cairns were found, one marked X.
1934. A new cairn, marked W, placed 262.8 m from cairn X and nearer to the glacier, in the same line of direction.
1935. The front line of the glacier and a whole system of moraines were surveyed with a tachymeter.
1936. Moraines plotted on the preceding year's map.
1940. Photogrammetric survey of glacier and moraines.
1941. A new cairn was built 180 m from cairn W.
1948. Another cairn had to be built, 166 m from the last mentioned. The old direction line now passed clear of the glacier, and had to be changed.
Total retreat 1902—54, 706.6 m.

Veslbreen (in Leirdalen).

1933. Øyen's cairn was found, but an element of doubt was involved, as the top stone, marked ARE, was lost.
1934. This top stone was now recovered, and a new cairn was built, 100 m nearer to the glacier, and marked W.
1935. Tachymetric survey of front line and moraines.
1940. Stereo-photogrammetric mapping of the glacier tongue and the moraines.
1943. A torrent had swept away all cairns, leaving only bare rock.
No further measurements have been carried out.

Fig. 26. Leirtjønnbreen and Smørstabbtindene. (Photo: Widerøe, Aug. 1947.)

Bøverbreen.

1936. Øyen's cairns from 1903 were found. A new cairn was built 166.6 m from the old cairn, nearest to the glacier.
1937. Part of the front line was surveyed with a tachymeter.
1938. A white W was painted on the cairn.
1945. The cairn had tumbled down.
1946. The cairn had been rebuilt in the wrong place.
1947. The cairn was now placed in the correct position.
1948. The line of direction now passes outside the front of the glacier, and a new line had to be fixed.
Total retreat 1903—54, 404.2 m.

Leirtjønnbreen (Leirbreen).

1936. Øyen's cairns from 1909 were found.
1937. The front line of the glacier was surveyed with a tachymeter, and a new cairn was built 45 m from Øyen's cairn, and nearer to the glacier, marked with a W.
1939. Another cairn was built 40 m nearer the glacier.
1948. Liestøl put up a cairn, 270 m from cairn W.
(That is, 185 m from the cairn built in 1939.)
Retreat 1909—52, 338.9 m.

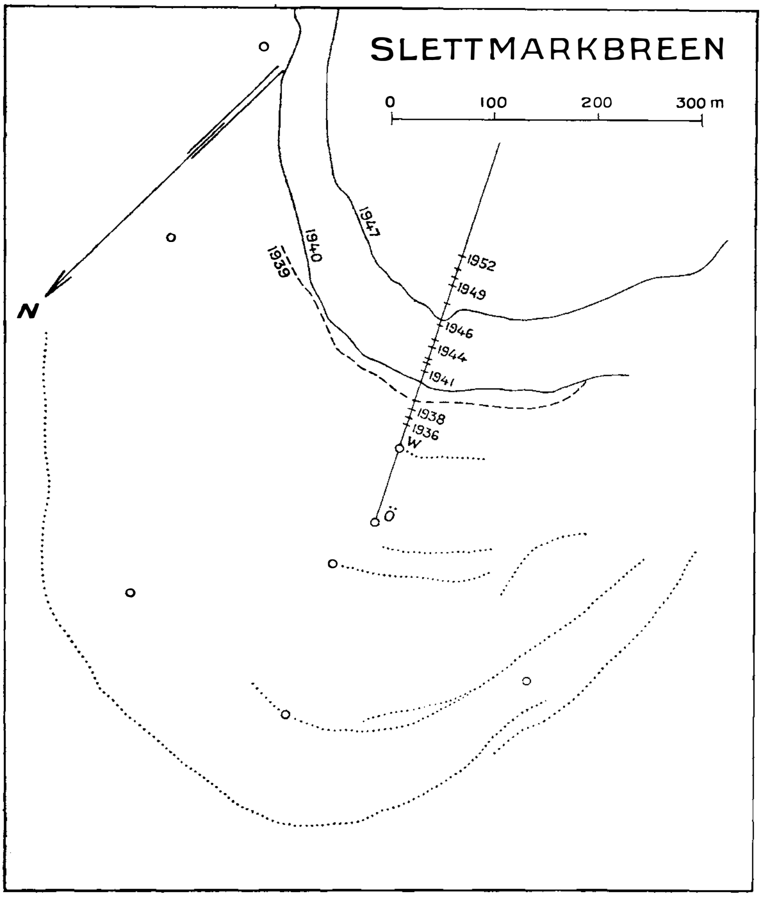


Fig. 27. Tachymetric map of the moraines (dotted) and the front of Slettemarkbreen. The outermost moraine probably dates from ca. 1750.

Slettemarkbreen.

1936. Øyen's cairn, marked with a cross, was found, and a new cairn was built on a high moraine wall, 64.3 m from Øyen's nearest cairn.
1938. This cairn was now marked with a W.
1939. Tachymeter survey of glacier front and moraines.
1943. Cairn tumbled down, but put up in the same place.
1947. Tachymetric survey of front and moraines.
Retreat 1902—54, 265.9 m.

Langedalsbreen.

1936. Øyen's cairn from 1902 was found, a tall stone slab marked with a cross. A new cairn was built, 61.4 m nearer to the glacier.
1938. A white W painted on the new cairn.
Retreat 1902—54, 175.8 m.

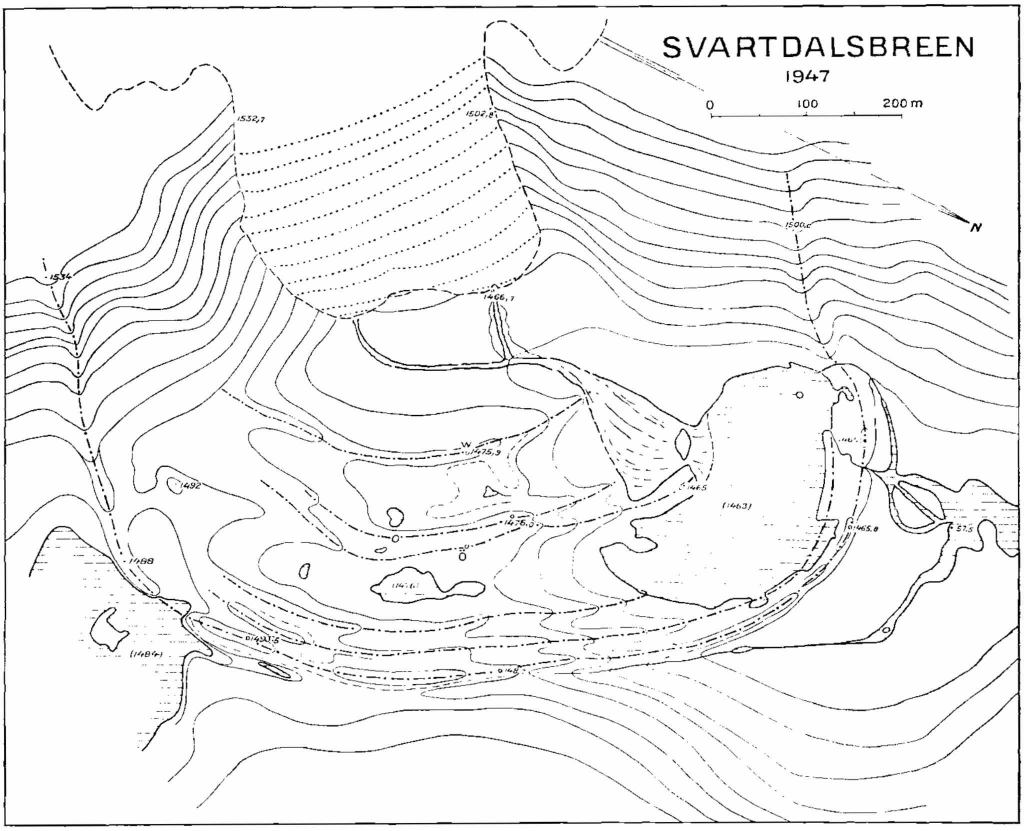


Fig. 28. Tachymetric map of the moraines in front of Svartdalbreen. Note the little lake which is dammed by the outermost moraines (1750?). The moraine ridge nearest to the glacier with the point "W" represents the advance about 1925. Contour interval 5 m.
(O. Liestøl.)

Svartdalsbreen.

1936. A cairn was found on a high moraine wall, presumably Øyen's from 1902.
A new cairn was placed 98 m nearer to the glacier, on a moraine.
1938. A W painted on the new cairn.
1939. The cairn had fallen down, but the slab with the W was found. and the cairn put up in the same place.
1947. Glacier front and moraines were surveyed with a tachymeter. Retreat 1902—54, 285.9 m.

Sandelvbre, Leirungsbreen, Blåbreen (Blåtjønnholsbreen).

At these glaciers it was impossible to find Øyen's cairns; new ones were built, but no further measurements have been made.

Austre Memurubre.

1936. Øyen's cairns from 1902 were found, on two huge blocks, 63 m apart. A new cairn was built 381 m nearer to the glacier, and marked with a W.

1945. The cairn could not be found.

1948. The cairn had fallen down, but was found again this year. Liestøl built a new cairn, 330 m from W.
Retreat 1902—54, 844.2 m.

Vestre Memurubre.

1936. Øyen's cairn from 1902 was found, and a new one was built 123.5 m nearer to the glacier, and marked with a W.

1939. A raging torrent along the front of the glacier made measurements impossible.

1943. During a cold spell the river had shrunk so much that it could be crossed; a new cairn was built on a big boulder, 80 m from cairn W. One more cairn was built by Liestøl in 1951; the line of direction had to be changed, as the former line now passed clear of the 'snout' of the glacier.
Retreat 1902—50, 697.5 m, and 1951—54, 66.4 m.

Veobreen.

1937. Øyen's four cairns were found, and a new one was built 168.9 m nearer to the glacier, in the same line. But after an exceptionally heavy rainfall in the autumn of 1938 the river overflowed its banks, and the new cairn was swept away. No subsequent measurements have been made.

Hellstugubreen.

1928. Øyen's cairn from 1901 was found. The glacier has been surveyed, mapped and measured every year, and from 1933 the work was extended to measurement of flow and ablation, and in addition the accumulation of snow has been determined for several years. See text.
Retreat 1901—54, 441.3 m.
In 1939 a limnigraph was set up in the Hellstugu stream and apart from a few interruptions the apparatus funktioned until September 1946.

Tverråbreen.

Øyen's cairn from 1901 was found in 1927. This glacier, too, has been surveyed, measured and mapped every year, and from 1938 regular measurements of accumulation have been carried out, in the early summer.

Retreat 1901—54, 511.6 m.

Svellnosbreen.

1927. Øyen's cairn was found, on a high moraine wall. This glacier has also been surveyed and mapped many times. The upper basin, however, has not been mapped. The glacier has shrunk considerably, and the tongue is hanging in shreds on a steep cliff.

SPECIAL INVESTIGATIONS ON HELLSTUGUBREEN AND TVERRÅBREEN

(Mainly based on the observations and computations of Alfred Koller.)

BY OLAV LIESTØL

Survey

For precise determination of the variation, velocity and ablation of a glacier, the first step is to prepare a map on the proper scale, e. g. 1 : 2500, which is much larger than the scale of the maps of the Geographical Survey (1 : 50 000). Accordingly a detailed topographical survey of the glacier and its surroundings had to be carried out.

A base line was measured in Visdalen, and a series of trigonometrical points were fixed by copper bolts. The triangulation was connected to the first order of triangulation of the Geographical Survey. Fig. 92 shows the triangulation net. Thus several permanent, fixed station points at convenient places on both sides of the glacier have been established. From these points photogrammetric surveys could be made, and the necessary points on the glacier surface could be determined in order to measure the velocity and the amount of ablation. For this purpose, a series of points on the surface of the glacier had to be permanently marked (fig. 42). Vertical holes were bored into the ice, in which canes were placed, with hooks at the lower end, and projecting somewhat above the surface. The positions of these holes were determined by intersection from two stations (32 and 40 at Hellstugubreen). For the determination of the lowest situated points a third station (33) was also used. The surveyor had an assistant who placed a distance rod over the centre of the hole. For the farther points the error will probably amount to ± 8 cm, for the nearest ± 3 cm. The difficulty in determining and marking the centre of the bore holes must also be considered. The holes will expand by melting, sometimes as much as 20 cm in diameter, and this expansion is not always concentric. Fixing the centre is, therefore, often done at random, but normally the error will not exceed ± 2 cm.

The sources of error are about the same for measurements in the horizontal and vertical plane. Evaluation of the error in height measurements is vital for determining the directions of the stream lines in the vertical plane.

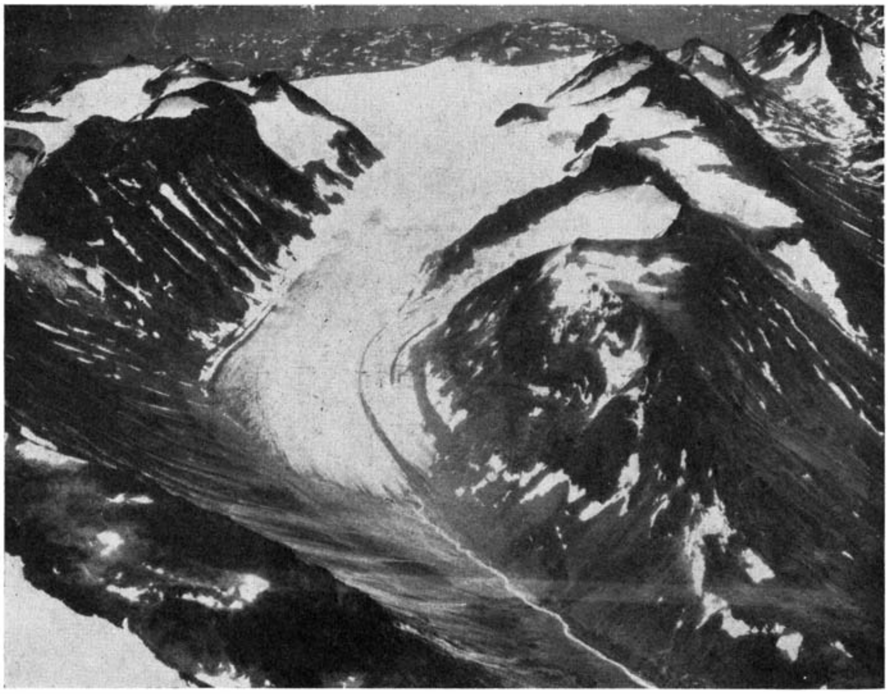


Fig. 29. Hellstugubreen. (Photo: B. Luncke, Norsk Polarinstitutt, Aug. 1955.)

Observations have been made twice a year, but the dates of observation have varied somewhat from year to year. It has also been impossible to measure all the canes in one day; but the series of observations have been referred to the same date by interpolation.

ABLATION

In 1937, 41 stakes were drilled into the surface of the lower part of Hellstugubreen. These were to be used both for measuring glacier flow and ablation. The amount of melting was determined by measuring the part of the canes which protruded above the surface.

Fig. 30 shows the ablation in relation to altitude for some selected measuring periods. In fig. 31 the curves represent the ablation during two extreme summers, as well as the annual mean value for melting during the period 1937—44.

There is a marked difference between the curves for the autumn months and those representing the whole year, fig. 31. The reason is that the curves show only the melting of the actual ice. This does not begin until the snow cover is melted off, a date depending upon the altitude. This is plainly demonstrated by the curve for the melting between September 16th, 1940, and July 24th, 1941, which in the main represents the melting during the early summer of 1941, when the winter snow gradually disappeared from the glacier tongue.

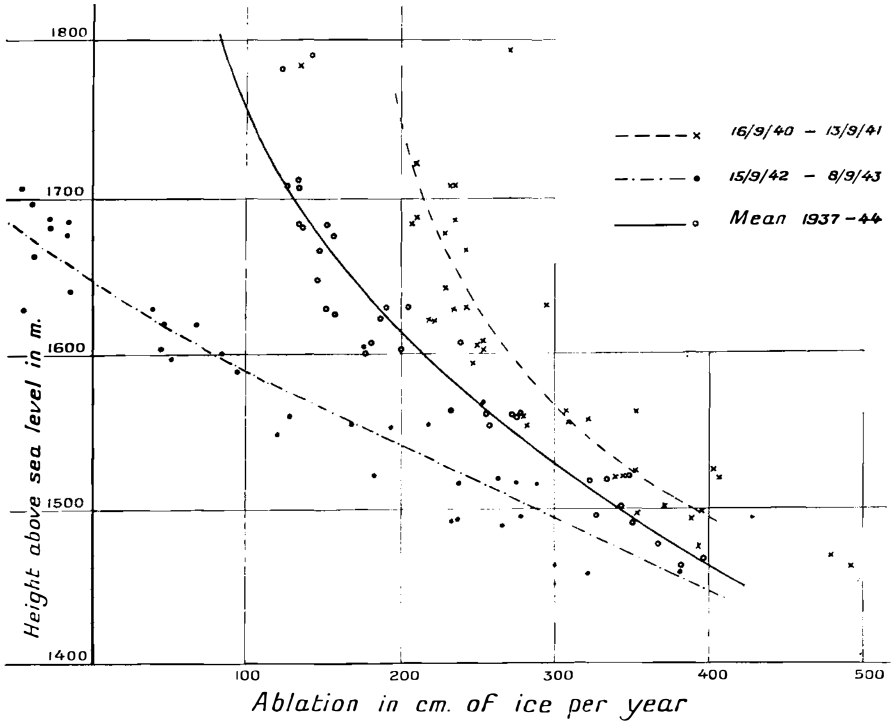


Fig. 30. Ablation of ice (on Hellstugubreen) during two extreme summers. The low ablation of 1943 is mainly due to the extremely high accumulation of the preceding winter. The unbroken line represents the annual mean value for the whole period 1937—44.

The points representing the different observations of the ablation are rather widely scattered. This may partly be due to the uneven accumulation of snow; at some places the winter snow has been totally swept away, thus exposing the glacier ice. Darker bands in the glacier ice will also melt more rapidly than white bands (fig. 32). On Hellstugubreen this effect is very conspicuous — dark narrow longitudinal grooves are separated by white ridges.

The curves of the mean annual ablation indicate that the firn line lies at an altitude of more than 1800 m for this interval of time, possibly as high as 2000 m. The curve showing the distribution of areas at different altitudes, fig. 33, shows that the centre of gravity of the glacier surface lies about 1850 m above sea level. Later researches at Storbreen, where the distribution curve greatly resembles that of Hellstugubreen, have led to the conclusion that the centre of gravity of the surface must be situated above the average firn limit, if the glacier is to maintain its equilibrium. The years from 1937 to 1946 must, therefore, have been a period of deficit for Hellstugubreen as a whole. The curve showing the

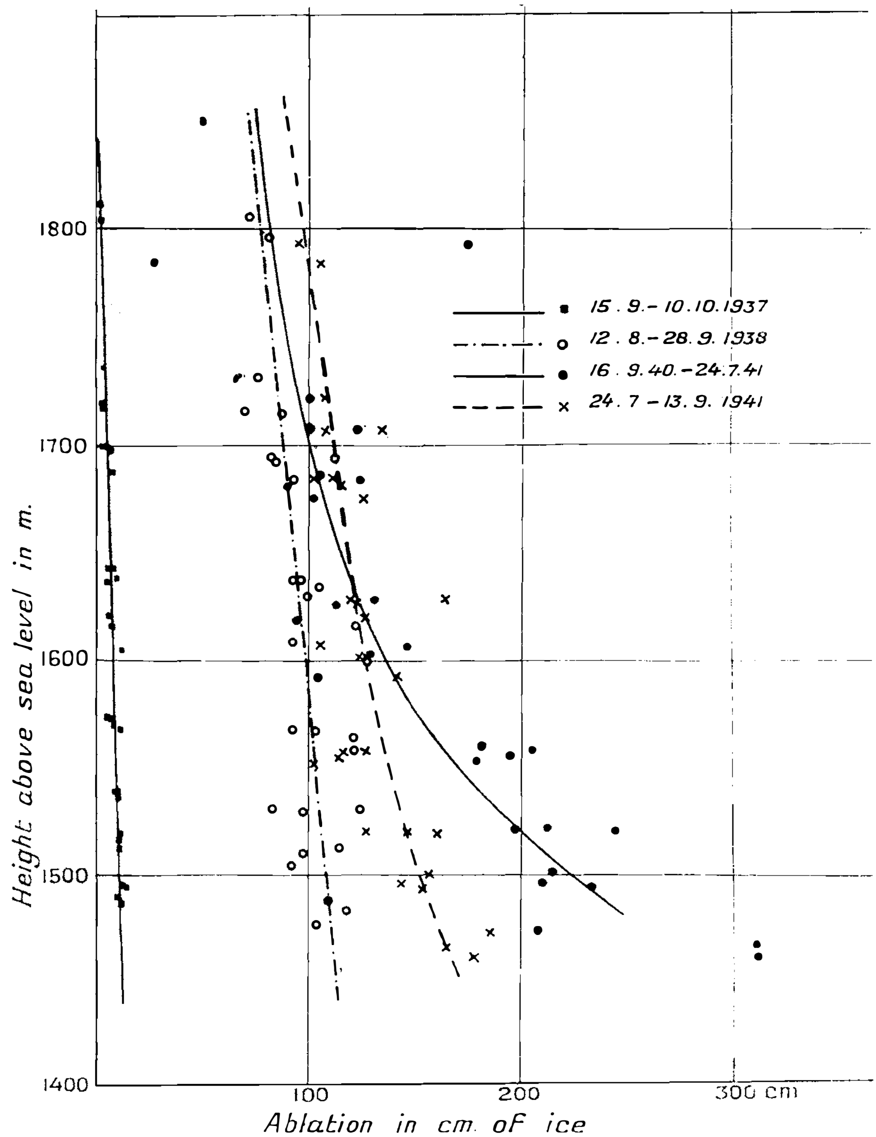


Fig. 31. Ablation of ice on Hellstugubreen in relation to altitude for some selected periods.

distribution of areas in different altitudes also reveals how sensitive this glacier must be to climate variations. A shifting of the firn limit of about 100 m will disturb the entire balance considerably.

FLOW MEASUREMENTS

Hellstugubreen is not a very active glacier, the maximum flow does not exceed some 6 cm per day, and the observed velocities are often less

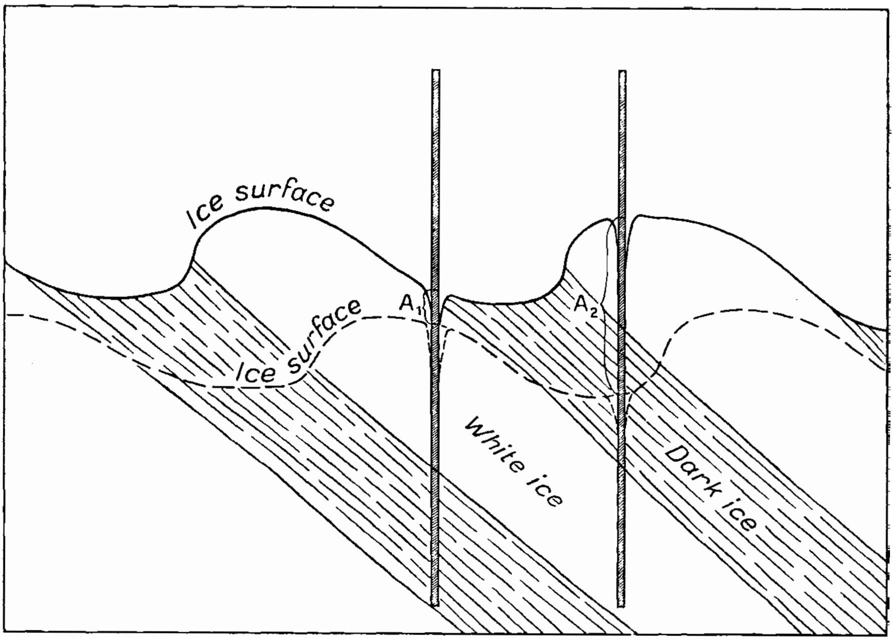


Fig. 32. The effect on ablation caused by different albedo of inclined layers. Measurement on the two stakes will give a different value for the ablation in the same time interval.

Table II.

1937	15/9 — 10/10
1938	12/8 — 28/ 9
1939	4/8 — 18/ 9
1940	13/8 — 16/ 9
1941	24/7 — 13/ 9
1942	29/7 — 15/ 9
1943	8/9
1944	13/8 — 5/ 9
1945	3/9
1946	27/9

than the errors of observation. The tongue, however, has a very regular shape and the flow may be expected to be fairly regular. Unfortunately the observations have not been made at the same date every year.

In table II are stated dates of measurements for the different years. With the exception of the years 1943, 1945 and 1946, there are two sets of observations for each year, with an interval of about 1½—2 months, one in late summer, the other in September, when the snow line is highest. There is a difference between the average flow of the two periods — the summer flow being the greater. This phenomenon has been known ever since the beginning of the measurements of glacier flow.

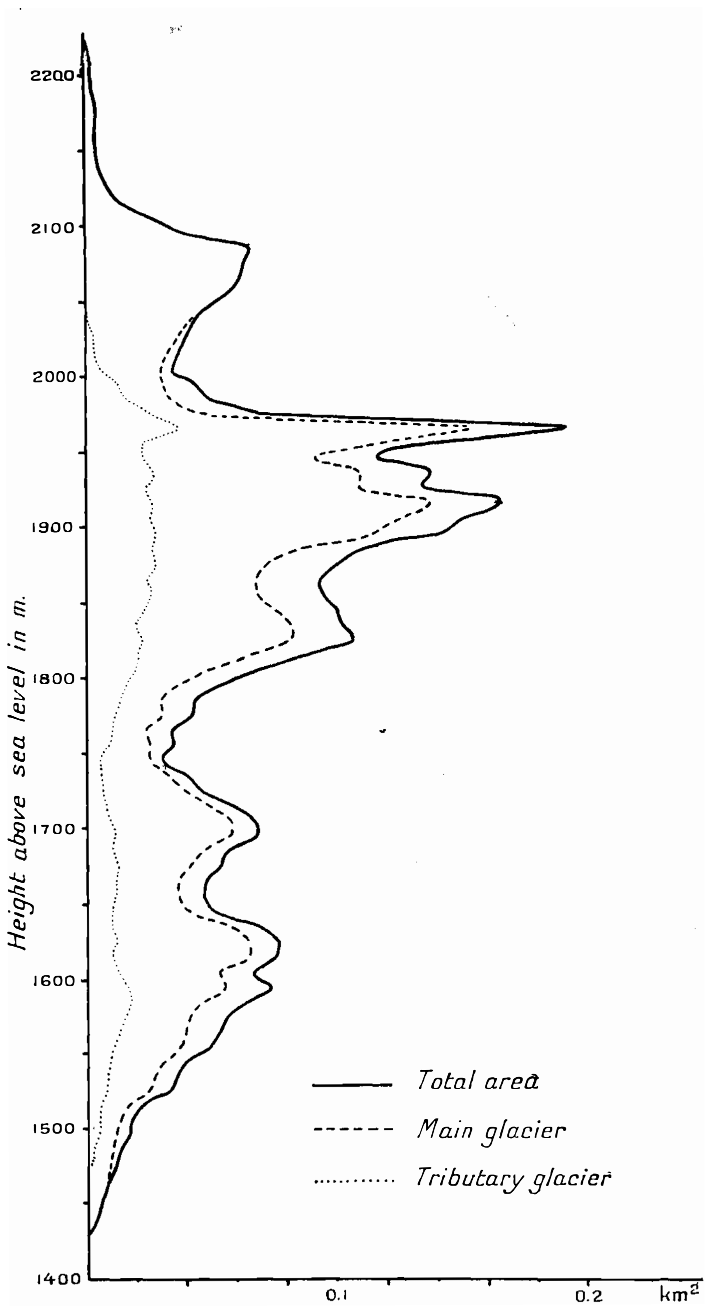
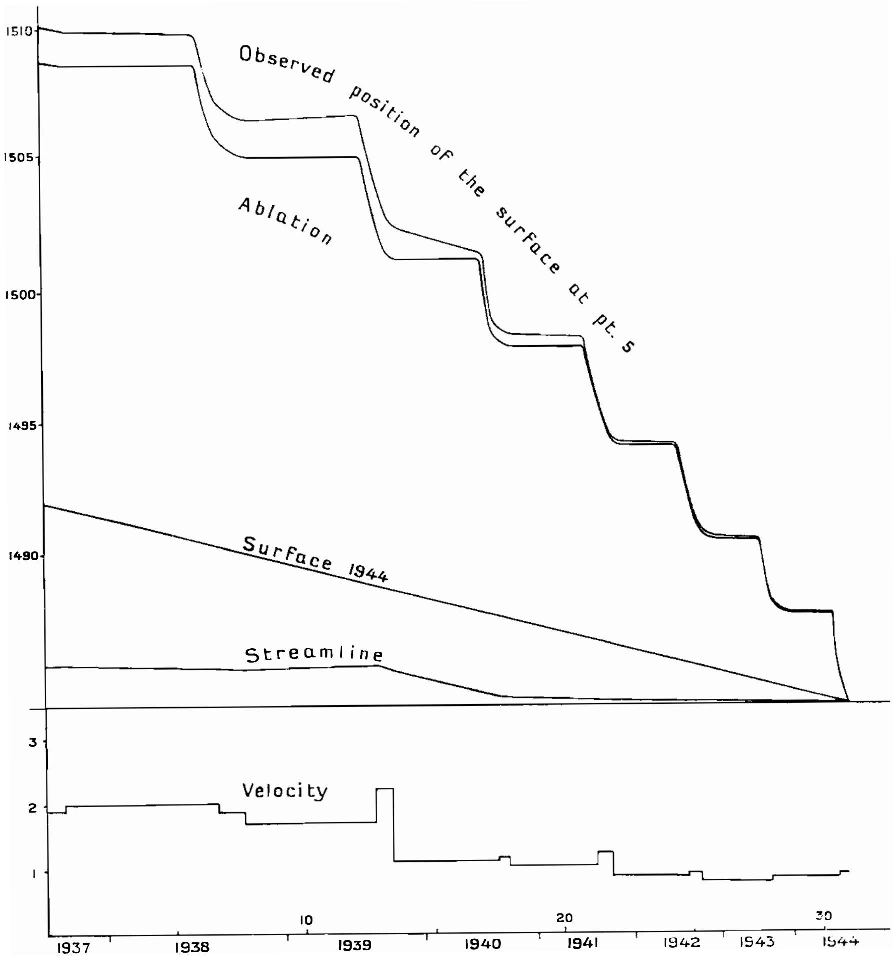


Fig. 33. Area distribution curve of Hellstugubreen. The horizontal scale represents the area for every 10 m altitude.



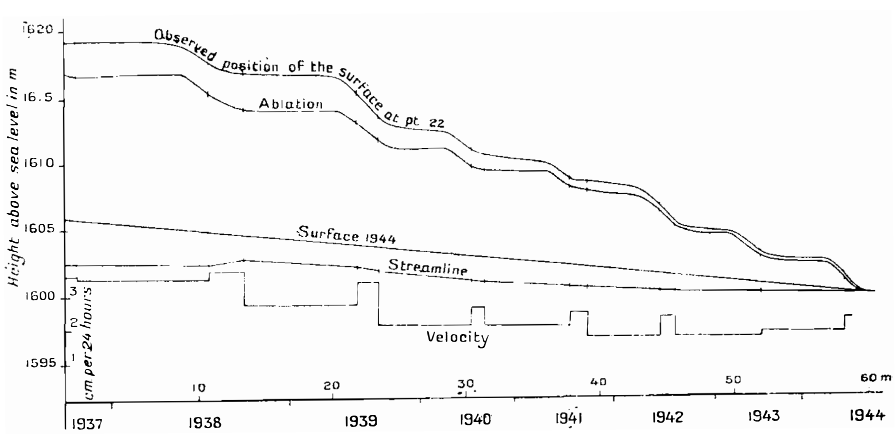


Fig. 34. Digram showing ablation and flow measured at stakes 5 and 22. Note the higher summer flow rate.

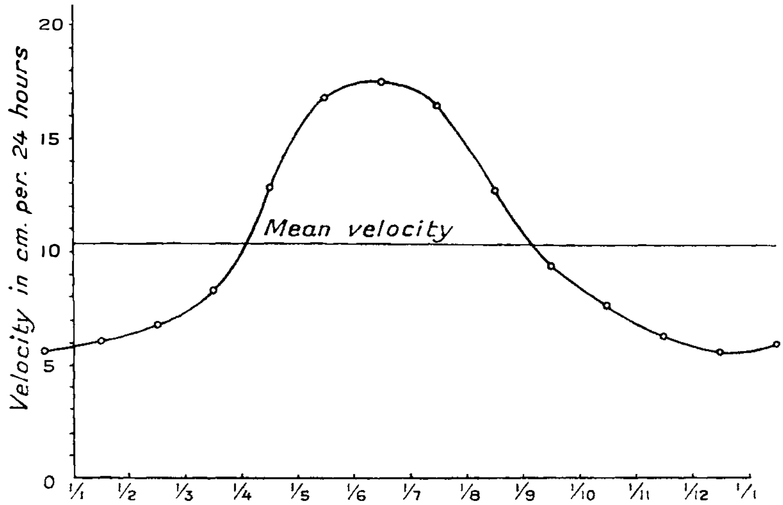


Fig. 36. Diagram showing mean fluctuation in flow rate of the tongue of Ober Grindelwald Gletscher through one year. The curve has been computed by the author from a continuous series of 5 day observations by O. Lütschg in the years 1921 to 1928.

Investigations by O. Lütschg (1932) on the Ober Grindelwald Gletscher (Switzerland) have shown that the flow is variable during the year, the maximum summer velocity being more than three times the minimum velocity in winter, fig. 36.

Such detailed studies have not been made at Hellstugubreen, but the averages for the year 1938—39 and 1941—42 show the flow in the winter period to be 73 and 83 per cent of the flow of the preceding and following summer periods, respectively.

A more continuous series of observations would no doubt show considerably greater deviations from the mean.

The difference between summer and winter velocities seems to be independent of the altitude, contrary to results obtained by measurements of alpine glaciers, where this difference decreases with the altitude.

For the explanation of this difference between summer and winter flow, several theories have been proposed. The surface layers are frozen to a solid shell during the winter, with a decrease of plasticity and flow. The effect should be largest where the glacier is thinnest — but no such evidence can be found. The water content of the glacier tongue is larger in summer, causing a higher plasticity and an easier flow. Measurements on the Ober Grindelwald Gletscher, however, show that the velocity is highest in June — but in that month the melting of the snow has scarcely begun! A reasonable explanation may be that the accumulation of winter snow in the upper regions of the glacier will lead to an increase of the total thickness in this part, leading to a corresponding increase in the velocity above the firn line. This increase is transplanted downwards

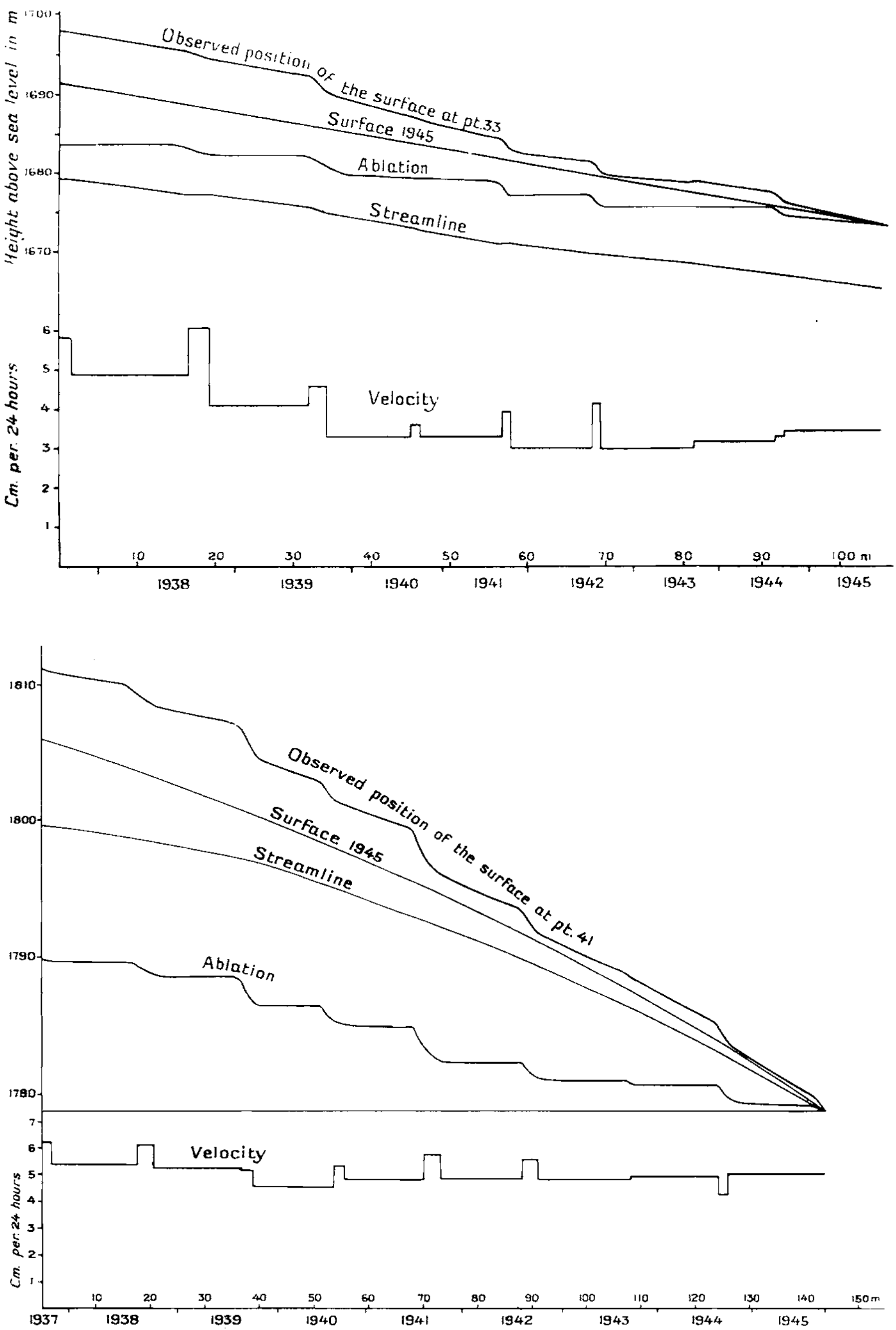


Fig. 35. Diagram of ablation and flow measured at stakes 33 and 41. Note the increase in flow rate and glacier thickness in the years 1943 and 1944.

along the glacier, like a wave, and reaches the lower parts of the tongue in spring and early summer.

In order to test this assumption, series of observations would have to be made along the entire glacier, and throughout the year. But no such measurements have ever been made, and would be very difficult to carry out.

In fig. 37 the lines of equal velocity (isotachytes) have been drawn for the year 1942. The picture would be much the same for another year, but there might be wide difference in the absolute values, especially as regards the lower parts of the glacier. At "cane 17", for instance, the velochy decreased by 40 per cent from 1937—38 to 1939—40, fig. 40.

In general the flow decreased rapidly during the first years of observation; but later on it increased. Apparently this increase has taken place in two waves, starting in the higher parts of the glacier, and proceeding down along the tongue. One wave made its appearance in 1940, but cannot be traced farther down than to 1650 m above sea level, the other wave appeared in 1943, and the subsequent year it had travelled almost to the very front of the tongue, fig. 38.

S. Finsterwalder (1901) has recorded similar waves on the Vernagt Ferner in Tirol. Finsterwalder (1908) also gives a theoretical explanation of the phenomenon.

The increase in velocity in the period 1943 to 1944 may be caused by the unusually large accumulation of snow during the winter 1942—43.

TRANSPORT OF MATERIAL

It is difficult to extract from the data at hand any reliable values for the "regime" and transport of material at Hellstugubreen because the measurements cover only the glacier tongue, that is about 40 per cent of the entire glacier. There is no record of the accumulation and ablation in the remaining area.

We shall give an explanation, first, of the profile drawn in fig. 43. It is placed along a stream line which goes through cane 6, 17, 22, and 29, between point 9 and 11, 32 and 33, 38 and 39, and a little to the west of cane 41. The surface lines for 1937 and 1944 have been drawn, partly according to photogrammetrical maps, partly from observations of the stakes. The profiles for 1929 and 1948 are plotted from photograms and tachymeter traverses. Included also is a profile of the glacier's maximum expansion. The latter is not very accurate, since it is drawn only by considering the front and side moraines. As an experiment, the bottom profile and the directions of the separate stream lines are drawn in fig. 43. On the surface and near a stake, the direction of the stream lines may be determined with a considerable degree of accuracy, particularly if measurements have been made throughout several years. When a stake is

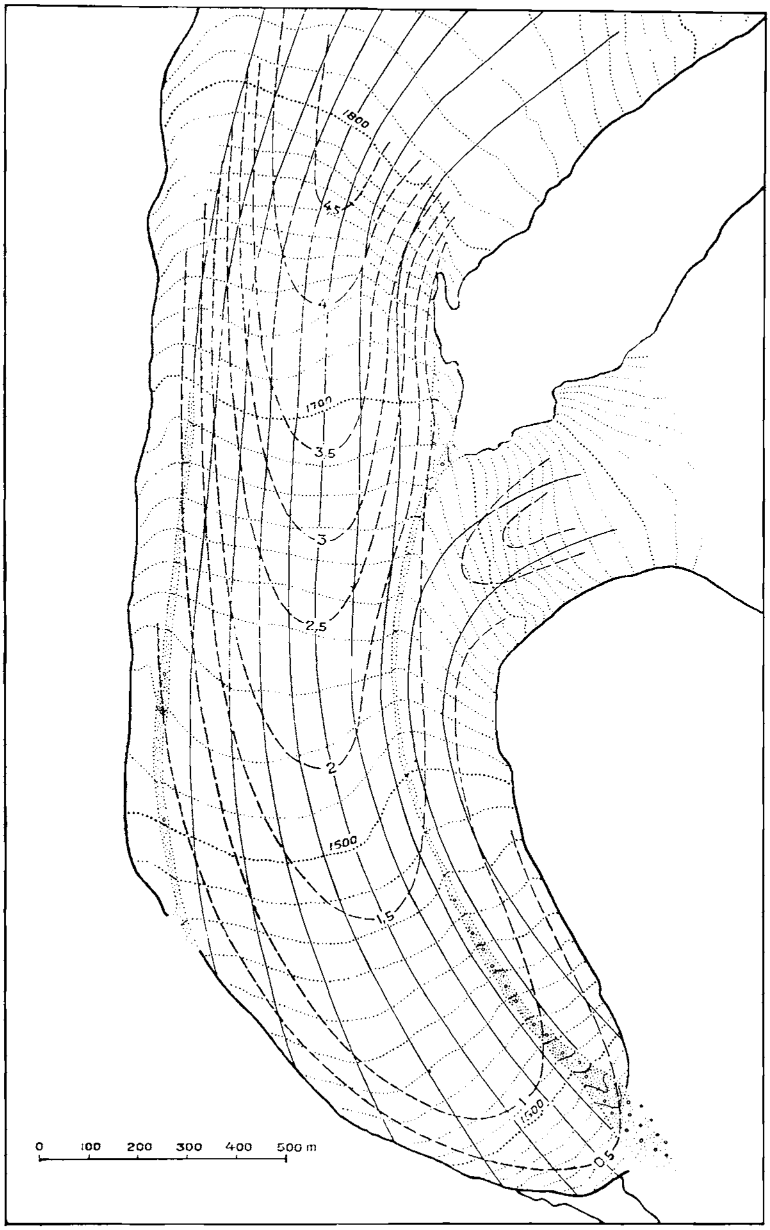


Fig. 37. Map of Hellstugubreen with lines of equal flow (isotachytes) for the year 1942.

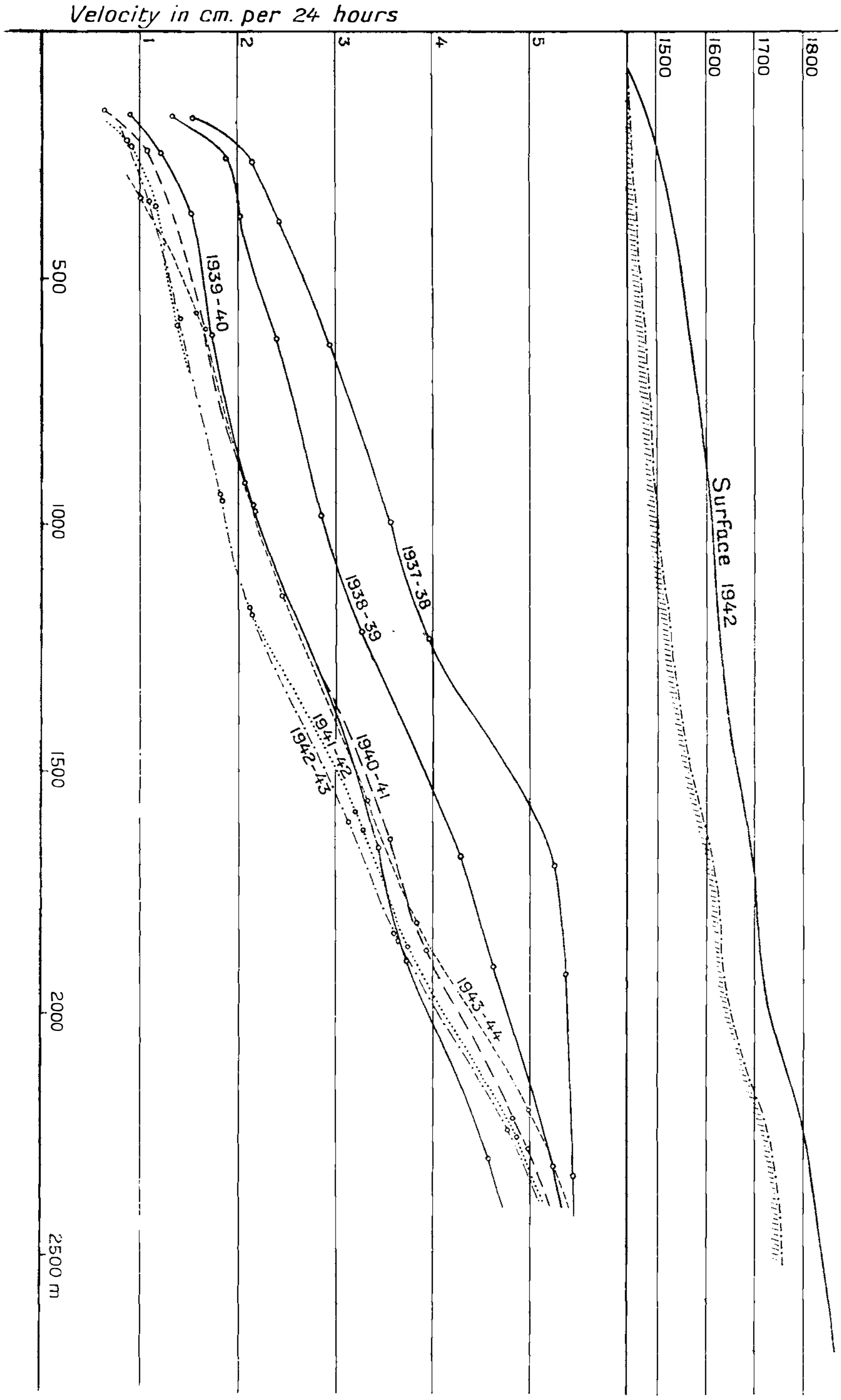


Fig. 38. Longitudinal flow profile and section through the tongue of Hellstugubreen.

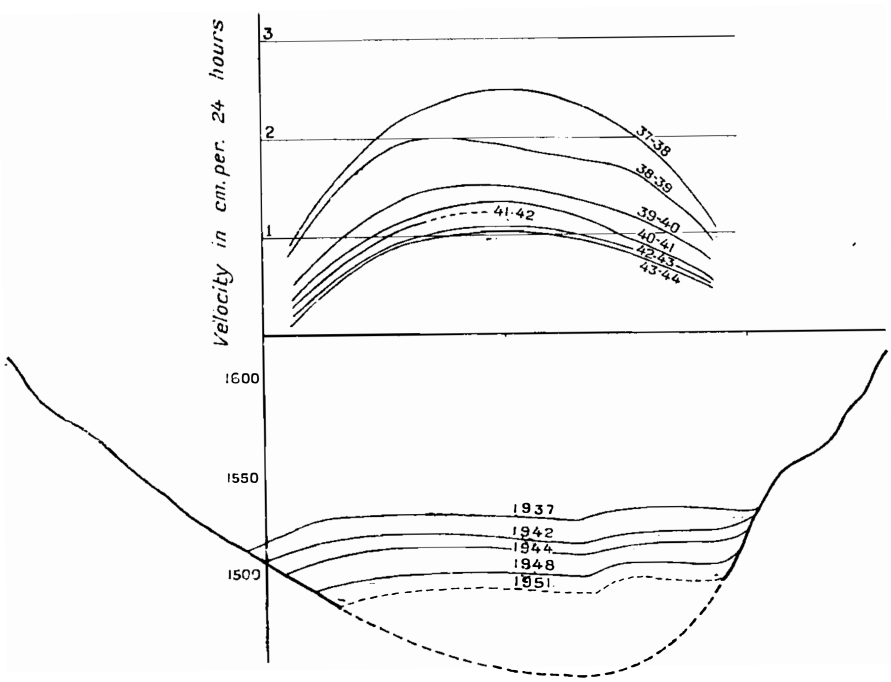


Fig. 39. Flow profile and cross-section of Hellstugubreen through points 8—13, showing variation in flow rate and the height of the ice surface.

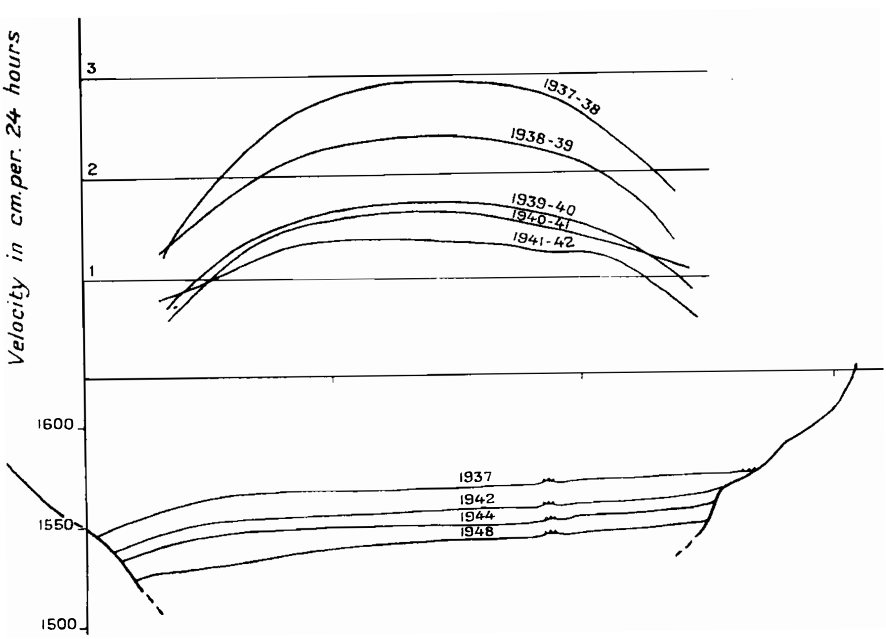


Fig. 40. Flow profile and cross-section of Hellstugubreen through points 14—19

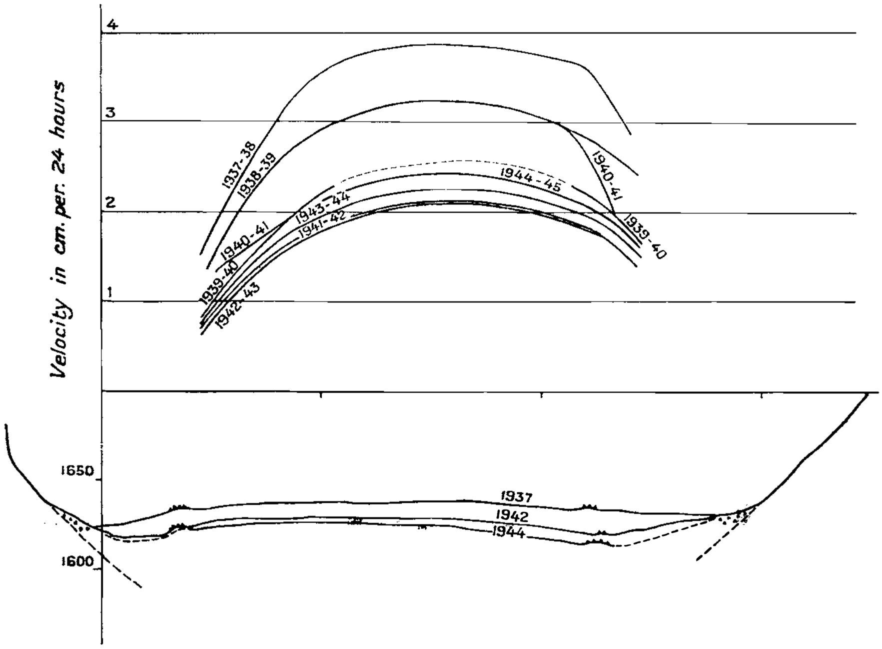


Fig. 41. Flow profile and cross-section of Hellstugubreen through points 27—31.

anchored into the ice, each point on the stake will move in the direction of the stream line. In order to determine the direction of the stream line it is necessary only to triangulate one point on the stake and to repeat the measurements at suitable intervals of time. In fig. 44 α represents the inclination angle of the stream lines, H_1 and H_2, the surface height at the stake, S is the horizontal distance travelled by the stake and β the surface inclination angle. From the figure:

$$\tan\alpha = \frac{\Delta H - A}{S} \quad \tan\beta = \frac{\Delta H - M}{S}$$

Furthermore, $T = S(\tan\beta - \tan\alpha)$ and $T = A - M$. A represents the vertical measured ablation on the stake, M the vertical increase or decrease of the glacier and T that part of the ablation compensated for by the transport of the glacier. When $M = 0$, the glacier is stationary, the ablation is just compensated for by the transport of the glacier. In fig. 26 the stream lines are shown graphically and indicate the average direction of flow for the years 1937—44. The construction is, of course, somewhat hypothetical, but should give some valuable information, for instance as to the depth and transport of the glacier. According to theoretical calculations (B. Weingarten, 1903, W. Werenskiold, 1915, C. Somigliana, 1931, and M. Lagally, 1934) velocity depends on depth according to the formula:

$$D = K\sqrt{\frac{V_0}{\sin\beta}}$$

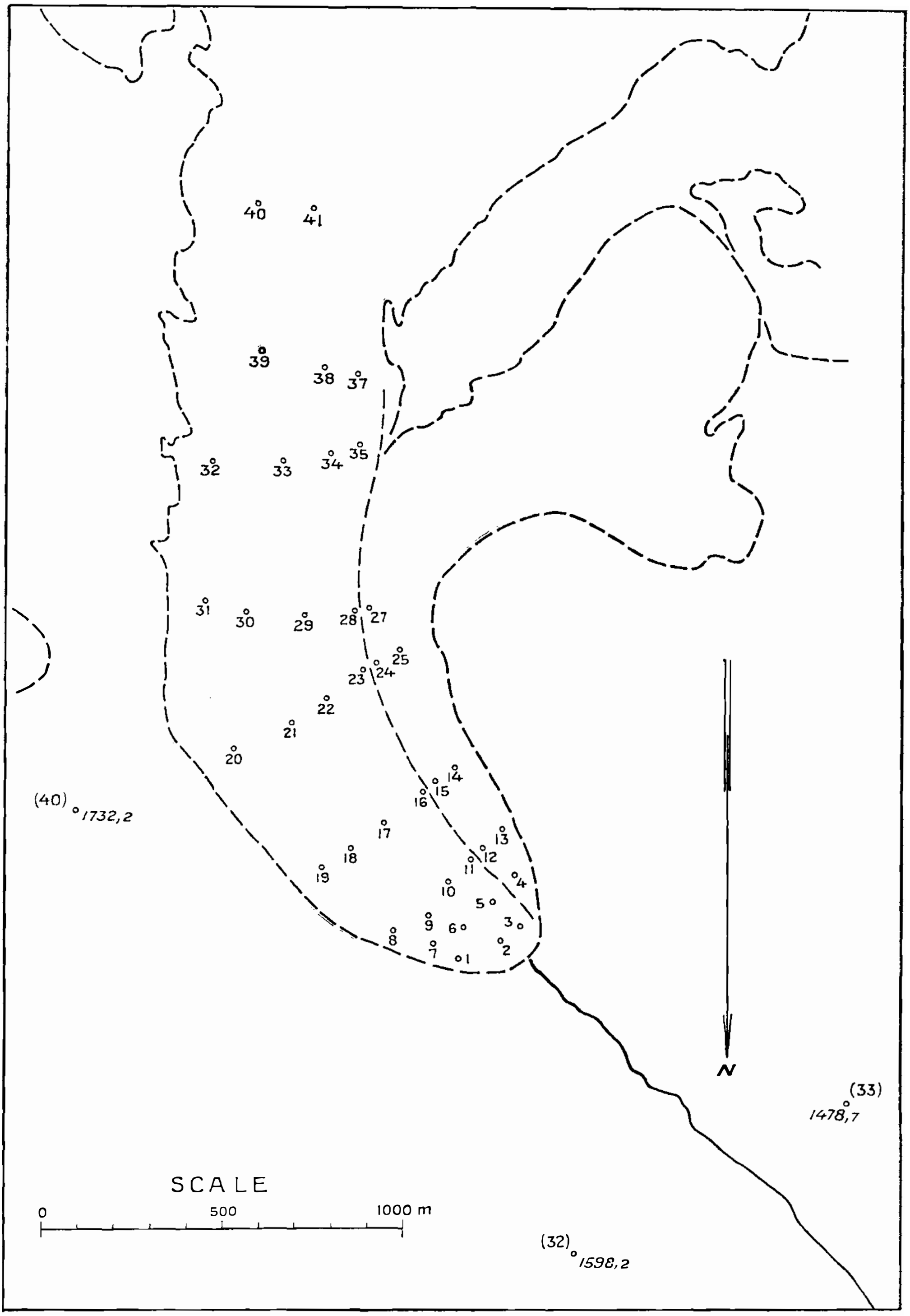


Fig. 42. Map showing the positions and numbers of the stakes on Hellstugubreen in 1938.

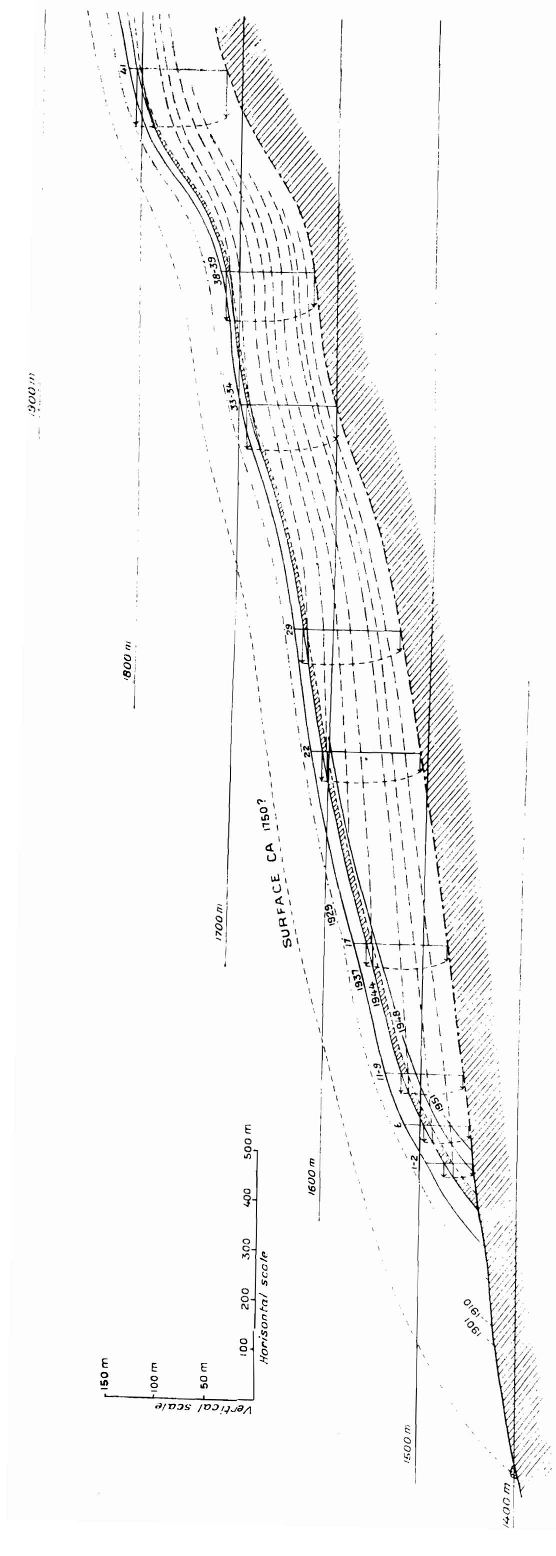


Fig. 43. Profile through Hellstugubreen showing thinning of the tongue, transport of material, stream-lines, computed bedrock surface and some vertical flow profiles.

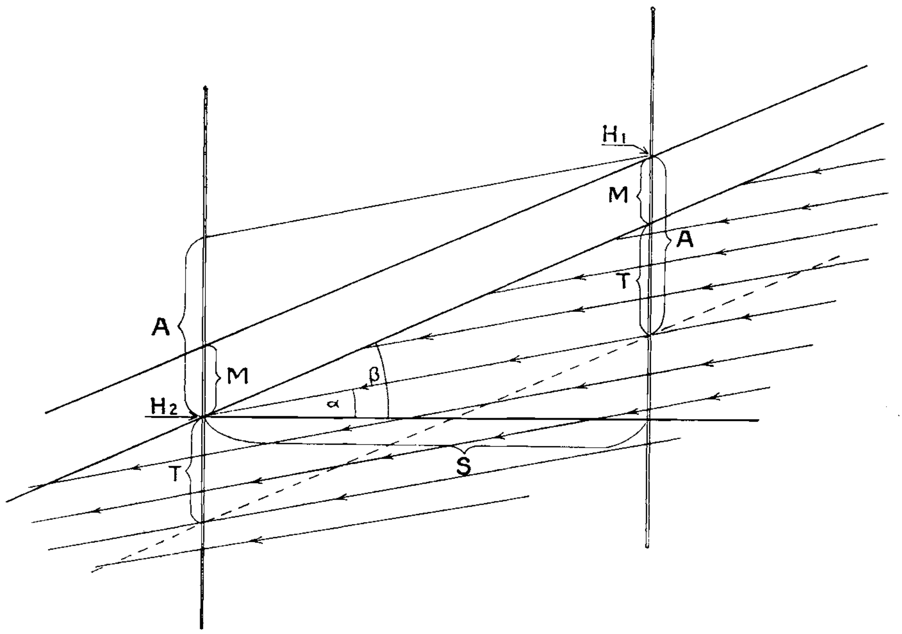


Fig. 44.

where β represents the surface inclination angle, V_0 surface velocity, K a constant and D depth. This formula has often been used for determining the depth of glaciers, and even for drawing depth profiles normal to the direction of the flow. For the following reasons it is evident that such calculations are not completely reliable: First the constant K includes the coefficient for the inner friction which is a variable quantity and very difficult to determine, secondly, the velocity will not be constant even if the depth remains the same. Variations of $\pm$ 50 % in the course of one year seem to be common for most glaciers. The observations at Hellstugubreen yield depth values which appear reasonable. On the other hand, calculations by A. Bergersen of the movement of Engabreen in Svartisen gave depth values that were three times too large. For Bergersen's calculations some old velocity measurements were used from an area which is now entirely free from ice, whereby the previous depth is known. There are, however, on Hellstugubreen, a number of factors which indicate a connection between velocity and depth. Examining, for instance, fig. 18, it is seen that the velocity at cane 33 decreased during the first year, and that the glacier at the same time has decreased in thickness. In 1943 and 1944 the thickness increases again, and the velocity as well, but in 1945, however, the situation was reversed.

Through each section normal to the flow of a stationary glacier tongue there must be transported the same amount of ice that melts away below. If the transport falls short of the melting, as is the case with Hellstugubreen, the glacier will decrease, and the decrease will equal melting minus transport. Consider a plane normal to the glacier flow and limited by the surface and the bottom of the glacier, fig. 45. In unit time the volume transported between two vertical planes through stream lines that are a distance b apart is then:

$\int_0^D b\, v\, dz$ or $b\, D\, \bar{v}$ where $\bar{v}$ is the average velocity between the surface and the bottom. In the time t the total volume transported is $t\, b\, D\, \bar{v}$. In a stationary glacier the total volume transported through the plane must also equal $\int_0^L b\, A\, dx$ = the ablation on the distance L from the plane to the end of the glacier.

$$\text{Therefore:} \qquad \int_0^L b\, A\, dx = bt\, D\bar{v}$$

With a glacier that is not stationary:

$$\int_0^L b\, T\, dx = \int_0^L b\, (A - M)\, dx = b\, t\, D\, \bar{v}$$

The integral can be evaluated because A, M and L can be measured. Then the product $D\, \bar{v}$ is known, but not D and $\bar{v}$. Knowing the surface velocity, an average value of the velocity can be found by assuming that the vertical distribution of the velocity corresponds to the distribution which has been derived from observations of alpine glaciers (Perutz 1950). Thus the depth D at the profile under consideration can be found. On the other hand, when knowing the depth, the average velocity from the surface to the bottom can be found. No depth measurements have so far been carried out on Hellstugubreen. By using a value for the depth that seems reasonable in relation to the shape of the valley sides bordering the glacier, the average velocity is found to represent ca. 90 % of the surface velocity. If this is true, extrusion flow is not possible in this part of the glacier. When applying the above formula it must be assumed that b remains constant. Observations prove this to be true at the surface. The absence of twisting movement in the glacier must also be assumed. In a non-stationary glacier, L and D are not constant, and average values must be used. For the profile in fig. 43 the depth D has been calculated in such a manner that area inside the velocity distribution curve for each cross-sectional profile equals the measured supply below (shaded area).

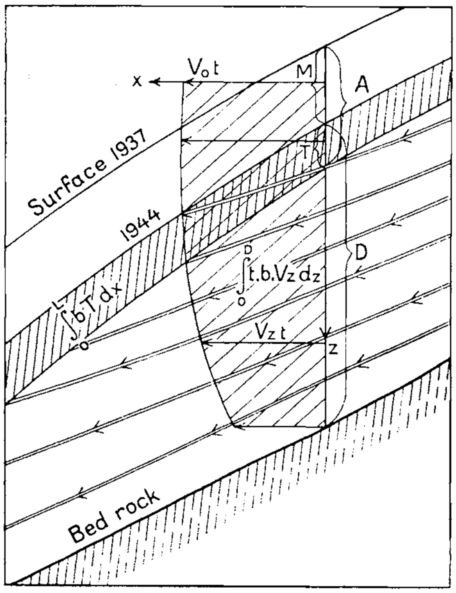


Fig. 45.

It may be of interest here to calculate the transport throughout a cross-section during the years 1937—44. Selecting, for instance, a cross-section 1 m wide at cane 38—39, one finds by means of a planimeter that the shaded sections in fig. 43 represent a volume of 8600 m^3. Thus this volume was transported downwards by the glacier flow. The ablation, on the other hand, amounted to about 31 000 m^3, meaning that the transport accounted for only *28 per cent* of the volume of ice required to maintain the glacier at equilibrium. Therefore, it stands to reason that the glacier front receded rapidly during the period.

The transport capacity of a glacier depends on the flow and the area of the cross-section. Both these features, in turn, depend upon depth. Suppose that the area of the cross-section and velocity of flow are approximately proportional to the thickness of the glacier and the square of the thickness, respectively. The transport capacity, then, is proportional to the third power of the thickness. If the glacier tongue begins to decrease during a warm period, the thinning is much more rapid in the lower parts than the increased melting might indicate.

The effect of this phenomenon is noticeable with most of our glaciers: The decrease is always larger in the lower part and gradually becomes smaller in the higher parts. At the upper part of the firn area there is hardly any decrease at all.

A periodical variation is also possible, even in a comparatively constant climate — approaching the conditions present on the Spitsbergen glaciers, though to a lesser degree. Theoretically it would be hard to explain this effect adequately, though it may be possible on the basis of S. Finsterwalder's explanations in the treatise above mentioned.

VARIATIONS IN THE LENGTH OF GLACIERS

In 1901, P. A. Øyen, of the Geological Museum of the University, Oslo, began his observations of glaciers in Jotunheimen.

Øyen's observations were discontinued in 1912 for lack of funds. In 1933 W. Werenskiold resumed this work.

The measurements were made once a year, ordinarily towards the end

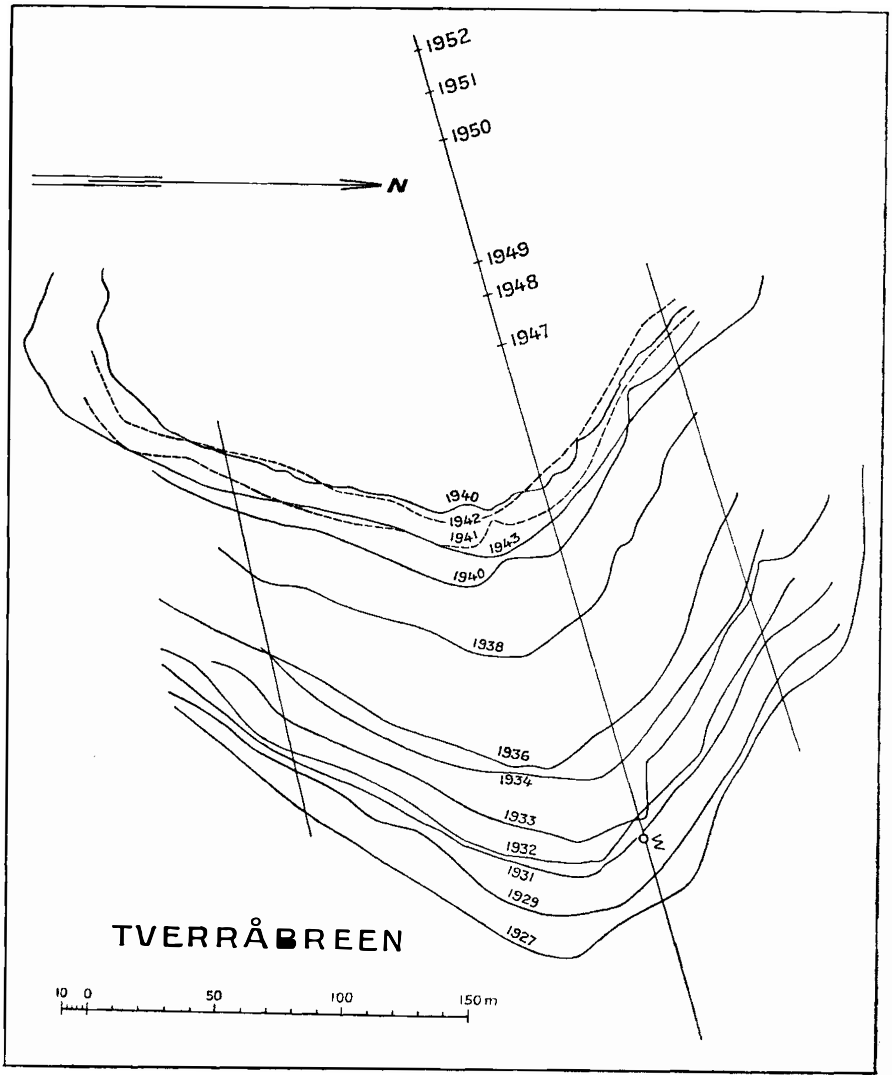


Fig. 46. Frontal retreat of Tverråbreen. The line in the middle represents the sigthing line along which the variation in length has been measured.

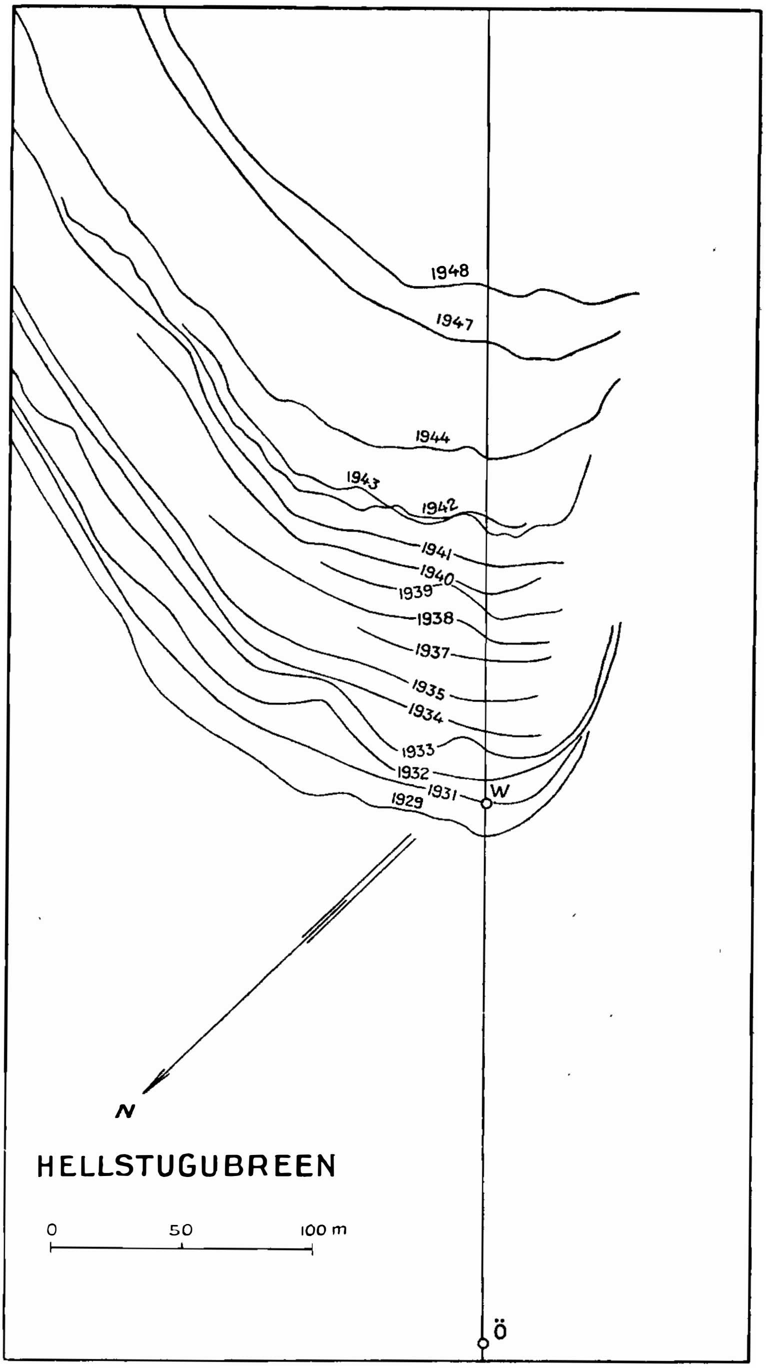


Fig. 47. Frontal retreat of Hellstugubreen. Points marked Ø and W indicate the cairns erected by Øyen and Werenskiold in the years 1901 and 1933, respectively.

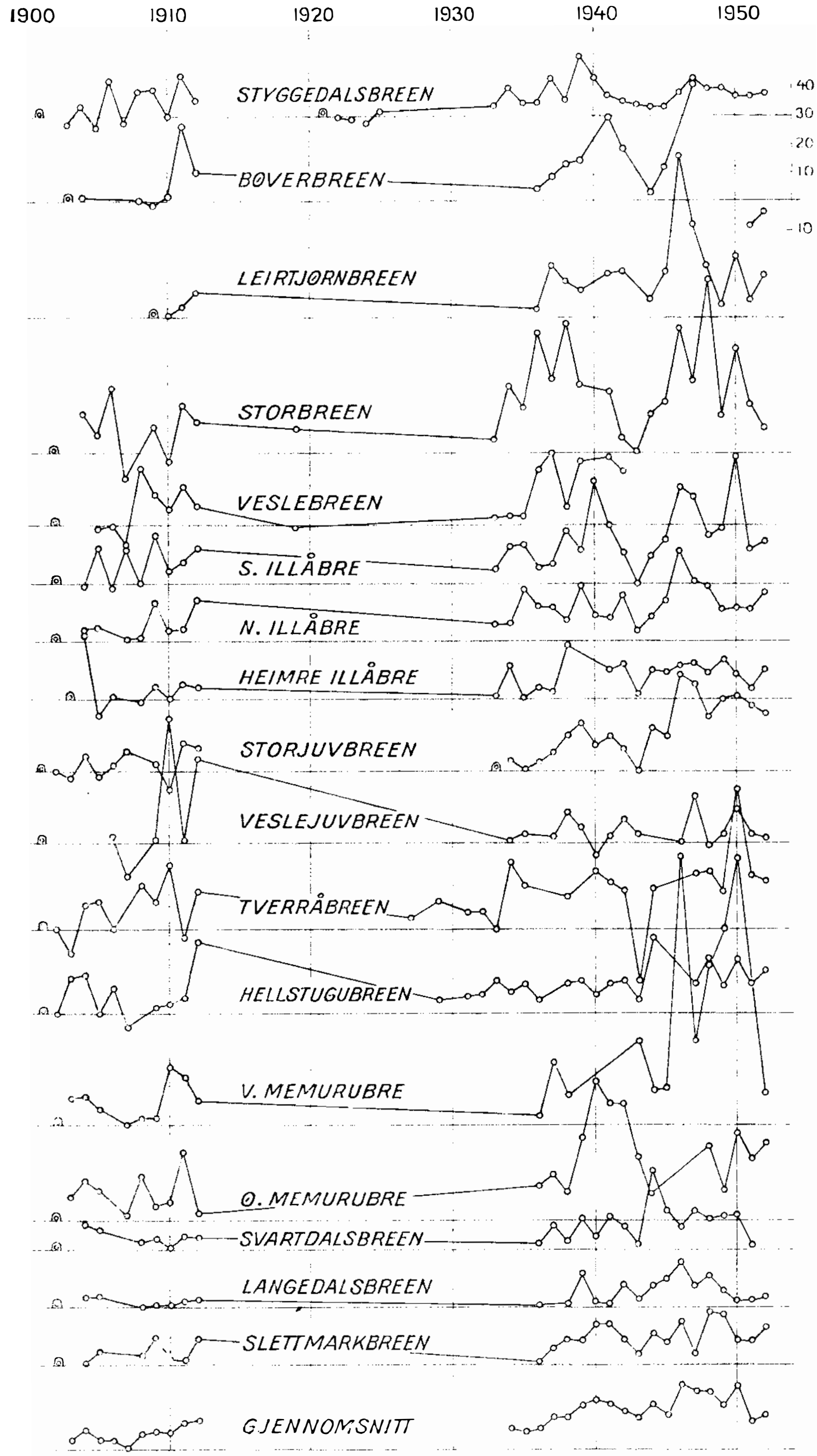


Fig. 48. Annual fluctuations of the glaciers of Jotunheimen.

of August. Fig. 49 on pp. 198—200 and fig. 50 show the result of these measurements. The variations for each and the average for all glaciers are shown on the curves in fig. 48. P. A. Øyen had, of course, fixed the directions of his tape measurements as he had found most prudent, and had built a secondary cairn in each line. He placed this cairn so that the line should reach the ice at the central projecting of the glacier tongue. But, as a result of enormous melting in later years (fig. 47), the glaciers have retreated to a degree making the directions laid down by P. A. Øyen inconvenient or quite useless in some cases, for instance at Bøverbreen where the line fixed by P. A. Øyen does not hit the glacier at all. If the line hits the glacier to the side of the tongue, the measured retreat will be too great. All glaciers have retreated considerably since Øyen began his observations. See figs. 49 and 50.

CHANGES IN VOLUME

Maps of the snout of Tverråbreen and Hellstugubreen have been constructed to a scale of 1 : 2000, with contour interval of 2 m. These maps are reduced to the scale of 1 : 2500. They are based partly on tachymetric surveying, partly on terrestrial stereophotogrammetry. The maps are to be found in the accompanying map case.

From these maps it is possible to determine the changes in the volume from one year to another; the maps are printed (or traced) on transparent paper; one map is placed in the correct position upon the other, and a set of curves are drawn through the points of intersection of the contour lines of the two maps. In this way we obtain a map of the height difference of the two glacier surfaces; by well known graphical methods the change in volume can be found, using a planimeter.

Fig. 50 is a graphical representation of the decrease in volume of the two glaciers. Evidently they have behaved in the same way, which was to be expected, considering the short distance between them.

In the same figure the longitudinal change along Øyen's sighting line has been plotted. It may be observed that the change in length corresponds quite closely to the change in volume.

Maps have been plotted also by tachymetric measurements of the frontline of the glacier. Here, too, Øyen's direction line has been included. The results of these measurements are shown in fig. 46 and fig. 47. The mean longitudinal change year by year may be determined by measuring the area between two frontal positions and dividing by the width. In fig. 51 the solid line represents the longitudinal change per year, measured along the sighting line. The dotted line shows the mean longitudinal change along the entire glacier front. With the smoothing over a number of years, there will be a great similarity between the curves, as, of course, there ought to be.

HELLSTUGUBREEN

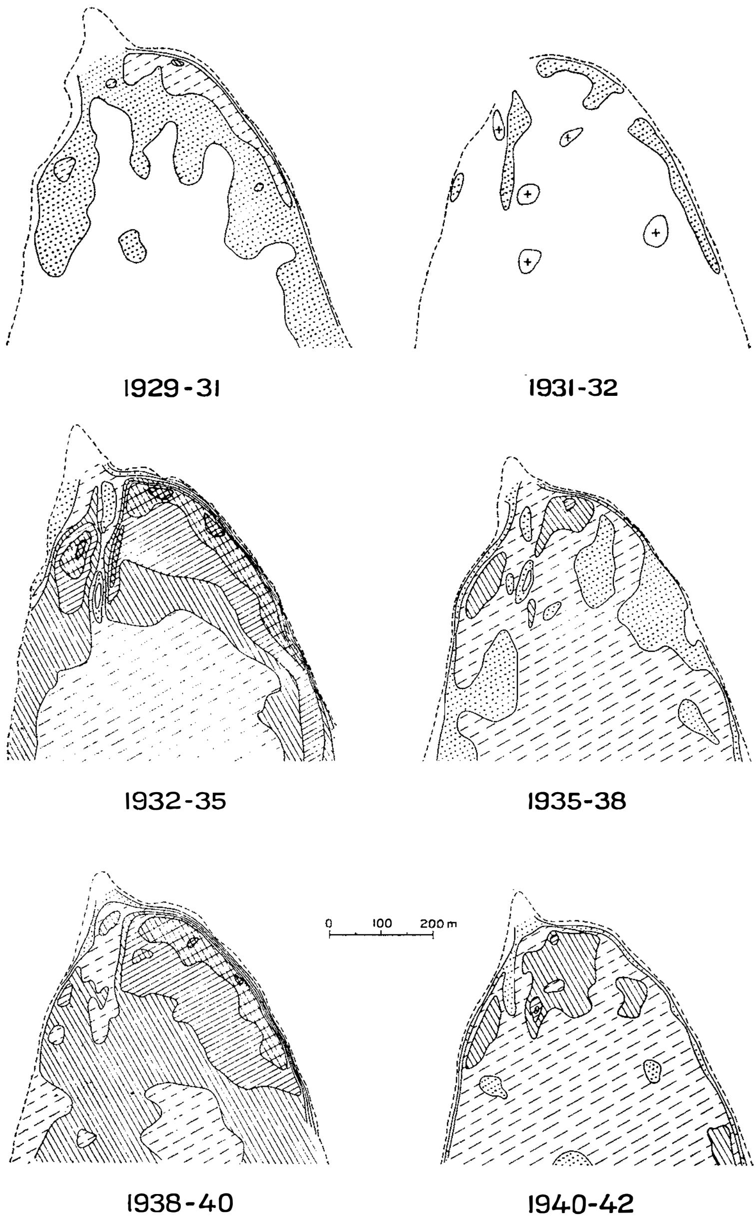


Fig. 49. (Continued next p.)

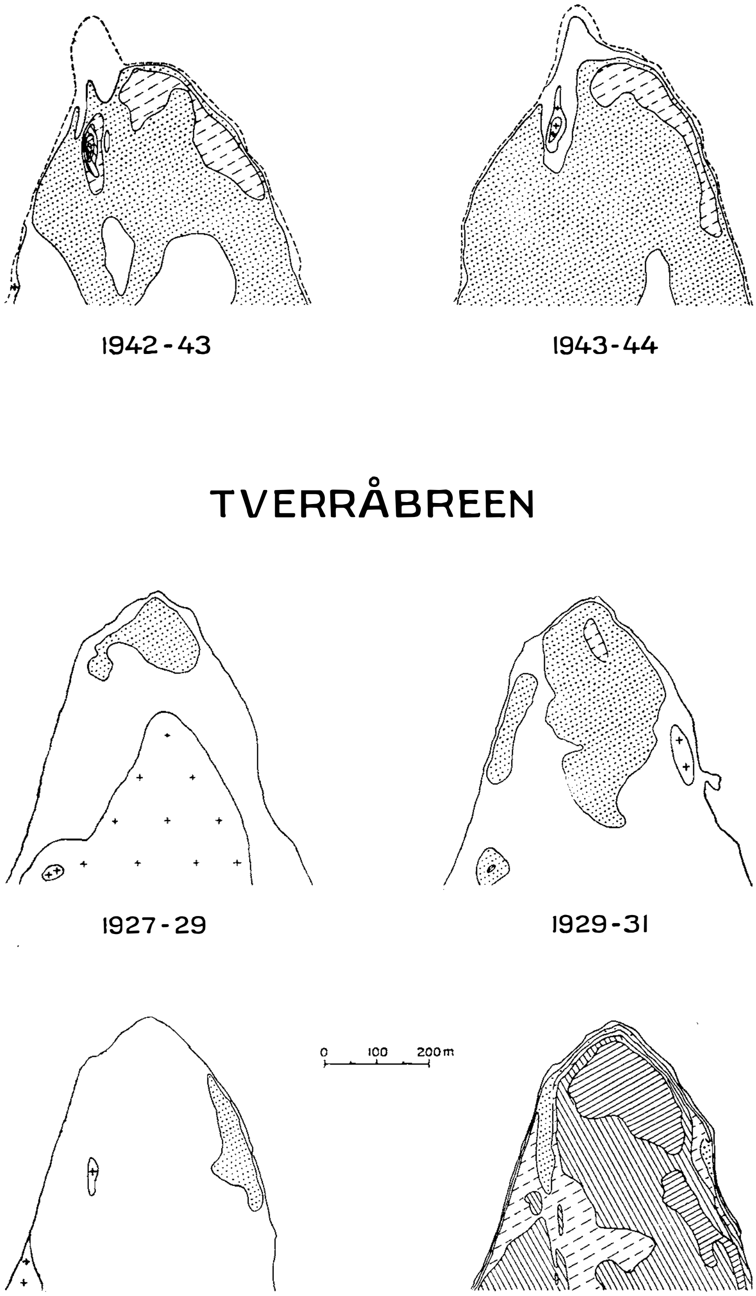


Fig. 49.

(Continued next p.)

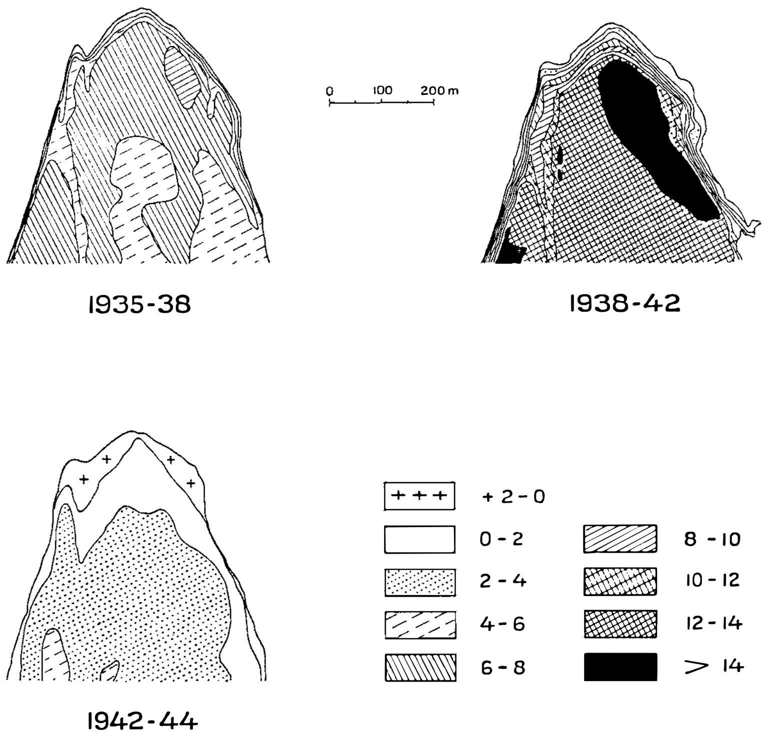


Fig. 49. Vertical decrease of the snout of Hellstugubreen and Tverråbreen, worked out according to maps constructed to the scale of 1 : 2000, with 2 m contour intervals.

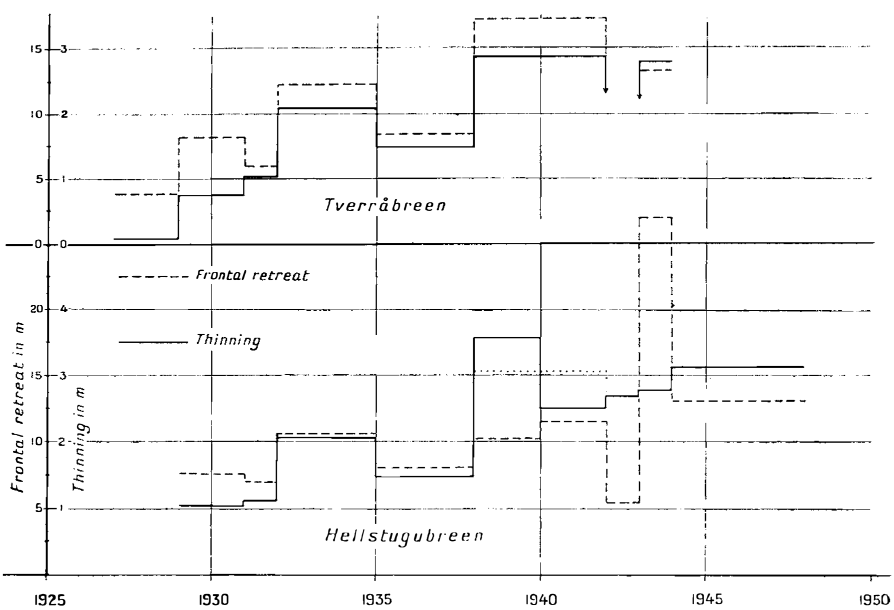


Fig. 50. Thinning and frontal retreat according to the maps in fig. 49.

Fig. 51. Longitudinal fluctuations of the front of Tverråbreen. The dotted line is the mean change along the front, the solid line represents the change measured along the sighting line.

From this it may be concluded that the simple length measurements made along a sighting line will give a good indication of the changes in volume of the glacier tongue. On the other hand, it is very doutful whether the same will apply to the changes in volumes of the glacier as a whole.

In addition to the 1 : 2000 maps, other maps have been constructed to the scale of 1 : 10 000, including the entire area of Hellstugubreen and Tverråbreen. The first map of Tverråbreen in its entirety was drawn in 1927 by means of stereophotographic and plane-table photogrammetry. In 1942, the glacier was measured again, this time only by stereophotographic survey, and under very favourable snow conditions. The first map has been printed, and is included in the map folder.

These maps of Tverråbreen have been used in the same way as the 1 : 2000 maps for determining volume change.

As appears from fig. 52 the decrease is not evenly distributed over the entire glacier. The greatest decrease occurs at the lower parts; however, there are two areas on the south side, at an altitude of 1700 to 1800 m, that have a similar or even greater decrease. It is difficult to give an exact explanation of this phenomenon, but the older map of this area is less accurate and indicated by dotted lines. A tachymetric map partly covering this questionable area surveyed in 1931, also indicates errors up to 20 m, thus reducing the surprisingly high ablation figures to what would be expected at this height. The total decrease in volume during these years amounts to 100×10^6 m^3 of ice, or an average of $6 \times 7 \times 10^6$ m^3 per year. Distributed over the entire glacier, the vertical decrease amounts to 12.8 tons per m^2, corresponding to 0.85 tons per m^2 per year. This is more than twice the amount of decrease measured at Storbreen in the years 1949—55. The surplus of water thus added to the glacial stream corresponds to 0.18 m^3 per second — or 0.027 m^3 per second from each km^2 of glacier.

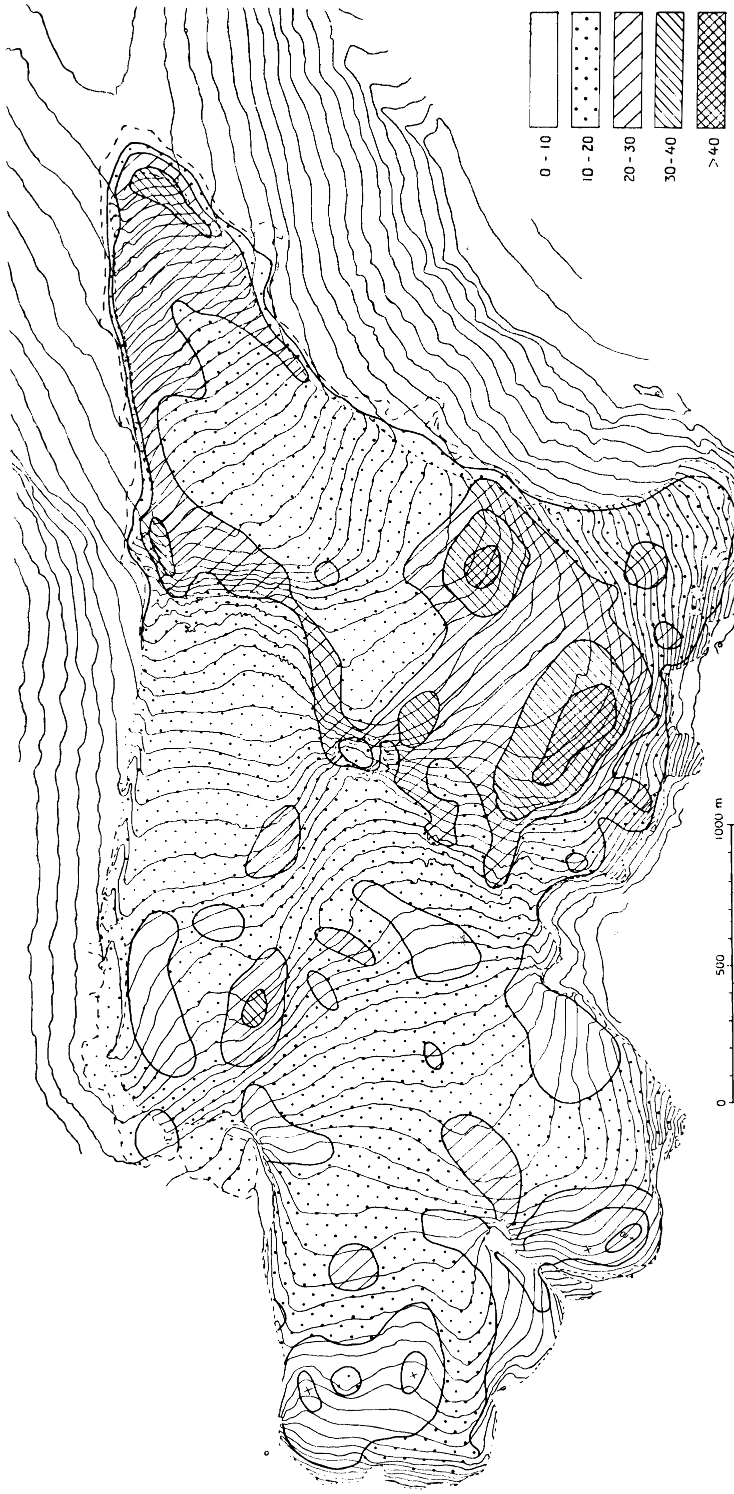


Fig. 52. The decrease of Tverråbreen in metres between the years 1927 and 1942.

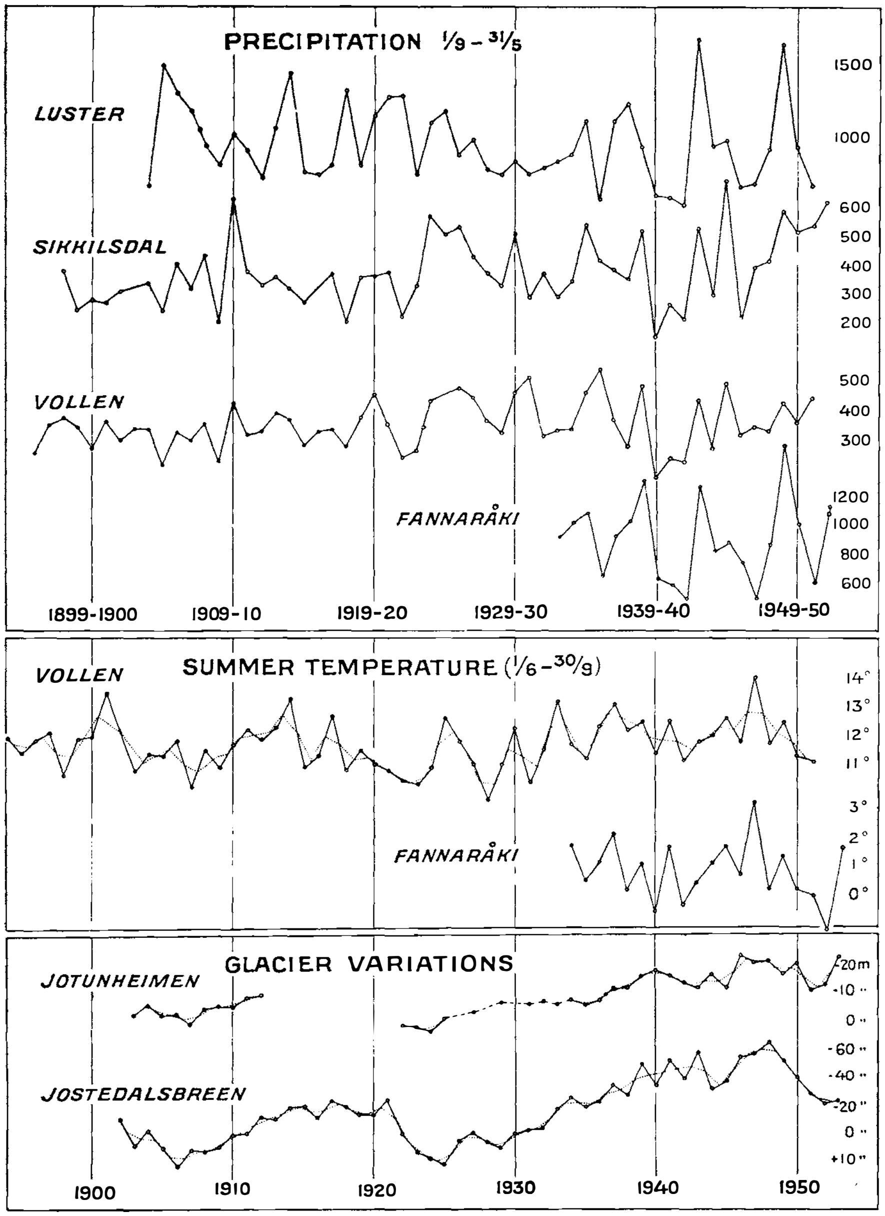


Fig. 53. Winter precipitation and summer temperature for some stations around Jotunheimen. The lowest curves represent the mean annual variations of 16 glaciers in Jotunheimen and 12 glacier outlets from Jostedalsbreen.
Dotted line is 2 years mean.

Annual retreat or advance of some glaciers in Jotunheimen

Year	Stygge-dals-breen	Bøver-breen	Leir-tjønn-breen	Stor-breen	Vesle-breen	Søre Illåbre	Nordre Illåbre	Heimre Illåbre	Storjuv-breen
1901	x								x
1902	—			x	x	x	x		0
1903	+ 5.4	x		—	—	—	—	x	+ 2.6
1904	— 3	— 1.3		—27.5	—	+ 2.3	— 7.9	—22.3	— 5.1
1905	+ 4	—		— 6.3	+ 3.3	— 12.7	— 4.7	+ 5.7	+ 1.8
1906	—12.5	—		—22.5	+ 0.2	+ 1.9	—	— 1	— 2
1907	+ 2.6	—		+ 9	+ 6.8	— 11.9	— 1.3	—	— 7
1908	— 8.4	— 1		—	—20	— 0.4	— 1.3	+ 1.4	—
1909	— 8.8	+ 1.9	x	—16.7	—10.7	— 16.7	— 13.1	— 4.5	— 5.3
1910	— 0.2	— 1.4	— 0.3	+3.6	— 5.4	— 4.1	— 3.3	— 0.3	+ 6.5
1911	—13.8	— 26.2	— 3.3	—16.1	—13.9	— 7.5	— 4.2	— 5.3	— 9.3
1912	— 5.2	— 10	— 8.1	—10.5	— 6.4	— 12.3	— 14.1	— 4	— 7.9
1913		—	—	—	—	—	—	—	
1914		—	—	—	—	—	—	—	
1915		—	—	—	—	—	—	—	
1916		—	—	—	—	—	—	—	
1917		—	—	—	—	—	—	—	
1918		—	—	—	—	—	—	—	
1919		—	—	—59	+ 6	—	—	—	
1920		—	—	—	—	—	—	—	
1921	x	—	—	—	—	—	—	—	
1922	+ 0.5	—	—	—	—	—	—	—	
1923	+ 1.3	—	—	—	—	—	—	—	
1924	+ 2.7	—	—	—	—	—	—	—	
1925	— 1.5	—	—	—	—	—	—	—	
1926	—	—	—	—	—	—	—	—	
1927	—	—	—	—	—	—	—	—	
1928	—	—	—	—	—	—	—	—	
1929	—	—	—	—	—	—	—	—	
1930	—	—	—	—	—	—	—	—	
1931	—	—	—	—	—	—	—	—	
1932	—	—	—	—	—	—	—	—	
1933	—25.3	—	—	—66	—38	—105	—119.6	—21.8	x
1934	— 9.5	—	—	—23	— 3.1	— 12.9	— 6	—11.9	— 3.3
1935	— 4.2	—	—	—15.5	— 2.5	— 13.5	— 17.8	— 0.4	— 0.4
1936	— 4.2	—111.7	—69.4	—41.5	—19	— 5.2	— 12.2	— 4.2	— 2.85
1937	—12.4	— 8.3	—18	—25.5	—25.1	— 6.7	— 11.8	— 2.5	— 6.15
1938	— 5	— 12.6	—12.8	—44.1	— 6.4	— 18.1	— 7.2	—18.7	—12.3
1939	—20.5	— 14.1	— 9.2	—23.4	—22	— 11.6	— 19	—	—16.2
1940	—12.7	—	—	—	—	— 35.3	— 9	—	— 9
1941	— 7	— 58.3	—31.5	—43	—47	— 20	— 8	—30.7	—12
1942	— 5	— 18	—16	— 5.2	—18.9	— 10.5	— 16	—12.1	— 7.5
1943	— 3.5	—	—	— 1		+ 0.1	— 3.3	— 1 5	+ 0.3
1944	— 3	— 6	—12	—13.8		— 9.6	— 8.7	—10	—14.8
1945	— 3	— 12	—15.5	—17.5		— 15	— 14	— 9	—12
1946	— 7.7	—	—56	—43.3		— 33	— 31.5	—11.7	—33.7
1947	—12.7	— 81	—32	—25		— 30	— 20.5	—12.3	—30
1948	— 9	—	—18	—60		— 16	— 19	— 9	—18.5
1949	— 12	—	— 4.5	—13		— 19	— 11	—13.5	—25
1950	— 6.7	x	—23.5	—36		— 44	— 11.5	— 8.5	—26
1951	— 9	— 12	— 6	—16.8		— 11.8	— 11	— 3.6	—22.5
1952	— 7	— 16.2	—14.5	— 8.7		— 14	— 17	—10	—20

Annual retreat or advance of some glaciers in Jotunheimen

Veslejuv-breen	Tverrå-breen	Hellstugu-breen	Vestre Memuru-bre	Austre Memuru-bre	Svart-dals-breen	Lange-dals-breen	Slett-mark-breen
x	x	x					
—	0	0	x	x	x	x	x
—	+ 8.6	—12.7	— 9.7	— 8.4	—	—	—
—	— 8.2	—14	— 10.2	— 14	—17	— 7	— 1.5
—	— 9.6	— 0.3	— 5.8	— 10.9	— 7	— 3.9	— 4.5
—12	+ 0.2	— 9	—	—	—	—	—
+12	+	+ 5	— 0.25	— 4.6	—	—	—
—	—30	—	— 2.7	— 16.2	— 8.1	+ 0.1	— 8.6
— 1.7	— 9	— 4.4	— 2.6	— 5.5	— 3.6	— 6	— 9.1
—43.1	—22	— 3.6	— 20.4	— 6.5	— 0.6	— 0.3	— 2.2
— 1.9	+ 3.4	— 5.7	— 16.8	— 24.9	— 4.9	— 2.3	— 1.8
—29	—12.9	—25.3	— 8.7	— 2.9	— 4.2	— 2.5	— 9
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—52.6	—	—	—	—	—	—
—	—	—	—	—	—	—	—
—	— 9.5	—87.3	—	—	—	—	—
—	—	—	—	—	—	—	—
—	—17.4	—13	—	—	—	—	—
—	— 6	— 7	—	—	—	—	—
—14.4	+ 0.4	—12	—	—	—	—	—
— 3.1	—23.2	— 8	—	—	—	—	—
— 4	—	— 5	— 76	—304	—57.4	—20.9	—32
—10.5	—	— 8	—22.3	— 16.4	— 8.5	—	— 5.8
— 5.2	—34	—11	— 10.5	— 10.4	— 3.5	— 2.9	— 8.7
+ 4.7	—	—12	—	— 30	—11	—12	— 8.5
— 2	—40	— 7	—	— 50	— 5	— 2.2	—14
— 8	—16	—11	—	— 42	—12	— 1.5	—14.5
— 3	—13	—12	—	— 42	— 8.5	— 8.1	— 9
—	+18	— 5	—149.5	— 22.5	— 2	— 3	— 4
—	—14	—27	— 12.5	— 10.5	—28	— 7.5	—11
—	—	—	— 13	—	—14	—10	— 8
— 1	—	—	— 95.2	—	— 8	—15.5	—15
—16	—58	—43	— 30	—	—14	— 7.3	— 4
+ 1.5	—20	—20	— 57	—107	—11	—10.5	—18.5
— 3	—13	x	— 70	— 11	—12	— 5.5	—17.5
—11.5	—49	—19	— 94.5	— 31.5	—12	— 2	— 8.5
— 2.8	—18.5	—10.7	x	— 23	— 1.8	— 2.6	— 8.5
— 1.5	—16.5	—15.3	— 11.7	?	—	— 3.4	—13.2

With melting taking place for appr. three summer months, the surplus water will amount to 0.1 m^3 per second from each km^2.

Unfortunately, there are no meteorological stations within the Jotunheimen area with a comparatively homogeneous series of observations, but in the surrounding districts there are several stations. However, it is difficult to decide if these are representative of the glacial areas, particularly as to precipitation. In this high mountain district precipitation may be expected to occur with the wind from all directions. The station on the top of Fannaråki is probably the most representative, but unfortunately it has been operating only since 1932, and the precipitation measurements are not too dependable.

Fig. 53 shows some observation series from stations along the east, south and west sides of Jotunheimen. Only precipitation in the form of snow is of interest. The precipitation is therefore reckoned from September 1st one year to June 1st the following year.

The precipitation at Fannaråki corresponds fairly well to that at the western station of Luster, but it may reasonably be expected that eastern Jotunheimen receives a greater amount of precipitation with easterly winds.

It is also very difficult to estimate how the variations in precipitation will affect the advance or retreat of the glacier front. A heavy winter precipitation will naturally cause a larger part of the summer heat to be spent in the melting of snow before the actual melting of ice begins. Such was the case in 1943 (an average year with regard to temperature), when the snout of Tverråbreen, for instance, was covered with winter snow during the entire summer. The resulting effects may, of course, be recorded already during the glacier measurements the same year.

Greater difficulties are caused by the varying masses of snow accumulated. This may result in increased flow and increased transport downward on the glacier front. Here the effects may be adjusted and delayed in ways which may vary considerably at different glaciers.

Precipitation must not be considered as a separate phenomenon. Temperature seems to be, as shown below, the most important factor. The best basis for comparison between meteorological factors and glacier variations should be found by studying the combined effects of temperature and precipitation. A heavy winter precipitation and a high summer temperature may neutralise each other, while, for instance, the effects of light precipitation and high temperature both tend in the same direction.

The meteorological station at Volden in Slidre appears to be a satisfactory, representative station as far as temperature is concerned. Fig. 53 shows the temperature curves for June, July, August and September at Volden and Fannaråki.

For comparison with the curves for the Jotunheimen glaciers the average curves for the outlet of Jostedalsbreen have been added. As mentioned before, there is a break in the measurement series for the Jotunheimen glaciers from 1912 to 1933, during which period the glaciers made their most recent advances. In Jotunheimen these have not been directly measured, but a distinct moraine inside the area where Øyen last measured the position of the glacier front, shows that most of the glaciers actually moved forward. An examination of the temperature and precipitation curves for the early 1920-es reveals favourable weather conditions for glacial advance during those years. The temperature is below, and the precipitation above normal.

Temperature appears to have had the greatest influence upon glacial variations. Comparing the curves for the biennial average, great similarity, even in detail, is found between glacial fluctuation curves and temperature curves.

A number of measurements in later years have revealed that the incoming radiation on temperate glaciers normally accounts for more than 50 per cent of the total ablation, while the convection rarely accounts for more than 30 per cent. Therefore, a study of a curve for solar radiation should be used rather than one for temperature.

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THE HELLSTUGU RIVER

Investigations on run-off conditions.

BY H. KLÆBOE

Previously printed in Norsk Geografisk Tidsskrift, bd. XIV, h. 1—4. Oslo 1953.

At the request of W. Werenskiold and Adolf Hoel, run-off investigations were commenced in August 1939 in the Hellstugu river, a glacier stream in the Jotunheimen mountains. The object was to procure information of the melting conditions on the Hellstugu Glacier as the run-off investigations should be co-ordinated with the simultaneously performed glacier measurements.

On account of the remote position and the comparatively large variations in the discharge during the day, it was necessary to establish an automatic level recorder, a so-called limnigraph. It was of course desirable to have the limnigraph erected as near as possible to the glacier. But in spite of protracted and detailed investigations, it appeared impossible to find a suitable place nearer than 1500 meters from the glacier front. Above this spot the river is filled up with stones and gravel, which cause the river-bed to be constantly subjected to changes, by which means the ratio between gauge height and discharge will also be changed. At the selected spot the profile was apparently permanent and solid, a large block having jammed between the steep river banks consisting of solid rock. The aspect of the selected spot will be seen from the photograph fig. 54. In the narrow cleft between the stone block and the river bank on the right side, some smaller stones were situated. As these however, could not be moved, it must reasonably be supposed that the profile would be stable during a number of years, but unfortunately this was not the case.

As fig. 54 indicates, the limnigraph was erected at the northern bank of the river where the rock is almost perpendicular. By means of a floater the variations of the water-level were transmitted to the recorder itself. This consists of a cyliner on which the water-level diagram is shown to the scale 1 : 10, the cylinder being operated by a clock and making one turn a week. The floater moves in a 10″ wooden pipe with circular cross-section. The recorder itself was placed immediately on top of the pipe. For control, an ordinary watergauge was placed outside the pipe, by which the water-level was recorded at every inspection.

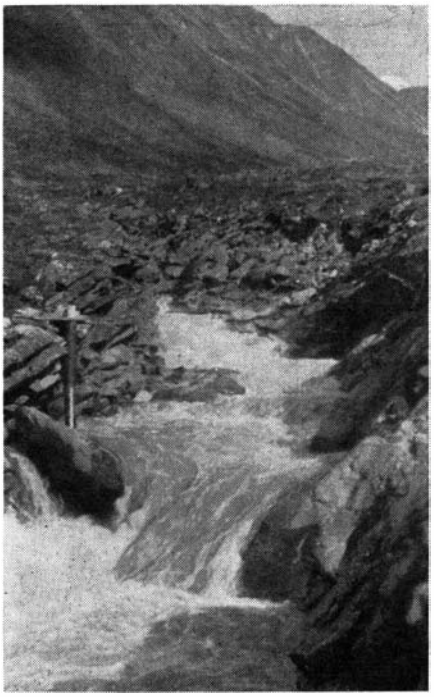


Fig. 54. The Hellstugu River at the limnigraph, q = 5.5 m^3/sec.
31/7 1941. H. K. phot.

The position of the selected spot will be evident from the small map fig. 55. The drainage area at the limnigraph amounts to 13.0 km^2, while the drainage area of the glacier is only 11.0 km^2.

As before mentioned, the recorder was erected in August 1939, and with some few interruptions was in operation till the end of September 1939. During the following autumn and winter the limnigraph was not in activity because of the frost. During this time and the subsequent winters, the water-level was measured once a month on an iron rod in the river-bed. As the run-off at this time of the year is gradually decreasing, and in the last part of the winter rather constant, this manner of proceeding gives sufficient exactitude. On the other hand, in the spring time it was very desirable to have the limnigraph in operation as early as possible, in order to obtain a reliable picture of the flood rise. This appeared to be very difficult to accomplish in spite of the fact the appointed observers had taken upon themselves this task. Thus, in 1940 the apparatus was not set in operation till July 23rd. It will then be easily understood, that it was impossible to have the observations of that year joined with those of the preceding year, as almost 2 months of the high water season are not included in the series of observations. However, in 1941 and 1942, the observations were commenced so early that continuity was maintained.

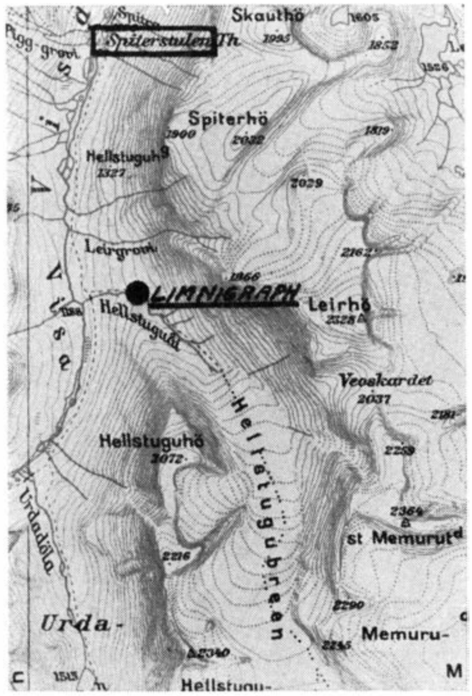


Fig. 55. The Hellstugu River and surrounding districts. Scale 1 : 100 000. From topographic sheet Gjende, by permission of Norges Geografiske Oppmåling.

In consequence, a continuous period of observation from August 1940 till September 1942 is available. For the years 1943 and 1944 all the observations have been lost, owing to circumstances connected with the war.

In 1945 the limnigraph was not set in operation till July 24th, for which reason the registration of the spring-flood is lacking for also this year. For the two subsequent years the observations are fairly complete, so that a continuous series is at hand covering the period July 1945 to October 1947. In the last year, the observer resigned, and as a new observer could not be found, the measurements were abandoned.

Consequently, the result of the investigations is that two usable periods of observation are available, i. e. 1940—42 and 1945—47.

However, other difficulties arose. At the beginning of this paper it is mentioned that the river-profile at the limnigraph was assumed to be stable, but that this proved not to be the case. Certainly, the conditions were unchanged from 1939 to 1942, as was proved by direct discharge measurements from time to time during these years. But during a great flood in August 1942 the profile was changed in such a way that the water-level was lower than before at the same run-off. The new discharge curve was fixed by direct measurements in the summer of 1943.

Once during the years 1943—44 a new change in the profile occurred, by means of which the water-level was considerably increased. The new discharge curve was available for the years 1945, 1946 and up to July 5th 1947, when a great flood anew caused a lowering of the water-level. In August 1947 this last discharge curve, the fourth, was fixed. All discharge measurements in the Hellstugu river were performed as ordinary current meter measurements, and undertaken from a provisional bridge, a short distance below the limnigraph.

As before mentioned, the result of the investigations is, that two usable series of observations are available, i. e. 1940—42, and 1945—47, the diagrams of the intermediate period having been lost. In table I, exhibited below, is given the discharge of every single month, together with the 4-year average.

Table I.

Monthly discharge in mill. m³.

	A	S	O	N	D	J	F	M	A	M	J	J	A	S
1940-41	3.89	0.87	0.31	0.18	0.12	0.06	0.04	0.03	0.03	0.23	3.00	10.01	4.55	1.31
1941-42			0.50	0.18	0.12	0.09	0.06	0.04	0.04	0.08	0.93	5.44	6.24	2.49
1945-46	4.45	0.91	0.22	0.10	0.06	0.04	0.03	0.03	0.05	0.74	2.34	6.46	4.10	2.39
1946-47			0.32	0.22	0.10	0.05	0.04	0.04	0.04	2.60	6.79	7.65	5.29	3.68
4-year average			0.34	0.17	0.10	0.06	0.04	0.04	0.04	0.91	3.26	7.39	5.05	2.47

As will be seen, complete information is available for only 2 calendar years i. e. 1941 and 1946. If, instead of the calendar year, the hydrologic year from October 1 to September 30 is used, 4 complete years appear, in which the total run-off can be calculated. The computed figures expressed in different units are exhibited in Table II.

Table II.

Annual discharge.

Oct. 1 — Sept. 30	mill. m³	m³ per sec.	l. per sec. per km²	m/m
1940—41	19.87	0.630	48.5	1 529
1941—42	16.21	0.514	39.5	1 247
1945—46	16.56	0.525	40.4	1 273
1946—47	26.82	0.850	65.4	2 062
4-year average	19.87	0.630	48.5	1 528

From the table it will be seen that the 4-year average coincides accurately with the 1940—41 run-off, corresponding to a specific run-off of 48.5 liter per sec. per km². This is considerably more than otherwise allowed for in this part of the country, and the reason of course is the melting of the glacier. This will, however, be dealt with later.

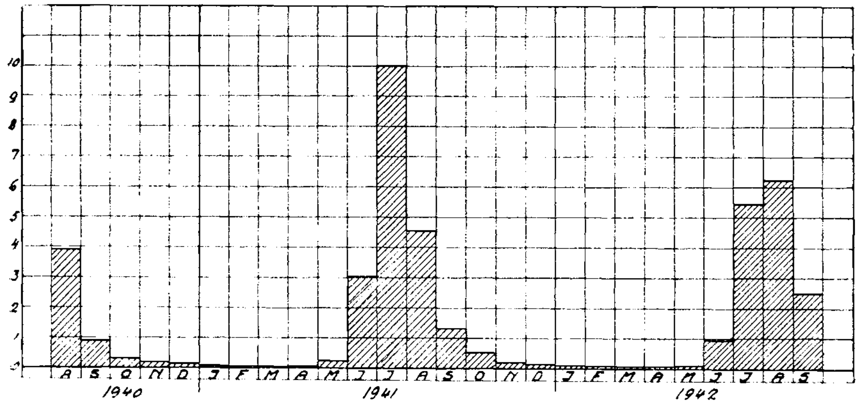


Fig. 56. Monthly discharge in mill. m^3.

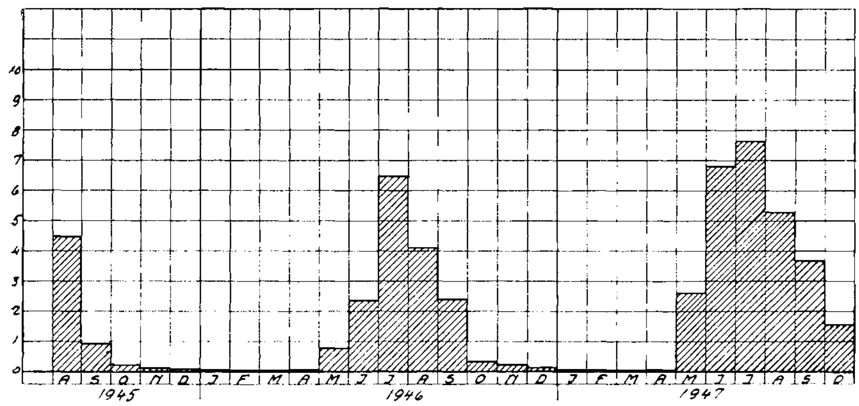


Fig. 57. Montly discharge in mill. m^3.

First of all let us inquire more closely into the figures of Table I which are shown graphically in fig. 56 and fig. 57.

As it appears, the difference between the summer and winter run-off is very great. While, in the driest winter-months, the run-off decreases to 40 000 m^3 on an average, the average for July amounts to 7 390 000 m^3. The extreme monthly average differs between 25 000 m^3 in the winter and 10 000 000 m^3 in the summer. Thus, the discharge of a summer month can be 400 times as great as in a winter month. A still greater difference is apparent between the upper and lower culmination discharges. Some years the discharge has sunk down to 8—10 liters per second, corresponding to 1 per mille of the highest flood peak, which amounts to 9 200 liters per second. After all, the winter discharge in the Hellstugu river will as a rule not recede below 12—15 liters per second, corresponding to 1 liter per sec. per km^2.

In looking at the curves of fig. 56 and fig. 57 one will get a vivid impression of the dominating character of the summer run-off. If, on the basis of Table I the discharge for the 5 summer months May—September is regarded in relation to the annual discharge, the following juxtaposition will appear:

Table III.

	Discharge mill. m^3			Summer discharge in per cent of annual discharge
	1/5-1/10	1/10-1/5	1/10-1/10	
1940—41	19.10	0.77	19.87	96.1
1941—42	15.18	1.03	16.21	93.7
1945—46	16.03	0.53	16.56	96.8
1946—47	26.01	0.81	26.82	97.0
Average	19.08	0.79	19.87	96.0

As it appears, the average of the 7 winter months is only 0.79 mill. m^3, corresponding to 4 % of the total annual discharge, while 96 % drains off during 5 summer months.

As precipitation measurements are not available for the glacier district, it is difficult to calculate the portion of the melting-water in the figures given above. Certainly, for the years 1938—1943 some meteorological observations at Spiterstulen are at hand. This material is however most incomplete, and little fitted for comparison with the hydrological material which also partly comprises other periods. As far as can be seen only the observations from the last days of July to the 31st of August 1940 can be used for such a comparison. The conditions in the period mentioned are set out in fig. 58, which shows the average daily discharge of the Hellstugu river together with the daily mean temperature and precipitation at Spiterstulen. As appears, the period is comparatively cold, the temperature at the beginning lying about 6—7° C., and then rising to a max. of 14° C, and then again falling to about 3° C in the last days of August. When the effect of the temperature is considered, it must be remembered that Spiterstulen is situated 1 100 m above sea-level, while the drainage area of the Hellstugu river lies between 1 300 and 2 300 m, and the glacier itself between 1 500 and 2 100 m. Consequently, the temperature must be considerably lower in the glacier area than at Spiterstulen. If the temperature is supposed to decrease by 0.7° C per 1000 m it will already at the glacier be 3° C lower than at Spiterstulen, and at the upper part of the glacier about 7° C lower. If this assumption is correct, the glacier melting will begin to decrease when the temperature at Spiterstulen recedes below 7°, and stops completely when it falls below 3°, whereas the precipitation in the

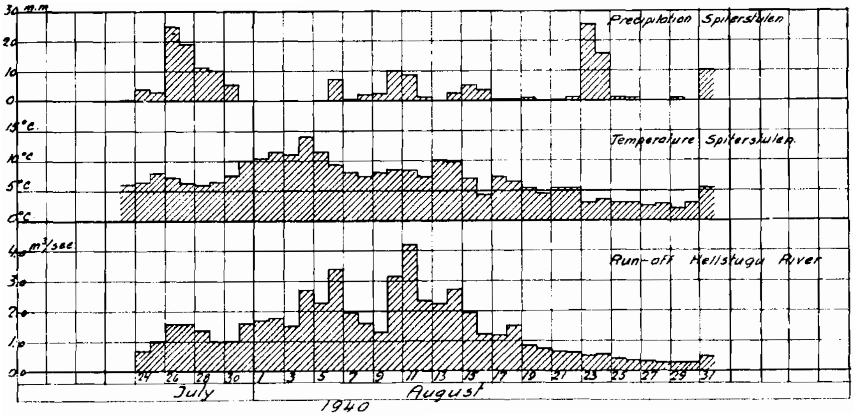


Fig. 58. Daily averages in precipitation, temperature and run-off.

glacier district will then mainly fall as snow. That this was so in the period in question, can be stated by the author who stayed at Spiterstulen during the last week of July 1940.

If the temperature curve is regarded under the supposition mentioned, it will be seen that the temperature at the upper part of the glacier was at first on an average just above 0°. It has then increased until about August 4, then decreased anew, and remained above 0° till August 22, after which time it has sunk below 0° on the whole glacier territory.

For a further comparison between the meteorological and hydrological data, it will be appropriate to divide the period into shorter intervals, namely:

Interval I. July 24 — July 30. These 7 days are characterized by a high precipitation and comparatively low temperature. At Spiterstulen the precipitation amounted to 77.6 m/m while the run-off in the Hellstugu river corresponded to a height of 55.5 m/m. If for want of other information it be supposed that the precipitation is the same in the glacier area as at Spiterstulen, it is apparent that a great part of the precipitation must have fallen as snow, but not the whole, as the discharge-diagram rises a little in spite of the decrease in the temperature. Later both precipitation and run-off decrease while the temperature rises.

Interval II. July 31 — August 5. During these days the weather was dry and warm without any precipitation at all. The mean daily temperature at Spiterstulen varied between 10° and 14° C and the max. temperature amounted to 21°. During this interval the greatest part of the snow that remained from the preceding week must be supposed to have melted which was also the case with a part of the glacier-ice. Upon the whole, during these 6 days, the total quantity of melting water amounted to 1.0 mill. m³ corresponding to 77 m/m over the drainage area.

Interval III. August 6 — August 16. The warm summer-weather had now ended, and instead of this a period of rain occurred with varying precipitation and a temperature between 5° C and 10° C. It must be supposed that the precipitation in this period has mainly fallen as rain over the whole area. At Spiterstulen the precipitation was 43.0 m/m while the total discharge of the Hellstugu river amounted to 173.0 m/m. Thus, considerable melting has probably taken place at the glacier area. On the night between the 10th and 11th of August, the greatest flood of the year occurred, culminating with a discharge of 6.5 m^3/sec. or 500 liter/sec./km^2. During the day mentioned the total run-off amounted to 400 000 m^3.

Interval IV. August 17 — August 22. This period comprises 6 days with some rain now and then, but the amounts were small, amounting to only 2.9 m/m upon the whole. The temperature was gradually decreasing, but the average of the day was mainly above 5° C at Spiterstulen. In the glacier district it has probably partly been below 0°, at least in the upper part. Consequently, the discharge was also decreasing, and for the period equalled a total of 37.5 m/m.

Interval V. August 23 — August 30. As the diagram indicates, the precipitation during the first two days was very great, amounting to 41.3 m/m at Spiterstulen. But as it will be seen, this was of no consequence for the discharge, which decreased throughout the whole period. The reason can only be that the precipitation has mainly fallen as snow in the glacier district. This is also indicated by the temperature curve, which shows that the temperature at Spiterstulen was about 3° C on an average. The temperature of the glacier district has then probably been below freezing point. The total precipitation of these 8 days amounted to 44.2 m/m, while the discharge was only equal to 19.0 m/m.

For the whole period July 24 to August 30 comprising 38 days, the observations show a total discharge equalling 362 m/m while the precipitation at Spiterstulen amounts to 168 m/m. If the precipitation of the drainage area is supposed to be the same, the difference between the discharge and precipitation is 194 m/m which consequently should be ascribed to glacier melting. However, as above mentioned, the diagrams of the last 8 days indicate that the precipitation has probably fallen as snow, which evidently has not melted within the end of the period. Consequently, the effective precipitation should be reduced by 44 m/m, by which means the quantity of melting water increases to 238 m/m over the drainage area. If this figure is divided over the glacier area, which is only 5.5 km^2, the melting for the 38 days will amount to 562 m/m.

Unfortunately, a computation such as that given above, must be characterized as in part unreliable, as it must be supposed that the precipitation in the glacier district is somewhat higher than at Spiterstulen.

Ultimately, it is only the direct measurements of the glacier's change of volume which can give information about the influence of the glacier melting on the discharge. Such measurements are at hand for a series of years, showing the changes in volume from autumn one year till the autumn next year, but not for the single months. According to a statement from Norsk Polarinstitutt the change in volume amounted to 5.9 mill. m^3 in the year 1940—41 and 3.5 mill. m^3 in 1941—42. For the years 1945—46 and 1946—47 such information is unfortunately not available, which is very much to be regretted, especially with respect to the latter year, in which the melting was unusually great because of the warm summer. This will also be seen from Tables II and III which show that the 1946—47 discharge was 35 % greater than the 4-year average. Consequently, the influence of the glacier melting this year is impossible to compute. Such a computation will however be possible for the years 1940—41 and 1941—42, in which the quantity of melting water was 5.9 respectively 3.5 mill. m^3. If these figures be subtracted from the figures of Table II, the following Table IV will appear, in which the figures should approximately correspond to the effective precipitation of the two years.

Table IV.

Annual discharge without glacier melting.

1940—41:	14.0 mill. m^3	corresponding to 34.1 liter/sec/km^2	or 1 075 m/m
1941—42:	12.7 mill. m^3	corresponding to 30.9 liter/sec/km^2	or 975 m/m

If, as before, the first year is supposed to correspond to an average year, the accordance with the specific run-off in neighbouring districts is now very good. If further the figures in Table III and Table IV be compared, it will be seen that the melting has amounted to 29.7 %, respectively 21.5 % of the discharge in the two years in question. The portion which glacier melting constitutes in the discharge of 1946—47 can only be guessed. It is however not improbable that the melting in this year amounted to about 50 % of the total run-off.

Above is shown the great difference between the summer and winter run-off, both seasonal and between the single months and days. Further it should be mentioned that, even within the single day, great variations in the discharge can occur. These variations are at times so regular, that a distinct day-rhythm can be proved. This phenomenon is apparent on warm summer days only, and is caused by the glacier melting which varies mainly in step with the temperature. As an illustration of the phenomenon, fig. 59 shows the discharge diagrams for 5 days in August

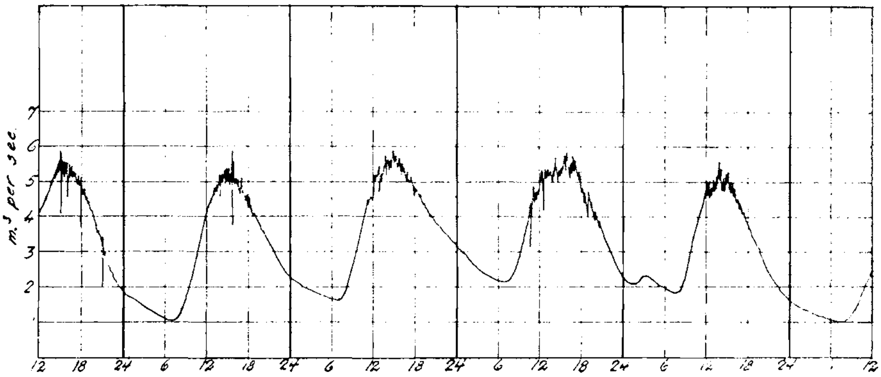


Fig. 59. Daily variations in run-off.

1947. As it appears, the maximum discharge, amounting to 5—6 m³/sec as a rule occurs about 2—4 o'clock p. m., almost at the same time as the maximum temperature. On the other hand the minimum occurs at about 7 a. m., in the first and fifth day decreasing to only 1 m³/sec. The three other nights have probably been warmer, especially the third one, in which the minimum discharge is not lower than 2.2 m³/sec. It will be noticed that the top of the curves are rather irregular, the run-off varying incessantly up and down. What the reasosn can be is difficult to explain. It may be that the variations are caused by changes in the meteorological factors, but they are more probably caused by temporary changes in the draining channels within the glacier itself.

At the beginning of this paper it was mentioned that the run-off investigations should be co-ordinated with the simultaneously performed glacier measurements. However, from the above information it will be understood that the co-ordination between the different investigations has been rather poor. And as it will be remembered, the main reason is the remote position of the field of investigation, which has caused difficulties in procuring qualified observers, a difficulty which however as a rule must be expected in the glacier districts of Norway. Another difficulty concerning glacier currents which must be considered, is the instability of the river beds, frequently causing profile-changes at the stations.

In connection with Table IV it should be mentioned, that the figures in the table correspond to the effective precipitation of the years in question, and that these figures appear by subtracting the quantity of melting water from the total discharge. If precipitation is P, the discharge Q, and the glacier's change in volume V, the following equation can be written: $P_{eff.} = Q \pm V$ in which $+ V$ equals the change in volume when the glacier is increasing, and $—V$ when it is decreasing. But $P_{eff.}$ is also equal to P — E, where P is the real precipitation and E is the net evaporation over the drainage area.

Consequently, if it should ever be possible to obtain a complete understanding of the run-off conditions of the glaciers, it will be necessary, in addition to discharge measurements and glacier investigations, to procure information on the precipitation in the drainage area itself, by which means all the factors of the following balance equation will be known:

$$P - E = Q \pm V$$

INVESTIGATIONS ON SOME GLACIERS IN NORTHERN NORWAY

BY ADOLF HOEL

The glaciers of the Okstindan mountains

POSITION AND MAPS

The Okstindan mountains are situated to the south of the Ranafjord, approx. 8 km west of the Swedish border, north of lake Røssvatnet and 10 km east of the Røssåga valley. The centre of the Okstindan glacier area is situated 66° N.Lat. and 14° 16′ E Long Gr. It is represented on the following gradteigs map sheets (1:100 000): Rana, surv. 1891—1894, pub. 1900; Umbukten, surv. 1891—1894, pub. 1897; Røsvand, surv. 1888—1893, pub. 1897; and Krutfjeld, surv. 1890—1892, pub. 1896. All these maps are surveyed and published by Norges geografiske oppmåling (Geographical Survey of Norway).

The glacier area on these maps and its immediate surroundings are also shown on a so-called "Turistkart" named Okstindan. The first edition was published in 1946, the last one in 1959. This is a reprint of the four other maps.

HISTORY OF THE NAME OKSTINDAN AND OF THE eXPLORATION OF THE OKSTINDAN REGION (1640—1874)

In order to obtain information about old maps and documents dealing with Okstindan I approached the vicar, Kristian Nissen, who is a well-known expert on this area. He has drawn up an account, which he sent me with his permission to make such use of it as I thought fit.

Below is an extract from his account. I am deeply indebted to Pastor Kristian Nissen for the valuable help he has given me in this way.

A local secondary school teacher, Mr. J. Norvik, has also supplied me with various items of information, for which I would like to express my best thanks.

The oldest known name of these mountains dates from 1640. It is to be found in the Swedish surveyor Olof Tresk's "Relation on Fjällryggen mellan Sverige, Norge och Ryssland" 1640. (Account of the mountain ridge between Sweden, Norway and Russia). Tresk was sent by his government to Torne and Kemi Lappmarker in order to survey this region

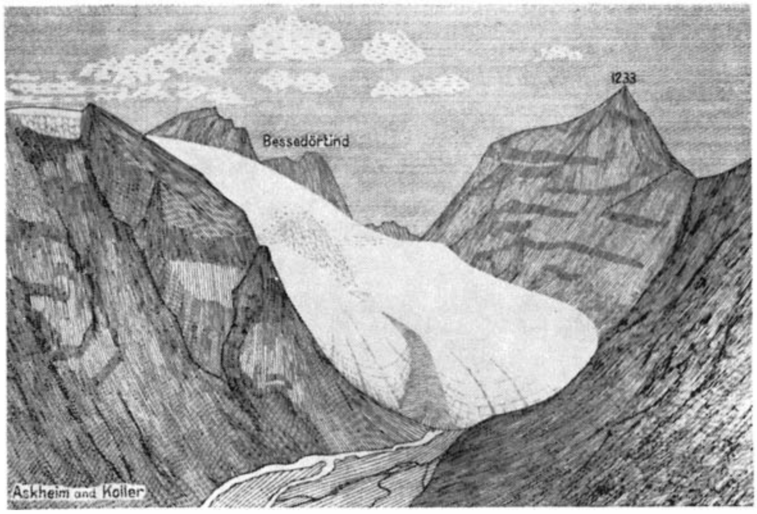


Fig. 61. Sketch of Oksfjellbreen 1934.

and to determine where the border line between Sweden and Norway and Russia ought to be drawn. From 1635—36 and later he questioned the inhabitants, mainly or exclusively Lapps, about the mountain regions there These Lapps mentioned a high mountain west of the border, called Oxe-fjäld (Ox Mountain).

He also mapped the border regions. His maps were printed in two sheets, one of Kemi Lappmark (1642) and the other of Torne Lappmark (1643). But the name Oxe-fjäld is not to be found on the map of Torne Lappmark.

All the statements Tresk had obtained from local inhabitants, as well as his maps, were kept secret, as these documents were not as favourable to Sweden's frontier demands as was desirable. For this reason they have exercised no influence on subsequent cartography nor on the boundary investigations which led to the drawing up of the frontier treaty still in force, the Strømstad Treaty of 1751.

The statement Tresk had obtained, and the maps that went with them, were printed in Stockholm in 1928 in a commemorative publication to Professor K. B. Wiklund which contained an historic introduction by Professor Nils Ahnlund. (See p. 22 et seq.).

About a hundred years later the Norwegian Major Peter Schnitler was dispatched on the same errand as Olof Tresk, viz. to determine the border line between Norway and Sweden.

His boundary investigations extended from the Røros district to East Finmark, and covered the period from April 1742 to November 1745.

Major Schnitler, like Tresk, also questioned Lapps, as they had their livelihood among the border mountains.

The first geologist who visited the border regions was the Swedish well known Mining judge Daniel Tilas in the 1740's. He was a member of the Swedish border commision. He travelled along the Norwegian-Swedish border from Femundsjøen in southern Norway to Lule Lappmark. He made collections of rock specimens and sketches and notes. This material was unfortunately destroyed by fire in 1751. See Foslie 1941, p. 11.

During these border investigations the name Oksfjell cropped up in several ways.

On August 31, 1742, we eventually find the name of the Okstind mentioned again, this time on the form "Ox-fieldet". This occurred during a witness's statement to Major Schnitler during his frontier investigations at Skoug in Vefsen on the date mentioned above. See Qvigstad and Wiklund, Dokumenter angaaende flyttlapperne, I. Kr.a. 1909, p. 7.

The name is also mentioned in the same form on a few further occasions in Schnitler's boundary investigations in 1742 (see ibid. p. 13 and 29 as well as Bilag Litr. E. p. 85—87, which deals with the Lapp tax in Rana for the years 1735, 1736 and 1737). After the names of the taxpayers the name of their place of residence is shown. In the case of four persons the name Ox-fieldet is given as their place of residence. Thus 1735 is the date of the first mention of the name of Mount Oksfjell in an official document.

In 1741 Eiler Hagerup, Bishop of Northern Norway, residing in Trondheim, entrusted Aaron Olufsson Norman, the missionary to the Lapps, with the task of drawing a map of the border region adjoining the Okstindan. It was to be used for the purpose of investigating this part of the border line. It was ready the following year. The map is in dublicate. A coloured original was sent to Bishop Hagerup. The other, a simplex version was given to Major Schnitler on the 24th August 1742. Some time later Major Schnitler also got the Bishop's copy.

On this map the name "Oxfield" was very distinctly visible between "Røsaae Vand" and "Græsvand", if anything, most like a perspective drawing of a markedly angular mountain. Norman's map is now in Riksarkivets Grensearkiv, Oslo.

During his stay in Hammerfest 1743/44, Major Schnitler worked up a very conspicious map over the whole of Nordlands amt (county). On this map we find "Oxfield" on the north side of the north-eastern shore of lake "Rys Vand". The basis for this map is Norman's and the oral information he had obtained during his boundary investigations in Rana and Vefsen in the autumn of 1742. The mountain is drawn as a perspective sketch of a group of peaks seen from the south as in Norman's map.

Two later copies from the 1770's also exist.

But immediately after Schnitler's boundary investigations, beating the bounds was carried out together with a survey of the boundaries which had been claimed respectively by Norwegians and Swedes. The work was carried out by two Norwegian and two Swedish surveyors, each group having the assistance of a secretary. The Norwegian surveyors were the brothers Thomas Hans Henrik Knoff and Frederik Christian Knoff, after whom the Norwegian set of "grensepretensjonskarter" (lit. boundary claim maps) are generally named the Knoff maps. The task of the secretaries was to take down statements from witnesses and keep records, a task which was greatly faciliated on the Norwegian side from the Røros district and further north, by the Schnitler boundary investigations.

The "boundary claim maps" are to be found in the Records Office in Oslo. Two separate sets exist, one for each country, and in them the claims put forward by the two sides with regard to frontier line are marked.

After supplementary investigations and negotiations between the senior boundary commissioners had taken place the final boundary treaty was finally signed by Mangelsen and Klinkowstrøm in Strømstad on October 2nd, 1751, and shortly afterwards approved (ratified) by the monarchs concerned.

In 1752 the final beating of the bounds, with the building of cairns and the cutting of a boundary swathe through the forests in accordance with the treaty of 1751, commenced, and by 1761 the work had been completed as far as Helgeland. As the work proceeded the huge and magnificent maps were made by the boundary engineers of the two countries working together — three from each country, — and both copies were signed by all six. Apart from the linguistic distinctions between Norwegian and Swedish, and the fact that on the Norwegian maps the Norwegian names come before the Swedish ones, and vice versa, there is no difference between them.

On the definitive boundary map (No. 15) the name "Store Ox Fieldet" occurs. It shows a very large mountain massif with a suggestion of two peaks rising from it in the south-east corner of the map, and three in the north or north-west corner.

On the corresponding sheet of the definitive Swedish boundary maps which have been printed, reduced to ½ scale (See References), the name "Stora Ox Fiäldet" is marked in the same way as in the Norwegian. No Little Ox Mountain, however, is to be found.

As Oxfjell was situated entirely on Norwegian territory west of the Norwegian-Swedish border, it is not mentioned by the Swedish boundary surveyor Marelius in his very useful treatise: "Om Land- og Fjällryggarne samt Gränsen imellan Sverige och Norrige" which was printed in the Kgl. Vetensk. Acad. Handl. Vol. 32/1771 and Vol. 33/1772. A map supplement accompanied this treatise, and this included "Oksfiäldet".

Here mention should be made of some small-scale maps of Northern Norway by Pontoppidan (1795), Arntzen (1826), Flood (1831) and Roosen (1841).

All these sources have the form "Oxe Field".

There seems, however, little point in enumerating all other small-scale maps or publications up to 1874, as they all show only slight variations from the names dealt with above, and none of them provide any new details of the topography of glaciology of the region.

In Jens Kraft's "Norgesbeskrivelse" VI, Chr.a., 1835 "Oxefjeld" (p. 247) or "Okstinden" (p. 255) is described as "a very high mountain covered with eternal snow and ice in the Leerskar district, which has narrow peaks. The central one, which is the tallest, can be seen far out at sea".

Nissen have been unable to discover the exact date when the name Oksfjeld was replaced by Okstinderne or Okstindan.

Nissen concludes his account by stating that from J. Qvigstad's work "De lappiske stedsnavn i Finnmark og Nordland fylker" (Lappish place-names in the counties of Finnmark and Nordland), Oslo 1938, it appears that in Lappish the Oksfjell mountains are called "Vuoks-olkie", the direct translation of which is "The Ox's Shoulder". There is, however, no information to show how old this name is, nor is there much likelihood of this point ever being satisfactorily decided.

The former part (Vuoks) of the name is a Nordic loan word (old Norse: Oxi). See J. Qvigstad, Nordische Lehnwörter im Lappischen 1938.

Both the Norwegian and Lappish names may be very old, as there have been settlements in this districts as far back as the Iron Age.

It would be strange if such a conspicious topographic feature as Okstindan had not had its own name in remote ages.

During my work in Okstindan in 1908 I climbed many of the peaks in this mountain and I could observe that the view to the west extended to the farthest islands and skerries. (See Hoel 1909). The highest peaks of Okstindan are therefore well suited as landmarks for sailors.

Norges geografiske oppmåling (Geographical Survey of Norway) has been aware of the importance of the Okstindan peaks as landmarks and has in one of its publications on the sailing directions of the Norwegian coast (Den Norske Lods, Vol. 8. Pl. 3. 1870) included Okstindan as a landmark between Hestmandøy and Lurøy. But the location of this landmark is very badly represented, as it appears to be situated near the coast.

HISTORY OF THE EXPLORATION AFTER 1874

The first person to visit Okstindan for scientific purposes, and the first person to carry out an ascent of a peak (Okstinden) of which a reliable account has come down to us, was C. A. Corneliussen, subsequently director of the Sulitjelma mines. He visited this region in 1875 on behalf of Norges Geologiske Undersøkelse (Geological Survey of Norway), and studied the geology and the glaciers of the region.

On the 31st July he made an excursion from Brygfjelddalen to the north-western part of Okstindan. He ascended Okstinden (1808 m) from the south and from this peak he descended across Vestre Okstindbreen and Leirskardalen to Tverrå farm, the uppermost farm in this valley.

His diary has been preserved in the archives of Norges Geologiske Undersøkelse. It contains a good sketch map showing the highest mountains, the main glaciers and his route, as well as a drawing of the Okstindan peaks seen from the west. (See References as well as the chapter named Fluctuations of the Glaciers in Okstindan, pp. 250, 234.

The next person to undertake scientific investigations in the Okstindan region was the well-known French glaciologist Charles Rabot, who went there in 1883. Rabot had his head-quarters at Tverrå. On the 9. July he went up Leirskardalen towards the northwestern part of Okstindan. Reaching the upper end of this valley he observed at first two glaciers (Mørkbekkbreen, Jordbrubreen) after which he came to a third glacier (Vestre Okstindbreen). Close to the front of this he established his camp.

He now intended to climb Okstinden, which he believed to be the highest of all the peaks in Okstindan. But bad weather prevented him from realising his plan.

On the 10th fog and rain prevailed, and he therefore descended to Tverrå.

The next day, 11th July, the weather was good and for the second time he proceeded up to his old camp. On that day he made many valuable glaciological observations and climbed the southernmost peak of Okskalven (1676 m). (See also the section dealing with fluctuations p. 247 and References).

On the 12th the weather was stormy, and heavy clouds covered the sky. He therefore left this region and proceeded to Ranafjord via Gressvatnet.

Rabot has presented to the Geological Survey of Norway many valuable photographs of glaciers in Okstindan.

Apart from the investigations carried out by these two scientists no geological or glaciological work had been done in Okstindan before my visit there in 1908. I was then a state geologist at the Geological Survey of Norway and had been ordered to proceed to Okstindan to study this very little known region. I stayed there from 10th August to 11th September. The results of the work were published in 1910. It gives an account of the geology and glaciology of the region. (See references p. 250.)

After 1908 no geological or glaciological work has been done in the Okstindan region.

The ascents made in this massif have especially been dealt with by K. Bing in two papers (1902 and 1903). The first ascent was made by the Norwegian Anders Ottersen of Brygfjeldal as early as 1860. In 1883 Peder Stordal made the first ascent of Okskolten (1915 m), the highest peak in Okstindan. Captain Grimsgaard, a surveying officer from the Geographical Survey, ascended several mountains in Okstindan. In 1900 many alpinists visited the area, including the well-known British climbers Victor H. Gatty and W. C. Slingsby. They were accompanied by Norwegian guides. K. Bing also visited Okstindan that year. I climbed numerous peaks during my travels there in 1908 (Hoel 1909).

PLACE-NAMES ON MODERN MAPS AFTER THE END OF THE 19TH CENTURY

The area round Okstindan is very sparsely populated. The few inhabitants are all farmers working on small holdings, who have little inclination to penetrate into the Okstindan's wild realm of glacier and mountain. For this reason there were originally only a few local place-names given by the local inhabitants to various features. Nor did the first geologists and glaciologists who visited the north-west area leave any new names behind. The surveyors of the Geographical Survey who worked here during the 1890's left only a few place-names behind. The maps issued during the 1890's contained very few names.

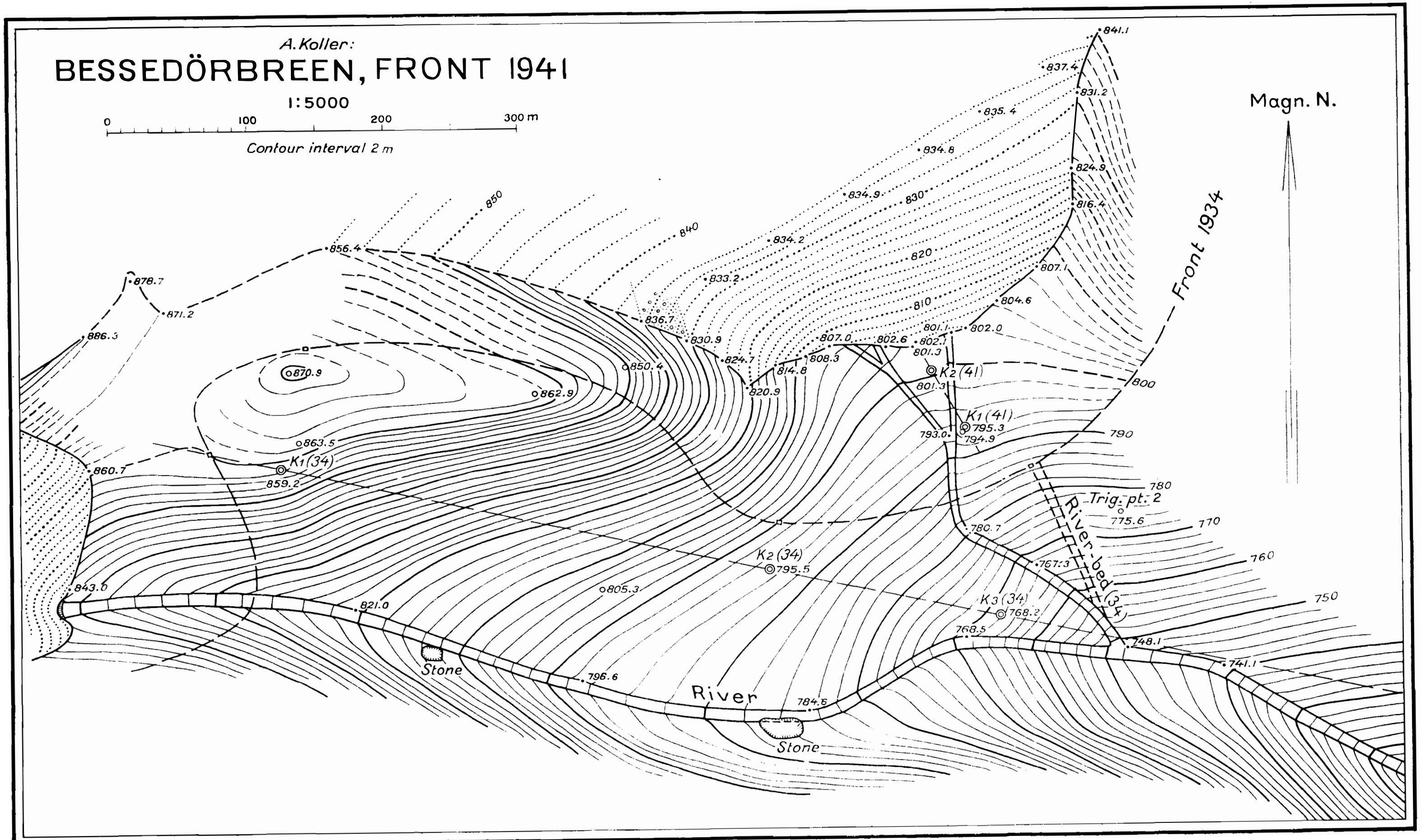
Mountaineers who have visited the Okstindan have contributed a number of new names, e. g. H. Bing, 1900 (Charles Rabot's Bre) and Victor H. Gatty, 1900 (E. Okstindbre and W. Okstindbre).

When I started my geological and glaciological work in 1908 I was obliged to invent a whole number of new names, viz. 14 glacier names and 6 names for mountains.

When the present paper was about to be published several new names had to be added to the map, some of them at the request of Mr. Kr. Gleditch, Director of the Geographical Survey of Norway, who wished to have more names on the new edition of the Okstindan Tourist map.

As the place-names come from several sources which in many cases were unfamilar with older names, a certain degree of confusion has arisen. On some issues of the Geographical Survey's Umbukten map-sheet, for instance, the second-highest peak (1907 metres) was shown as "Keiser Wilhelm II's Tind".

This name is not printed on the original survey from 1891—93 which forms the basis of the Umbukten gradteig map, issued in 1897. Nor is the name to be found on this first edition. The following editions of the map (up to 1907) no longer exists. The first edition of the map to include the name and to be preserved in the archives of Norges Geografiske Oppmåling is from 1908.


A. Koller:
BESSEDÖRBREEN, FRONT 1941
1:5000
0 100 200 300 m
Contour interval 2 m
Magn. N.
Front 1934
River-bed (34)
River
Stone
Stone
Trig. pt. 2
775.6
K1 (41) 795.3
K2 (41)
K1 (34)
K2 (34) 795.5
K3 (34) 768.2
841.1
837.4
831.2
835.4
834.8
824.9
816.4
834.9
830
834.2
820
833.2
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804.6
802.0
801.1
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801.3
802.6
807.0
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814.8
824.7
820.9
830.9
836.7
840
850
856.4
878.7
871.2
886.3
870.9
850.4
862.9
863.5
859.2
860.7
843.6
821.0
805.3
796.6
784.6
801.3
793.0
794.9
800
790
780
770
760
750
780.7
767.3
768.5
748.1
741.1

Fig. 62.

In an old proof file now in the archives of the Survey there is a note that the following addition must be made to subsequent editions of the map:

Kjensvand, a mountain road running on the Korgen and also Keiser Wilhelm II's Tind.

These amendments were inserted at the instigation of the amtmann, now named fylkesmann (county governer), in Nordland. The proof was sent to the technical department of the Survey on May 18th, 1905.

Furthermore, it appears from the file that a new issue of the map with the above amendments added came out in July 1905, but is not to be found in the archives of the Survey as mentioned above.

It may seem strange that the amtmann in Nordland (his name was Rasmus Theisen) should have given the name of the German Kaiser to a peak in Okstindan, but the reason is almost certainly connected with the following incident. In 1904 the town of Ålesund was severely damaged by fire, most of the buildings being razed to the ground. The German Kaiser reached promptly and generously, bringing aid to the stricken town before the Norwegian authorities had time to organise proper relief. The Kaiser's action, which included sending ships with supplies, food, bedding, etc., aroused a great deal of enthusiasm in Norway, and there is every reason to believe the county governor considered it appropriate to suggest that his name should be perpetuated by naming a mountain in Okstindan after him.

This was the name printed on the Survey's map sheet when I made my first visit in Okstindan in 1908, and when I published my paper in 1910. This is the reason why it is to be found on the geological maps included in my paper. I introduced the name Okshornet for the 1724-metre peak.

The Kaisers name was printed on every edition of the Survey's maps up to the 1956 edition, but on the 1957 edition it was changed to Okshornet.

On the map used in the present description of Okstindan I have therefore been obliged to find a new name for Okshornet on my map from 1908, and it is called Vesttinden.

The new names added to the map in the present work, and the transfer from old to new nomenclature and spelling, has been undertaken in co-operation with Per Hovda, in charge of archives in the Norske Stadnavnarkiv (Norw. State Place-name Archives).

The names to be found on the map in this paper will also be added to maps subsequently issued by the Geographical Survey. They must therefore be regarded as officially adopted.

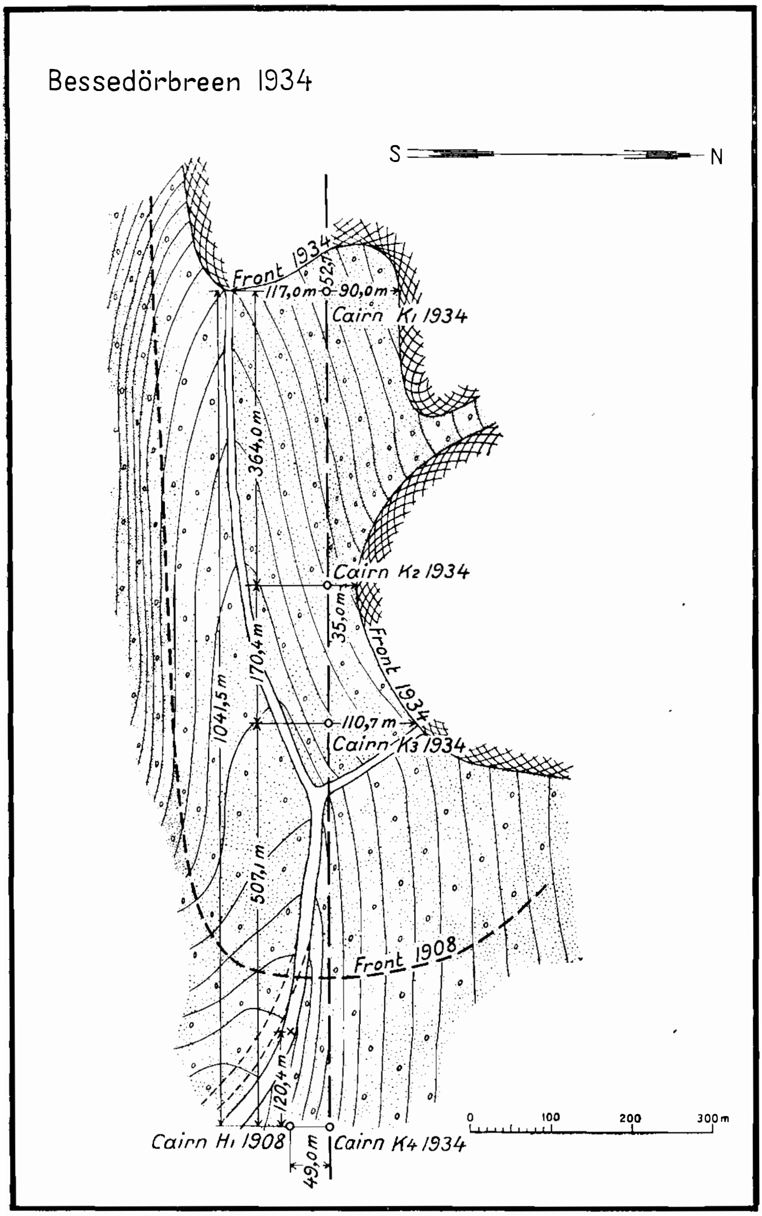

Fig. 63.

TOPOGRAPHY

Okstindan is a mountain massif rising high above its surroundings. Its highest peak is Oksskolten, 1915 m above sea level. It is the highest mountain north of Snøhetta in the Dovre range in southern Norway (62° 20′ Lat. N) 2302 m, and its neighbours for inst. Skrymtkollen 1984 m NW to Snøhetta.

The old accepted heights for Oksskolten, determined by surveyors from the Geographical Survey in the 1890's put the altitude at 1912 m. According to this figure Oksskolten should be the second highest mountain in Northern Norway, surpassed only by Suliskongen (1913 m) in the Sulitjelma range (67° 09′ N Lat.). Accurate surveys of Oksskolten, carried out in 1957 by the Geographical Survey, have as already mentioned above shown that the peak is in fact three metres higher than Suliskongen.

The second highest peak in Okstindan is Okshornet, 1907 m, one km to the south of Oksskolten. Three peaks are above 1800 m, three above 1700 m, six above 1600 m and a great many are above 1500 m. It may be mentioned that the height of Okstinden has been remeasured in 1957 and the altitude has been reduced from 1908 m to 1904 m.

Northern Norway is a mountanious region.

The dominating position of the Okstindan mountain group in northern Norway can be illustrated by the following facts:

The area of Okstindan is about 200 sq.km. The number of peaks above 1600 m in this region is 13. The area of the three northern counties is 113 000 sq.km, and the number of peaks above 1600 m is 235. The small area of Okstindan has consequently 5.5 per cent of the peaks of the altitude in the huge region of northern Norway.

Mr. Kr. Gleditsch, director of Norges Geografiske Oppmåling, has written a thorough and very interesting paper on the highest mountains in Northern-Norway (Nordland, Troms and Finnmarken counties.) Many of the figures quoted here are taken from his paper.

It might have been supposed that a mountain complex of this nature have consisted of hard rocks, gabbro and the like, but this is not the case. These mountains consists of softer rocks, especially mica schists.

Its boundaries with surrounding districts are clearly demarcated. These are formed by precipitous slopes, especially towards the east. To the west the mountains slope down more evenly to low flat foothills.

The tallest peaks are situated on two ridges running north and south. The easternmost of these stretches from Oksskolten to Svartfjellet.

DESCRIPTION OF THE GLACIERS

The glacier area of Okstindan is most extensive in the east-west direction, viz. approx. 16 km, whilst its north-south length is about 11 km. Its total area is 63.6 sq.km and this can be divided into three different parts.

1. An eastern ice cap, Østisen, between the eastern and western mountain ridges.

2. A western ice cap, Vestisen, to the west of the western ridge. These two areas are connected by two ice-covered passes.

3. Six smaller glaciers with separate firn basins.

1. *Østisen* is the highest. It rises to 1500 m in the west, and to 1620 m in the east, along the line from Okshornet to Okstinden. From here the ice runs towards both the north and the south, and a certain amount also flows westwards between Okstinden-Bessedørtinden to Vestisen.

The highest part of Østisen is situated near the peaks Oksskolten-Svartfjellet.

Towards the north flows *Austre Okstindbreen,* which further down curves off to the north-east. In its lowest part it divides into two tongues (Austre and Vestre arm). Its length is about 7 km and its width 3 km, and it terminates 750 m above sea-level. The catchment area of the glacier is 18 sq.km.

In a southern direction runs a very steep glacier, *Stekvassbreen,* which sends two arms down into Stekvassdalen. To the north is *Nordre Stekvassbreen.* It terminates on the north slope of the upper end of Stekvassdalen about 1 100 m above sea-level. Here the ice tumbles down precipitous 550 m slopes, producing a large regenerated glacier at the bottom of the valley. This glacier consists of pieces of ice of a size up to one metre in diameter. The horizontal distance between the most remote of the pieces of ice and the glacier from which they originate is 1000 m.

Vestre Stekvassbreen. Most of the ice of this glacier originates from a cirque bordered by a ridge to the north of Sørtinden (1562 m). It also receives a considerable affluent from the main glacier to the north. Its upper part runs to the south. It has an outflow glacier going to the east, a fine narrow icestream down the steep western side of Stekvassdalen and terminates on the flat bottom of Stekvassdalen with a mushroom-shaped frontal part.

The upper part of the glacier has many transversal crevasses and the lower numerous longitudinal ones.

The length of the glacier is approx. 4 km.

In the author's paper on Okstindan (1910) this glacier was treated under the heading Glaciers with separate firn basins. But as it receives a considerable amount of ice from Østisen it is more appropriate to consider it as an outflow glacier.

2. *Vestisen* has a convex surface sloping in every direction except to the east. The largest extent of this glaciercap is 8 km east-west, and it is 5 km from north to south. The upper portion of the glacier, facing towards Østisen, is situated at approx. 1600 m, and the central part at a height of 1440 m.

The bulk of the ice runs towards the northwest and has its outflow in four rather large glaciers, viz. Oksfjellbreen, Mørkbekkbreen, Jordbrubreen and Vestre Okstindbreen, reading from south to north.

Oksfjellbreen flows from the highest part of the Vestisen. It is very

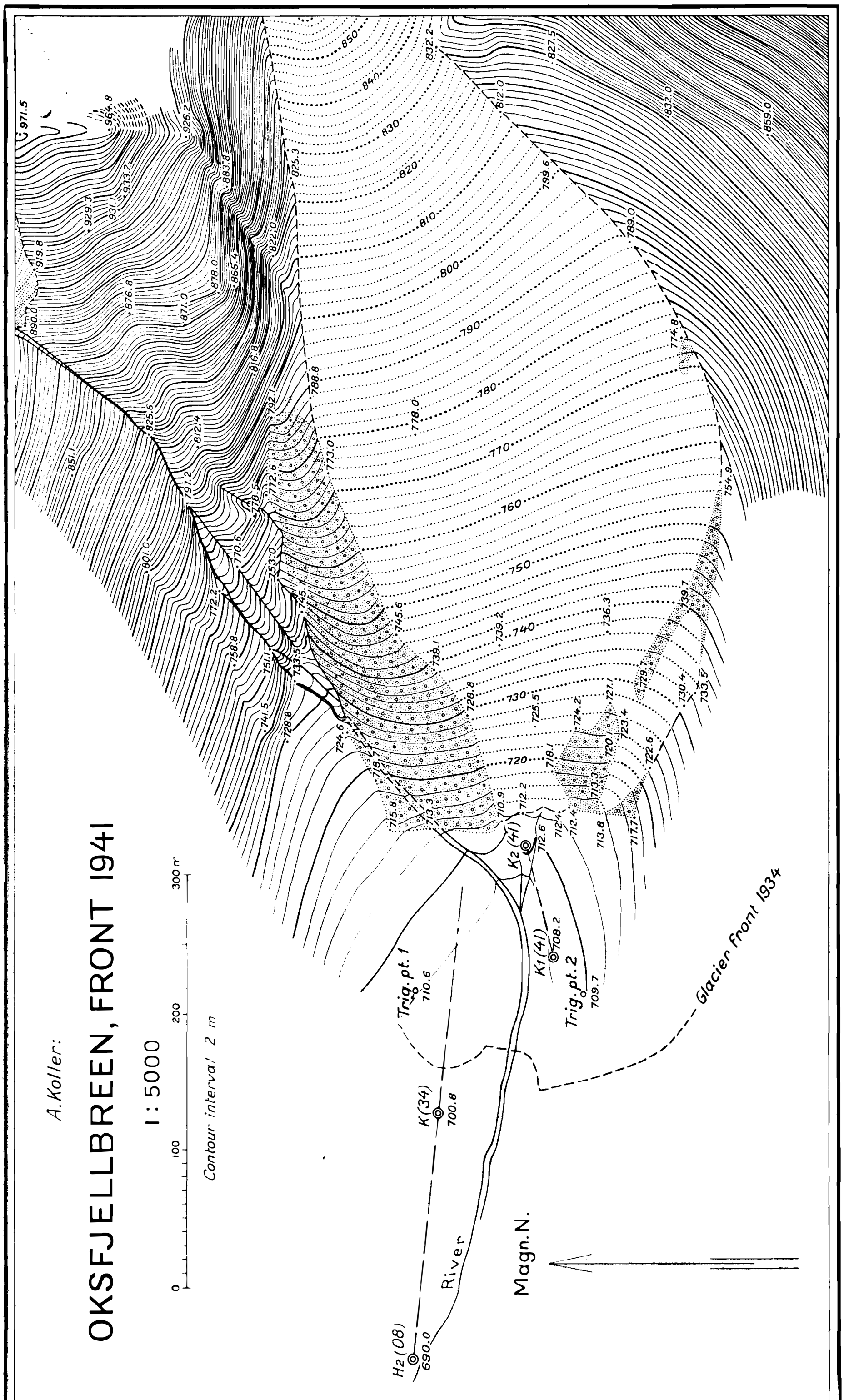
A. Koller:
OKSFJELLBREEN, FRONT 1941
1 : 5000
0
100
200
300 m
Contour interval 2 m
Magn. N.
River
Glacier front 1934
Trig. pt. 1
Trig. pt. 2
K(34)
K1 (41)
K2 (41)
H2 (08)

Fig. 64.

steep and flows first towards the south and at its lower extremity in a south-westerly direction. It terminates 688 m above sea-level in the Oksfjelldalen. It is 3 km long, while its width varies considerably. The catchment area of the glacier is 6.5 sq.km.

Mørkbekbreen runs first towards the northwest, but the lower portion flows precipitously down in a small gut towards the flat valley bottom, where it broadens out into a mushroom-shaped section with radial crevasses. It terminates at a height of approx. 840 m. Its length is 7 km.

Jordbrubreen is a short, steep, thin glacier. It consists of four narrow tongues which hang down a precipitous mountainside, and teminates by a small lake, Leirskarvatnet, situated at a height of 1000 m.

Vestre Okstindbreen has its source in the Østisen and Vestisen. It begins at the glacier divide in Østisen, and runs west through a narrow pass between the Okstinden and Bessedørtinden, after which it curves round first to the northwest and subsequently to the north, terminating at a height of 990 m above sea-level. It is approx. 6 km long.

3. *Glaciers with separate firn basins.* On the east side of the Okstindan, in the direction of Speltfjelldalen, the following glaciers are situated, reading from north to south.

Skoltbreen is situated in a cirque on the north slope of Oksskolten. It starts at a height of 1440 m and terminates 1250 m above sea-level. It runs to the north and is 1.1 km long and 1 km wide. Its area is 1 sq.km.

Charles Rabot breen, which is situated between Oksskolten and Okshornet runs towards the northeast. It is steep, and narrow, and almost reaches the saddle between these two peaks. It is 2.2 km long, and on an average 0.6 km wide. The area of the glacier is 0.8 sq.km. The catchment area of the glacier is 2 sq.km. It commences at a height of approx. 1710 m and terminates about 1020 m above sea-level.

The firn region of *Svartfjellbreen* is situated in a cirque bordered by a ridge with the peaks 1602, 1868 (Svartfjellet) and 1751. It flows in a south-easterly direction and terminates 840 m above sea-level. Its length is 2.8 km and its width, at its widest, a good kilometer.

Austre Stekvassbreen is a small hanging glacier on the south side of Svartfjellet, and joins up with Svartfjellbreen. Its length is approx. 1.4 km and its greatest width, which is at its uppermost extremity, is circa 0.8 km. It terminates in three small tongues 960 m above sea-level.

Bessedørbreen. The upper part of this glacier is situated in a huge cirque, the boundary of which is formed by a very steep ridge culminating in the peaks 1562 (Sørtinden), 1681 (Kvassnip), 1830 (Bessedørtinden), and also by an almost perpendicular wall stretching from Bessedørtinden to peak 1223. The upper limit of the glacier is just beneath these peaks. The glacier also obtains some ice from the Vestisen through

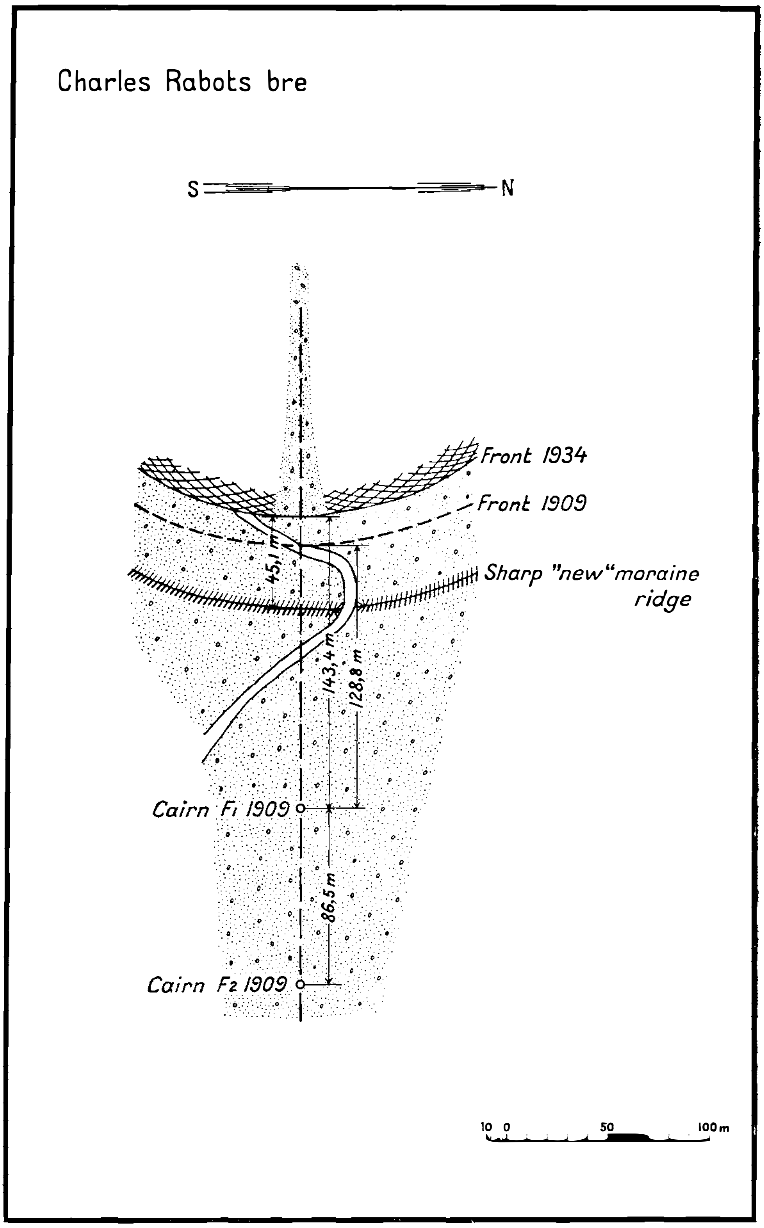

Fig. 65. Sketch map showing the variation of the front of Charles Rabots bre.

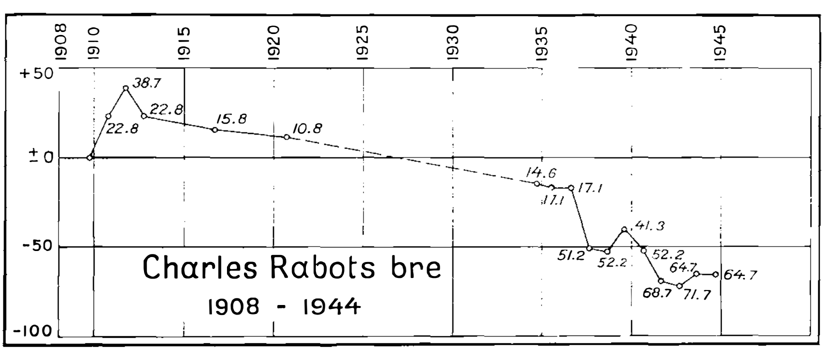

Fig. 66.

the pass to the north of peak 1223, where it is continuous with Oksfjellbreen. The glacier tongue is short and irregular and terminates at the upper end of Bessedørdalen at a height of about 770 m above sea-level. It flows in a south-southwesterly direction and has a length of circa 3 km and a width of 1.8 km.

On the north side of Oksfjelldalen there are *three small glaciers* clinging to the steep mountain side. Falls of ice occur from the eastern one, forming a little drift of ice.

THE FIRN LIMIT

I fixed the altitude of the firn line by measuring the altitude of the boundary between the ice and the snow on Austre Okstindbreen on 21st and 22nd August 1908. The altitude was determined partly by barometric observations and partly photogrammetrically. The boundary-line between ice and snow was very distinct and consequently easy to fix. I found the altitude to be 1350 metres above sea-level. The snow in 1908 had been subject to unusually severe ablation, and the altitude recorded was therefore above the mean average altitude of this line at that time.

SURVEY WORK FOR DETERMINING THE FLUCTUATIONS OF THE GLACIERS

Methods for measuring the fluctuations

The method here selected to determine glacier fluctuations was measuring with a tape from a cairn to the glacier front (measuring cairn) along a line fixed by this cairn and a directional one, a method previously used in Norway. It can be used as long as the movements of the glacier occur in a straight line, i. e. as long as the lowest point of the glacier is situated in the direction of the measuring line. In several cases, however, the line of flow of the glacier tongue forms a more or less curved line. As the glacier decreases, i. e. as the distance between the cairn from which the measures are taken and the glacier increases, a steadily increasing distortion factor will occur, and finally the measure obtained will be entirely illusory. In order to obtain reliable results in such cases, other and more expensive methods of measuring must be used, e. g. periodical surveys of the frontal area of the glacier and sufficiently large areas of the surrounding countryside of the glacier. In this way there are provided maps that can be compared with one another. In the case of glaciers with curved tongues new lines of direction must at intervals be surveyed for measuring, if this is to be done with a tape from cairn to glacier front. In flood periods glacial streams are liable to sweep away any measuring and directional cairns situated in their direction of flow.

When a glacier is retreating another disadvantage in measuring with a tape to the glacier front will gradually arise: the distance between cairns and glaciers will in time become so great that measuring becomes very difficult, and for this reason mistakes are liable to occur. It is therefore often necessary to move the measuring cairns nearer to the glacier front.

During the survey in 1934 there were also used tachymetrical and photogrametrical methods.

The author's survey in 1908

In order to determine the glaciers' fluctuations the author during his stay in Okstindan in 1908 set up cairns at the following glaciers: Austre Okstindbreen (Vestre and Austre arm), Vestre Stekvassbreen, Bessedørbreen, Oksfjellbreen, Mørkbekkbreen and Vestre Okstindbreen. He measured the distance with a steel tape from the cairns to the glaciers. In 1909 his assistent Per Kristoffersen Fjeldal, a farmer who lived in the vicinity of the Okstindan glacier, built cairns and measured the distance to the front of Charles Rabot breen. In all 8 glaciers were surveyed in this way.

Subsequently measurement of the glaciers was carried out in the following years by Fjeldal, but these ceased in 1922 as it was no longer possible to procure the necessary funds for this work.

Koller's survey in 1934

In 1934 and 1941, however, in connection with the author's and Werenskiold's glaciological investigations in Jotunheimen, p. 118, efforts to provide money for a continuation of this survey work were successful. Civil Engineer Alfred Koller, who participated in the work in Jotunheimen, was sent up to the Okstindan glaciers, where he carried out accurate surveys of the distance between the cairns and the glacier edge in connection with the mapping of glacier fronts with a tachymeter and a survey camera. His assistent was Jonas Tverå, the owner of Tverå Farm in the vicinity of the Okstindan.

Austre Okstindbreen, Vestre arm. The distance between my two cairns from 1908 was checked. In addition a new cairn was set up 127.1 m from the new front. From 1909 to 1934 the glacier retreat was 66.9 m.

Austre Okstindbreen, Austre arm. My cairns were found. A new cairn in a new line of direction was erected 233.1 m from the new front. Between 1908 and 1934 the glacier had retreated 169.7 m.

Charles Rabot breen. The two cairns from 1909 were found. The distance between the cairns was checked, and proved to be 86.5 m instead of 85 m as previously stated. Between 1909 and 1934 the glacier had retreated 14.6 m. Twenty-five m in the front of the edge of the glacier there was a sharp moraine ridge, which appeared to be of comparatively recent date.

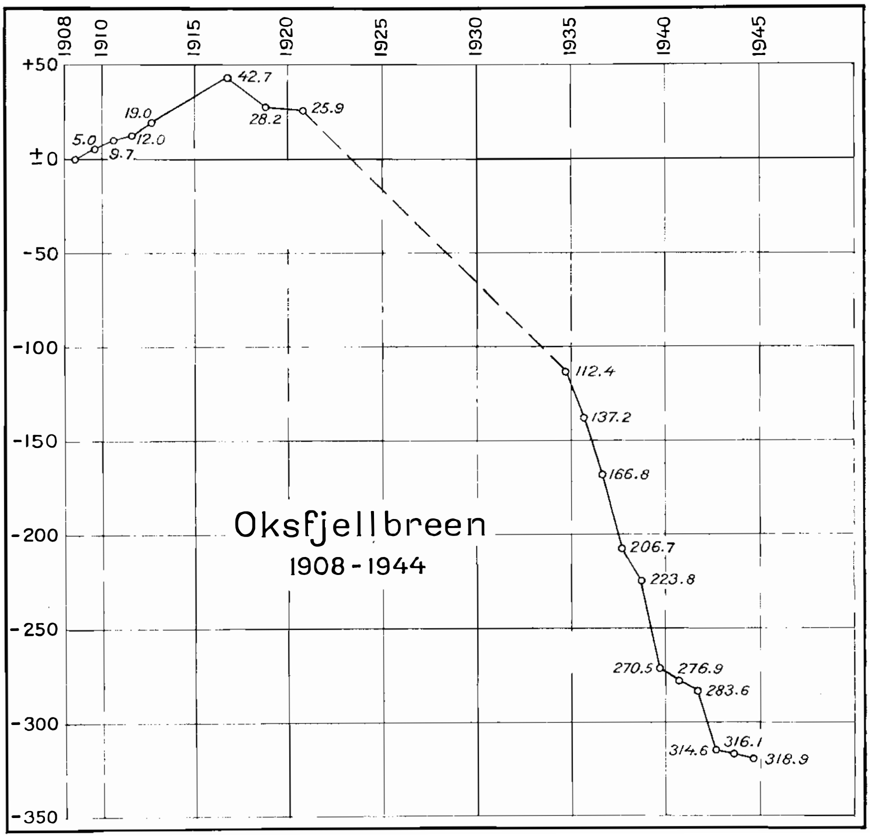

Fig. 67.

Vestre Stekvassbreen. The surveying of this glacier was rendered extremely difficult by a large glacial stream and by the fact that the tongue of the glacier had altered a great deal both in length and direction. The direction of measurement given by me no longer runs towards the point of the tongue, but comes approximately 25 m to the right of the point of intersection of the left edge of the glacier with the front line, in other words completely outside the glacier. A new cairn was erected closer to the front and at a distance of 68 m from my nearest cairn. By tangential sighting into the glacier front, perpendicularly to the previous direction of measurement, the retreat between 1908 and 1934 was determined at 249 m.

Bessedørbreen. This glacier had retreated very considerably. It was almost impossible to recognise it on the basis of the GeographicalSurvey's map and my photograph from 1908. During my visit to the glacier the front of the glacier faced in an easterly direction, while in 1934 it faced in a southerly direction. My eastern cairn was found, but not the western one, as it had probably been swept away by a glacial stream in spate.

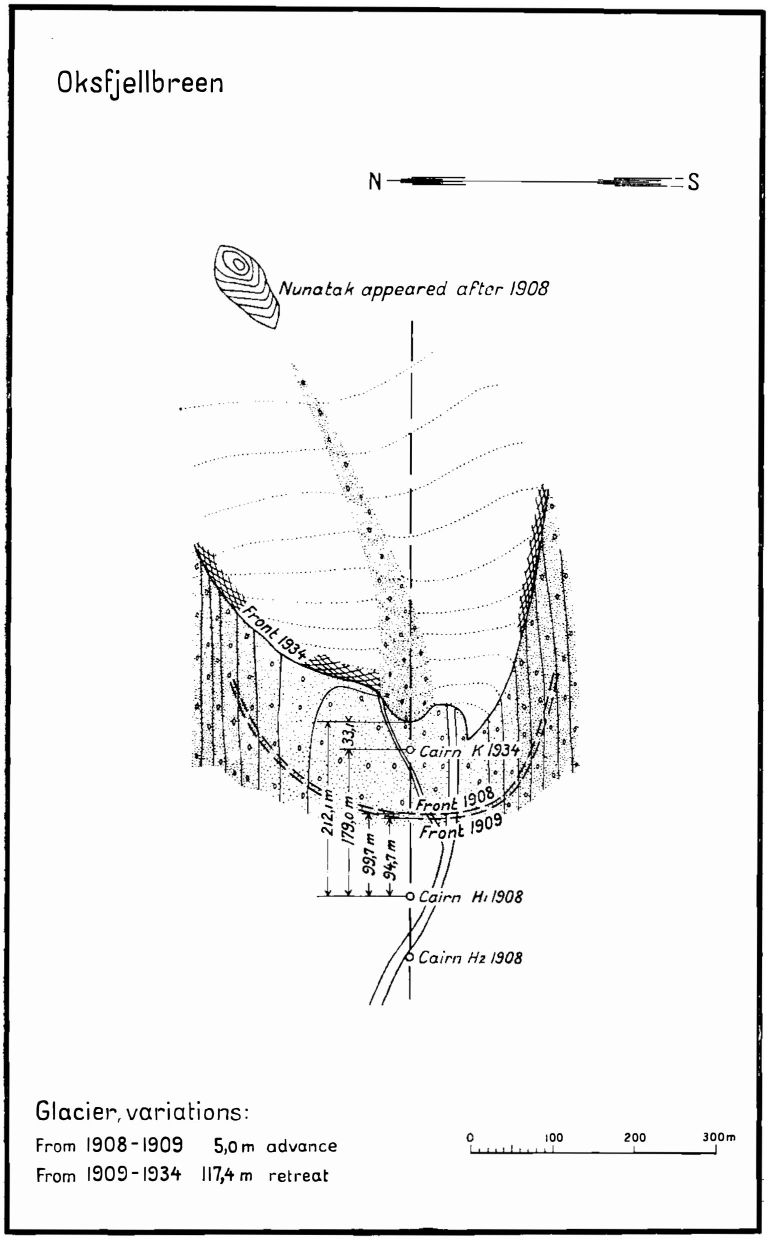

Fig. 68.

Owing to the completely new conditions prevailing on this glacier, Koller was forced to swing the line of measurement on a parallel basis 39.3 m due north until it reached the new glacier front facing east. The length of the new line was 1041.5 m, which placed it outside the glacier front. With the aid of a number of perpendicular measurements it proved

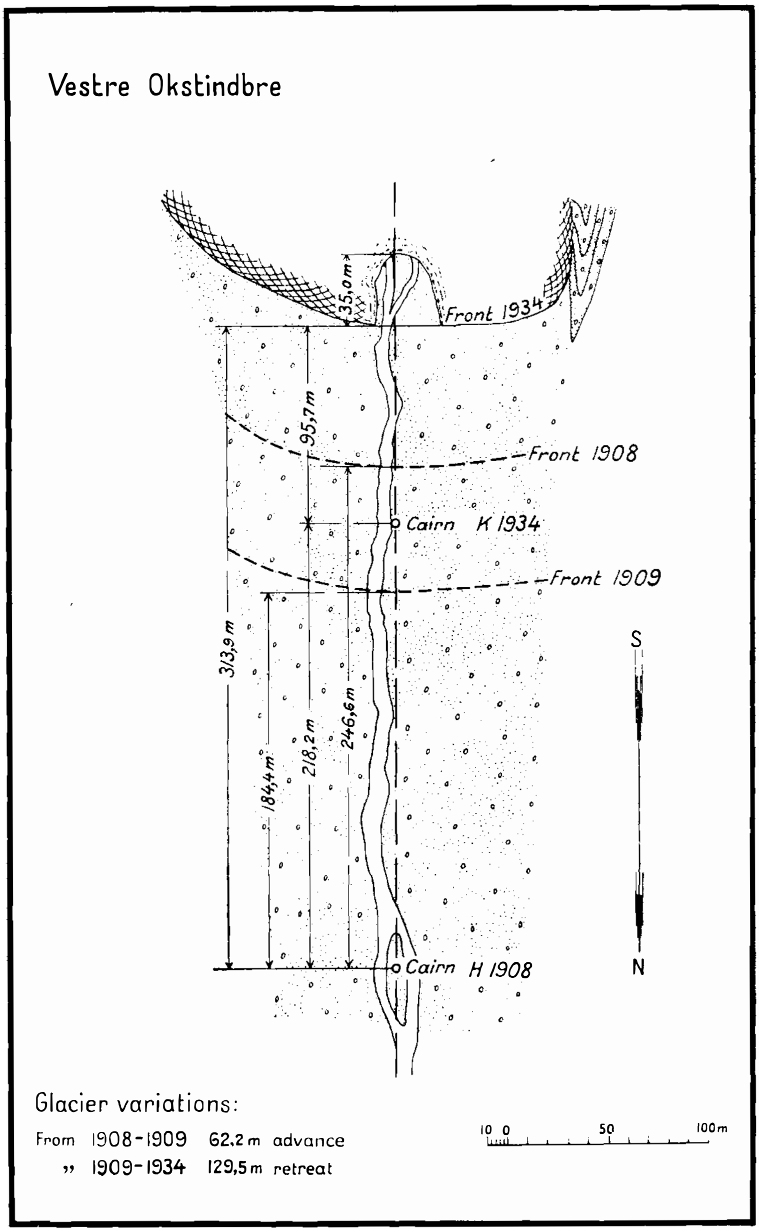

Fig. 69.

possible to plot the new position of the front. A direct comparison of the measurements for the distance to the fronts in 1908 and 1934 is therefore not practicable, but it is possible to assess the westerly retreat of the glacier at approx. 850 m.

Oksfjellbreen. Both my cairns were found and checked. Between 1908 and 1934 the glacier had retreated 117.4 m.

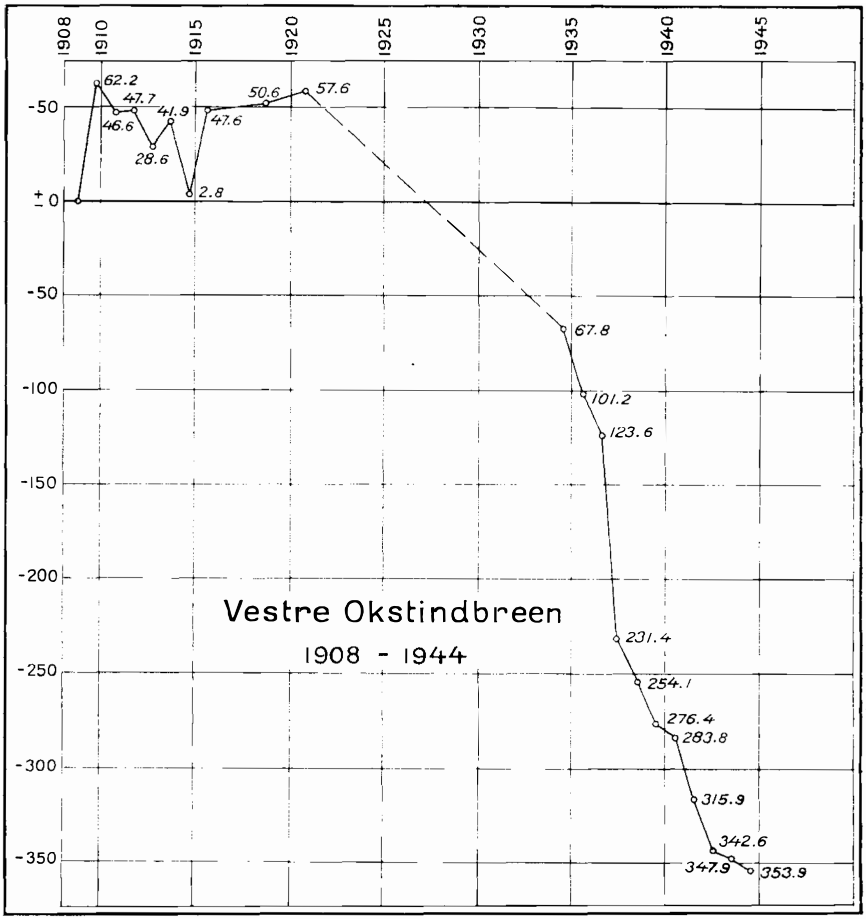

Fig. 70. The variation of the front of Vestre Okstindbreen.

Mørkbekkbreen. Both my cairns were found, and two new ones were erected closer to the glacier. The glacier had retreat 78 m since 1908. A sharp moraine edge, which was also measured, shows that during the period from 1909 to 1934 there had been a period of advance.

Vestre Okstindbreen. My cairns were found. Koller erected a new one 95.7 m from the new front. During the period 1909 to 1934 the glacier had retreat 135.5 m.

Koller's survey in 1941

During the subsequent years these glaciers were subjected to re-measurement by Koller's assistent, Jonas Tverå. As these check measurements showed that considerable changes were taking place in the glacier fronts, we considered it necessary in 1941 to re-check the measurements that had been undertaken. For this purpose Koller made his way to the Okstindan glaciers in that year. He remeasured all eight glaciers, which were surveyed in 1908 and 1909. Measurement took place during a period from August 18. to September 1.

Austre Okstindbreen, Vestre arm. The retreat was marked, but changes were not very great. Here two new directional cairns were erected, mainly for the purpose of avoiding flood damage. Observations were made at two stations. All the cairns, the entire front, certain points on the glacier, and a tarn in front of the glacial front, were tachymetrically surveyed. Two photogrammetrical relay stations facing the glacier, with four pictures in each, were taken.

In 1908 two streams flowed from the glacier. They joined forces and flowed down to lake Kjensvatnet. In 1941 the eastern watercourse had disappeared, and ran subglacially to the Austre arm of Austre Okstindbreen, which in turn runs down to Gressvatnet.

Austre Okstindbreen, Austre arm. Here a new measuring cairn was set up, but the direction of measuring was unchanged. Furthermore the entire glacier front and a number of points on the glacier itself were tachymetrically recorded. Photographs were taken from two relay stations.

Charles Rabot breen. A new directional line was set up a little to the left of the old one, and a cairn was erected at the end of it. The glacier front was tachymetrically recorded, and two photogrammetrical relay stations were taken.

Vestre Stekvassbreen. This glacier had become very small and thin since 1934. The narrow western glacier was still narrower, and there is very little left of the glacier down on the flat valley plain. Now there was a fairly large lake in front of the glacier. The old line of direction for measuring did not strike the glacier. A new measuring line was introduced, and two new cairns erected. Owing to the lake in front of the glacier it was impossible to make measurements direct from these cairns onto the glacier front. For this reason two extra cairns were set up, so that measurements were displaced in parallel. These two cairns are to be used as temporary measuring cairns. All cairns and the front were tachymetrically recorded. Two photogrammetrical stations were set up, thus providing a situation plan of the glacier and the area in front of it.

Bessedørbreen. This glacier had retreated markedly since 1934. It proved necessary to map a large area in order to obtain continuity in glacier changes. This work took no less than three day, and was carried out with a tachymeter and a camera. All cairns, the course of the streams, the glacier front, and the glacier were recorded. At the same time some of the trigonometrical points of the Geographical Survey were used in order that this special map might be used for the Survey's gradteigs maps. (1:100 000.)

From Bessedørbreen Koller made his way to Oksfjellbreen through

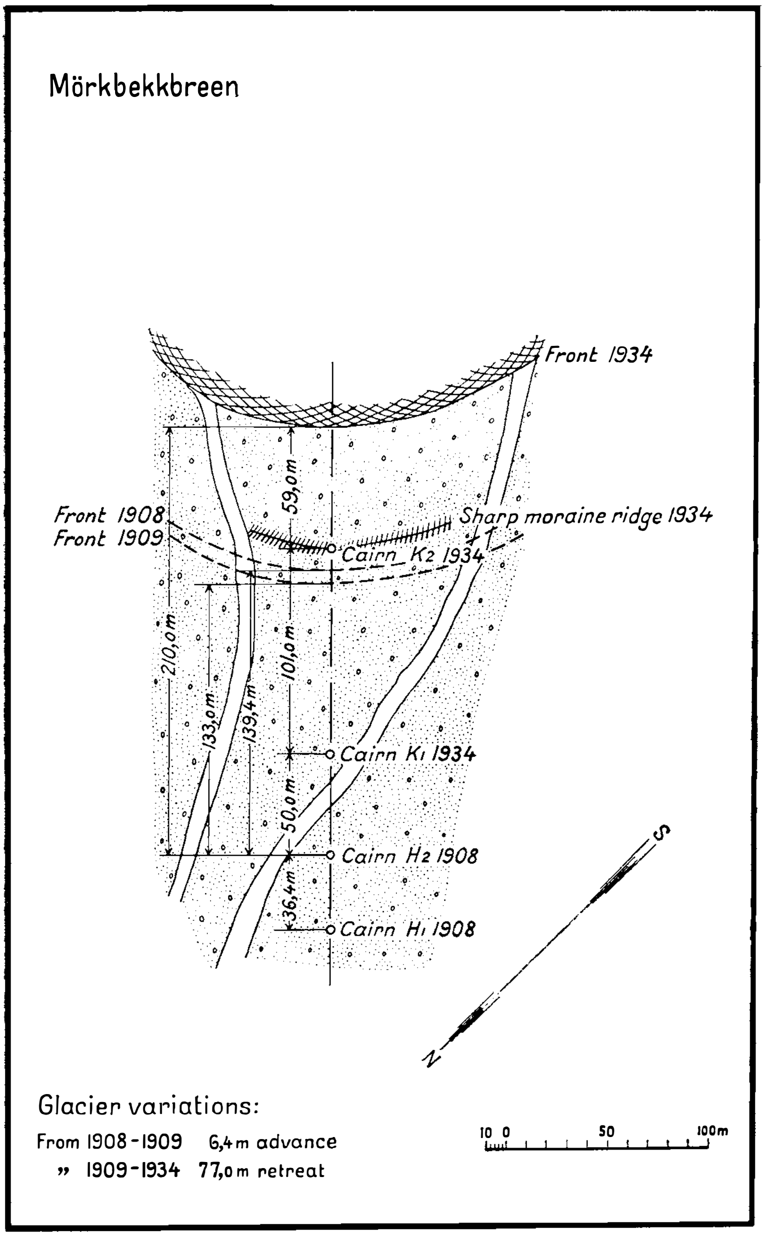

Fig. 71.

the pass between the two glaciers. This pass proved to be devoid of snow and ice for a distance of about 200 to 300 m. In 1934 it was covered with ice. Previously there were a great many crevasses in the glaciers on both sides of the pass, but now the glaciers showed signs of considerable ablation, and were almost devoid of crevasses.

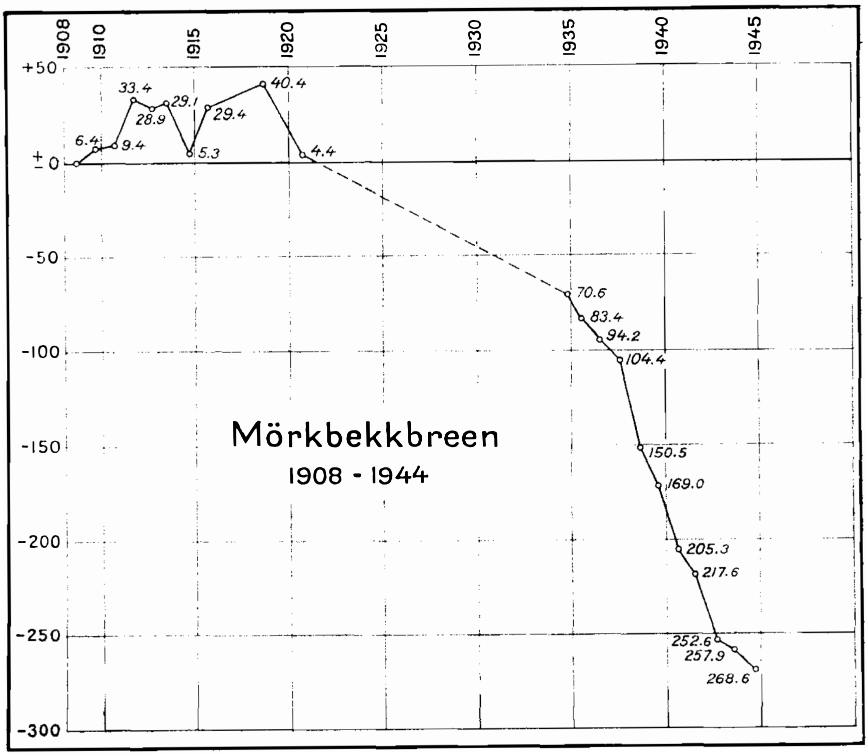

Fig. 72. The frontal variation of Mørkbekkbreen.

Oksfjellbreen had greatly changed its appearance. In 1934 an outcrop of rock had appeared, due to melting, in the middle of the glacier, and from it a central moraine ran down to the glacier front. In 1941 the entire right (northern) side and a very steep portion of the glacier had disappeared. The old central moraine had become a lateral one on the margin of the glacier. For this reason it was necessary to skift the measuring line further south. Two cairns were built. All cairns and the new glacier front were tachymetrically recorded. Two photogrammetrical relay stations were also set up.

Mørkbekkbreen. Tremendous changes had taken place on this glacier since 1934. The glacier had retreated considerably, and its direction of movement in its frontal points had changed completely. Three new directional cairns were erected, and of these the two furthest from the glacier are quite safe from flood damage. All lines of direction, both the old and the new, were tachymetrically surveyed (marked on the map), as well as the glacier front and a number of points on the glacier and part of the ground in front of the glacier, inter alia the new course of the stream. From two stations photograms were taken, so that it is possible to map the entire glacier below the icefall.

Vestre Okstindbreen. This glacier too, as might be expected, had

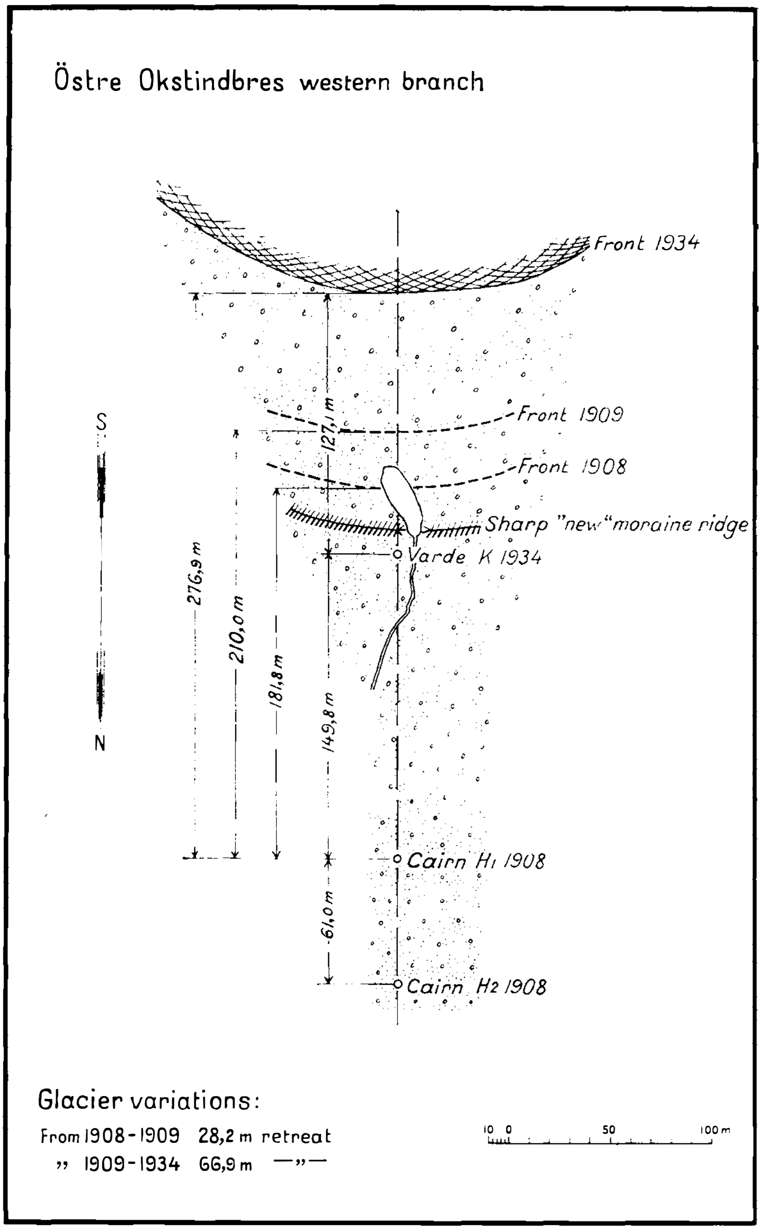

Fig. 73.

retreated considerably, but the direction of movement had remained unchanged, though the front was very uneven. A new cairn, closer to the front, was built on a flat boulder. It is not quite in the old direction, but is safe from flood damage. Observations were undertaken from two stations with a tachymeter. Both the old and the new cairns were included, as well as the bulk of the glacier front. A photogrammetrical panorama was taken from the topmost station.

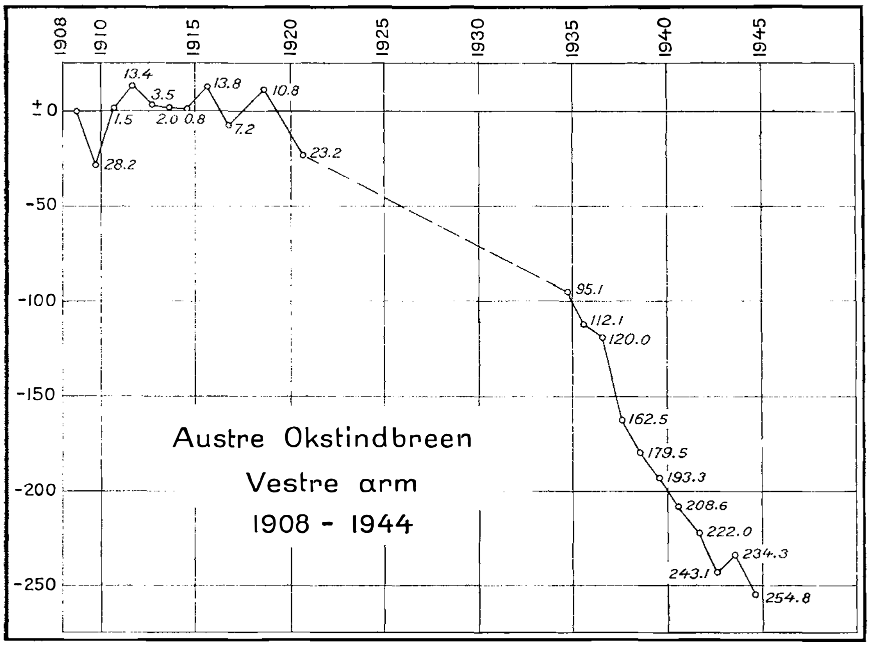

Fig. 74. Frontal variation of the western branch of Austre Okstindbreen.

FLUCTUATIONS OF THE GLACIERS

Moraines as evidence of fluctuations

Over the great extent of the glacierized area in the Quaternary period glaciers covered even the tallest peaks in Okstindan. This can be proved from the fact that I have found boulders transported by glacier-action up to 1800 m above sea-level.

The oldest evidence of changes in the modern glaciers in the Okstindan is supplied by moraines lying in front of some of them. Reference will here be made to some of these moraines as they were in 1908.

Austre Okstindbreen, Vestre arm. 1. Close to the front of this glacier there was a moraine two metres high which was in formation.

2. Immediately outside this a new and much larger moraine starts, terminating at a distance of 130 m from the glacier. It is completely void of plants and is consequently of comparatively new date.

3. At a distance of 150 m from it a third moraine starts. Its central ridge was 182 m from the glacier front. It is sparsely covered with crowberry (empetrum nigrum) and species of salix.

4. Finally there is a fourth moraine whose central ridge was situated 240 m from the edge of the glacier.

It is entirely covered with vegetation.

All these moraines were situated on the east side of the glacier

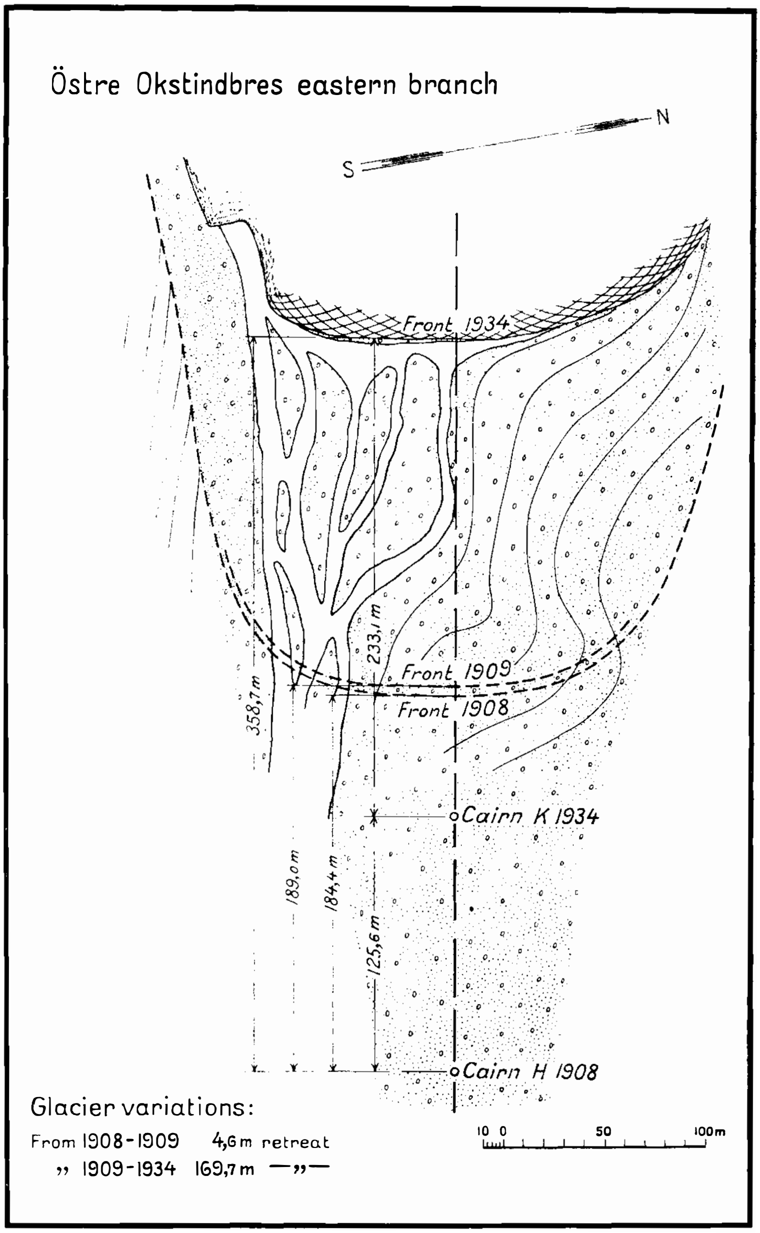

Fig. 75.

stream. On the west side there were only two moraines, a huge internal ridge, which was not covered with vegetation, and a small outer one overgrown with plants.

Austre Okstindbreen, Austre arm. In front of this glacier, too, there were four rows of moraines, but none of them of a considerable size.

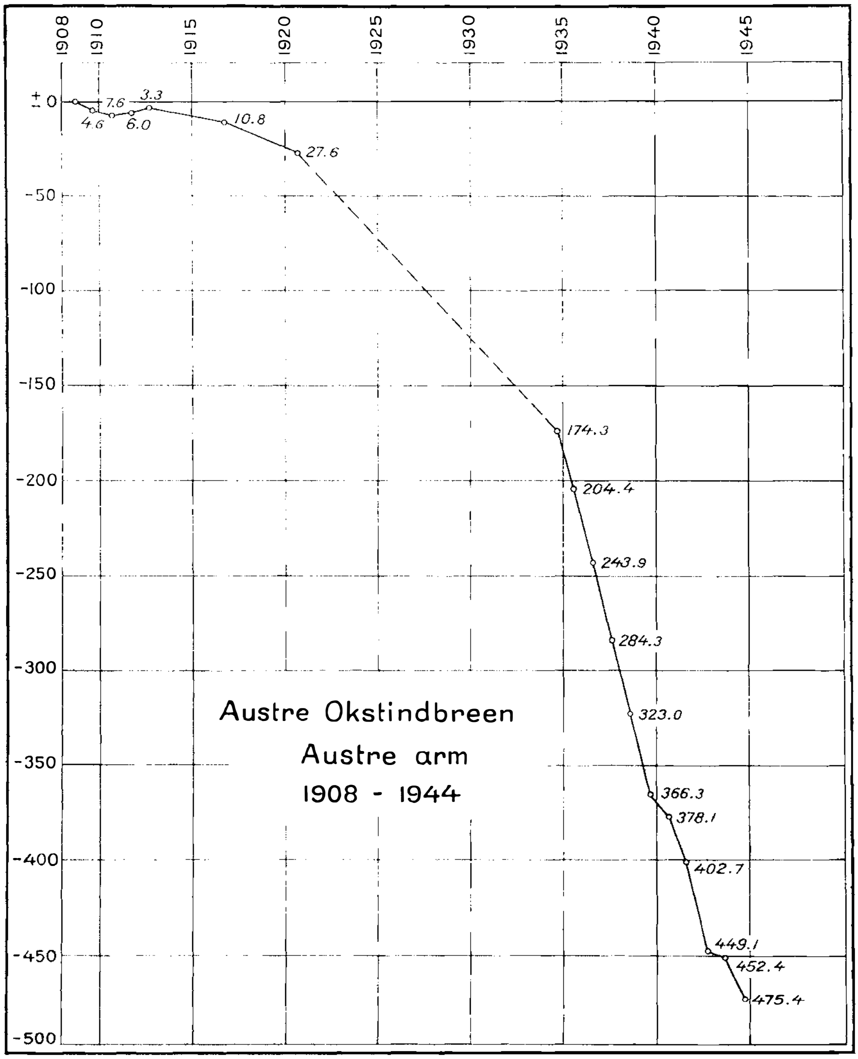

Fig. 76. Frontal variation of the eastern branch of Austre Okstindbreen.

Traces of a larger extent of Austre Okstindbreen can be seen on the mountain slopes framing the glacier. On the north side stretches a thin layer of moraine gravel as high as 40—50 m above the margin of the glacier. On the south side there is bare rock, up to the same level which therefore must have been scoured by the glacier at a comparatively recent date.

Some other glaciers in this region too have conspicuous frontal moraines. Here may be mentioned *Vestre Stekvassbreen* with five moraines. Their distances from the glacier were: 80, 280, 340, 420, 480 m.

On the west side of the upper part of *Mørkbekkbreen* there is a huge

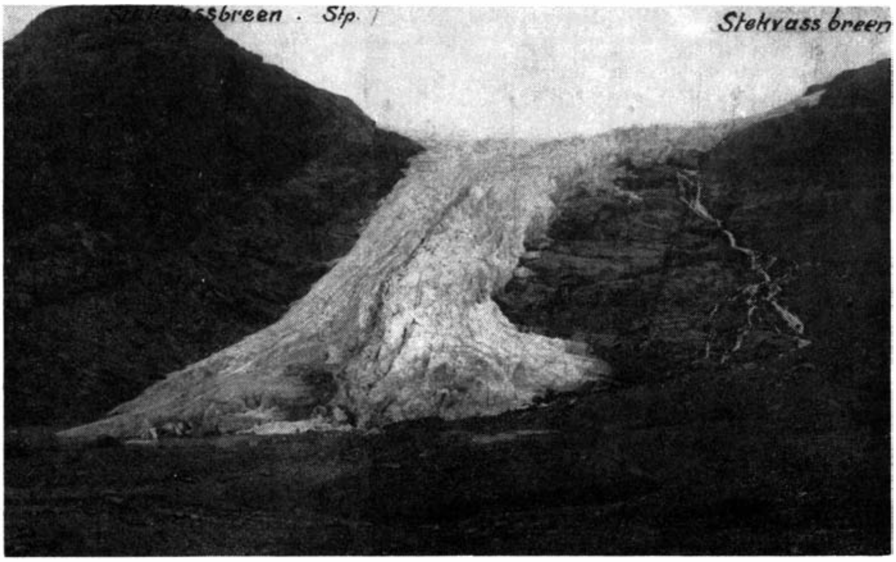

Fig. 77. The front of Stekvassbreen 1941. (Photo: Koller 1941.)

moraine. It is represented on the Geographic Survey's maps. It is 2.2 km long, 40—50 m wide and 10—20 m high. It consists of round stones and boulders. It is possible that a moraine of this large extent originates from the Quaternary Ice Age.

The outermost (oldest) of the moraines in front of the Okstindan glaciers probably dates from the great glacier advance which occurred in Norway during the first half of the 18th century, and the others from later and less marked advances at the beginning of the 19th century and continuing up to 1860—70. See also observations on moraine walls in front of glaciers in the Jotunheimen mountains.

Fluctuations according to observations by glaciologists in the 19th and 20th century

As mentioned above (p. 223) Okstindan was visited by two scientists in the last half of the 19th century, viz. the Norwegian geologist O. A. Corneliussen in 1875 and the French glaciologist Charles Rabot in 1883.

Corneliussen climbed inter alia Okstinden and from this peak he descended across Vestre Okstindbreen and Leirskarbotn to the Farm Tverrå in Leirskardalen. His journal contains as mentioned on p. 224 a good sketch map of Okstindan showing his route as well as a drawing of Okstindan from the west. (For the publication of the results of his journey, see also References.)

Accounts of Jordbrubreen and Vestre Okstindbreen exist by both Corneliussen and Rabot, and this makes it possible to some extent to

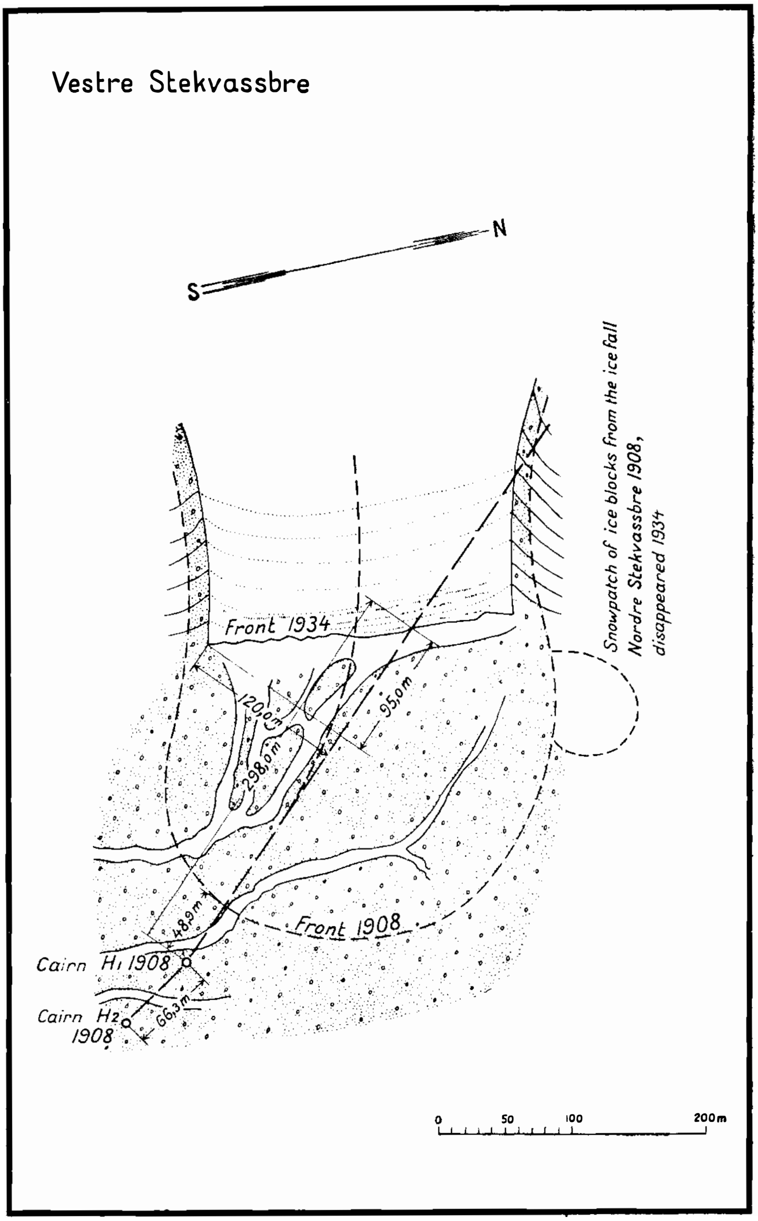

Fig. 78.

follow the fluctuations of these glaciers from the 1870's.

By comparing Corneliussen's and Rabot's observations it appears that these two glaciers have advanced considerably since 1875.

By studying the information made available by the two glacier

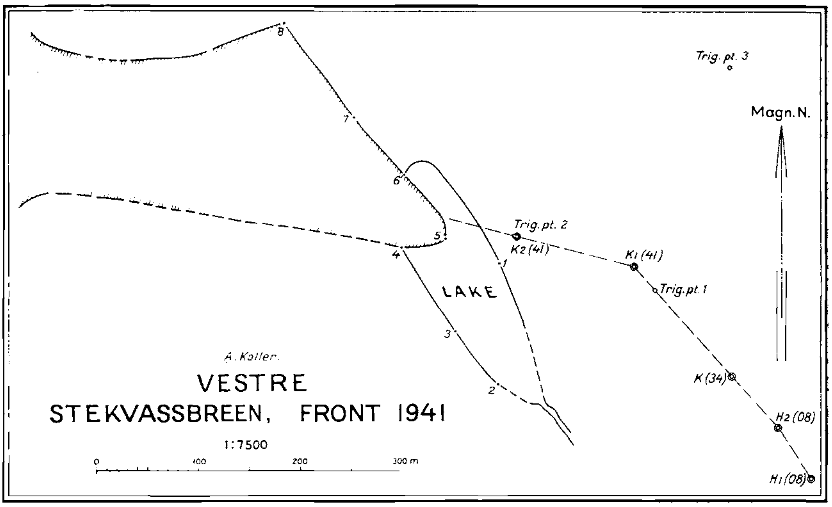

Fig. 79.

experts and furthermore by comparing the Geological Survey's map of the glacier surveyed in 1899, I have arrived at the following result:

Jordbrubreen. During Rabot's visit to this glacier it had about the same appearance as now: four steep branches ending in Leirskarvatnet. (See Rabot's drawing of the glacier and his description of it in his papers from 1898 and 1900.) Rabot's Lappish guide, Klemmet Persen Krokan, who was also my assistant in 1908, told him that seven years earlier these branches did not exist and the mountain side south of the lake was quite bare. The glaciers must thus have advanced about 600 m in the said space of time. Subsequently it appears to have remained unchanged, though it is probable that it advanced again some years after 1908 in common with the other Oxtindan glaciers.

Okstindbreen is the best known of the glaciers of the Okstindan mountains. From 1875 to 1883 the glacier advanced considerably. This advance continued until more or less the end of the 1890's. The total advance amounted to 1400 m. After that a period of stand-still followed, possibly succeeded by a minor retreat, after which the glacier once again started to advance, though evidence of this advance is available only for the year 1908—09.

Two of the surveyors of the Geographical Survey, who mapped part of the Okstindan area in 1891 and 1892, state in their reports to the Survey that the glaciers in this massif are receding. In support of this they quote information from local inhabitants, and mention moraines which must have been deposited in front of the present glacier from not so very long ago. The third of them considered the glaciers he had surveyed as stationary.

Fluctuations after 1908

The maps and tables in this paper indicate the changes that have taken place in all the surveyed glaciers. The most remarkable feature is an advance of which evidence was not obtained until 1908—09. This advance continued until 1912, and in the case of Oksfjellbreen until 1917. While this advance of the Okstind glaciers had been concluded, all the glaciers in Okstindan area started retreating. This retreat has been particularly rapid subsequent to 1925.

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Lars And. Thodal, David Mackuer, Jørgen N. Holm, Nils Marelius, Nicolai Frid. Krogh, Eric Wetterstedt.
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Glaciers between Ofotfjorden and Tysfjoden

(68° 18′ — 67° 46′ N. Lat.)

THE FIRST MAP OF THE REGION

The first map of Frostisen is to be found on the map of Northern Norway published in 1852 by the illustrious Norwegian historian, linguist and geographer P. A. Munch, Professor at the University in Christiania (Oslo).

The topography of the region between Ofotfjorden to the north, Tysfjorden to the west and the border between Norway and Sweden to the southeast was at that time practically unknown.

In a letter of May 17th 1846 to the below mentioned Helsing, Munch describes this region as one of the "darkest parts" of the topography of the whole of Northern Norway.

The sources for Munch's map of this area were the official coastal maps and the original border maps based on the treaty between Norway and Sweden signed in Strømstad 1751 (see pp. 219—220). These maps provided him with fixed points along the coast and along the border. The topography of the interior of the country he got from "Pontoppidan and other more or less trustworthy sources" (letter of August 26th 1845 from Munch to Helsing). These sources were probably in the main people in northern Norway who were more or less acquainted with the region in question.

His best informant was H. H. Helsing, teacher at the Trondenes Training college (near the town of Harstad). But as he lived far north of this unknown region he had no personal knowledge of it. He therefore wrote to the district police superintendent in Ofoten, Mr. Schjølberg. It was difficult even for this man to get information on the mountains and glaciers south of Ofotfjorden. The Norwegians were all unfamilar with the areas outside their own goat pastures. Those who knew the mountains were nomadic Swedish Lapps who crossed the frontier to reindeer pastures in Ofoten and Tysfjorden in summer.

The superintendent charged one of these Lapps, whose name was Ronka-Lasse, with the task of drawing a sketch of Frostisen and the country to the south of this glacier. This sketch was forwarded to Munch

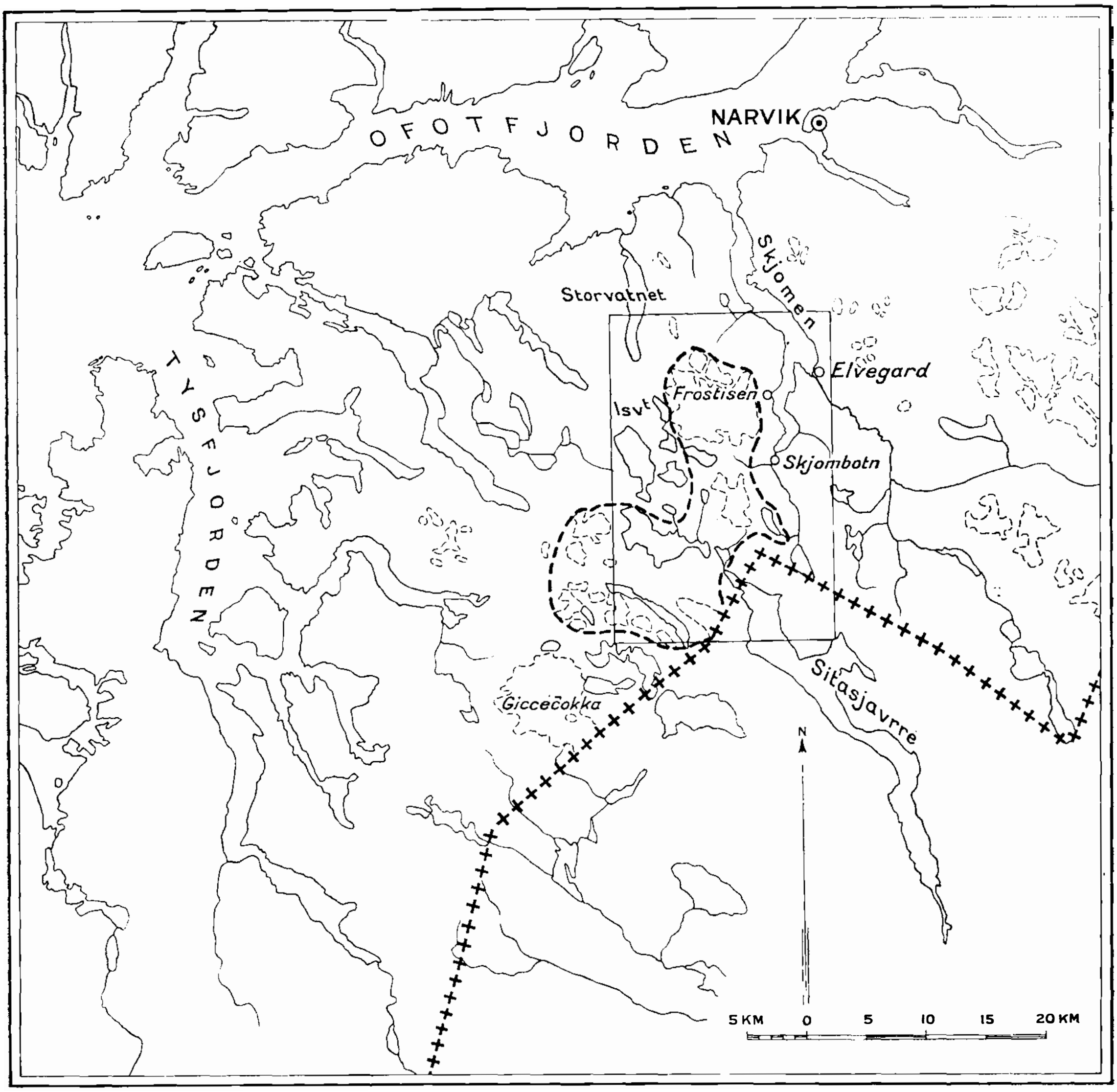

Fig. 80. Map showing the area investigated.

and by him used in preparing his map of northern Norway. But we know nothing of the value of the Lapp's sketch for Munch's mapping of Frostisen, as it does not exist in the archives of Munch that are deposited in the University Library in Oslo. It was probably of little use to him.

On Munch's map a large glacier is depicted south of Ofotfjorden. The northern end lies west of the southern part of Skjomen. The south-eastern end is situated west of the Swedish lake of Sitasjavvre just north of the border, and the south-western portion six km east of the head of

Tysfjorden. Its total lenght from north-east to south-west is a good 26 km. and its greatest width from east to west 19 km. This would give Frostisen an area of about 240 sq.km, and would make it a glacier of considerable size, second only to Svartisen in the whole of North-Norway, the latter having an area of 480 sq.km.

It is strange that on Munch's map Frostisen should be given an area more than five times its true size. The explanation is that there are many glaciers south of Frostisen. Some are fairly large. These glaciers are all, except for a few minor ones, ice caps situated along the main Scandinavian watershed.

Furthermore glacier names like Frostisen and Svartisen (lit. "black ice") are not only proper names in this region but indicate the actual idea of ice. Some small glaciers in the Tysfjorden region were also designed as "frostis". Munch had beyond doubt been told of these "frostises", and believed that, together with Frostisen at Ofotfjorden, they constituted a continuous large glacier.

Munch's map of the Ofoten-Tysfjorden region was the source of later maps of this area, and the first map on which the name Frostisen is to be met with. Various details were naturally corrected in the course of time, but the map of Frostisen was practically unchanged. The last of the subsequent maps was Per Nissen's map of northern Norway published in 1905. This was consequently the map that I had to use when I undertook my glaciological work in this region in 1906. Apart from the information available from the maps, little was known of Frostisen before 1906. Few references are to be found in print. It was known that an outflow glacier calved from a 900 m high mountain near Frostisen farm on the west side of Skjomen. The inner part of this fjord contains some of the most splendid natural scenery in Norway and it is often visited by tourist steamers. Charles Rabot mentions it very briefly, as does Yngvar Nielsen, and there have been occasional references to it in the handbooks published by Norwegian tourist organisations.

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THE FIRN LIMIT

In order to determine this limit I measured (in 1906) the height of the limit of the snow on many glacier tongues. On Frostisbreen, Nordre arm, I found this limit be 1100 m. Similar figures were observed on other glacier tongues. As there was much snow in the mountains this summer, it is therefore possible that the limit in a summer with thin snow cover is higher.

Gunnar Holmsen has introduced a new method for determining the firn limit (Holmsen, Snegrænsen i Norge, Kr.a. 1916.) He has measured the total area of eternal snow and ice on each sheet of the Geographical Survey's maps, scale 1: 100 000. He has compared this area with the area between certain level curves. For all map sheets on which a considerable area of ice-field and glaciers occurs he has drawn up the hypsographic curve. From this curve he has been able to determine the height of the area of snow and glaciers on the map sheets. With the help of this procedure a part of the local factor's variations is smoothed out.

On p. 141 Holmsen (1916) has a list of the height of firn limits. On the Ofoten map sheet he found this height to be 1100 m. This map sheet comprises the region immediately to the north of Frostisen and Mereftasfjellet. On Umbugten map sheet near Okstindan he indicates a height of 1300 m.

Steinar Foslie (1941, p. 257) has used the same method in order to determine the firn limit on the Tysfjord map sheet. He found that it was 1090 m.

The results obtained by Holmsen and Foslie agree very well with my own figures.

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THE MORAINES

As a rule there are no moraines on the surface of the glaciers in this region. The only exception is at Giccečoka where a conspicuous one stretches north-south from point 1249 (Foslie 1941, p. 257).

But there are more or less marked terminal moraines in front of most of the glacier tongues. The extention of these groups of moraines is not large. On the map sheets of Skjomen and Tysfjord, surveyed 1909 —16, the distance from the glacier to the furthest moraines does not exceed 200 m. But since then the temperature of the air has risen considerably. As a consequence of this the glaciers are much shorter than before, and their distance from the fronts is now much greater.

Outside these terminal moraines the rock ground is in most places completely free from basal ground moraines of the Quaternary period. This contrast between an area practically without moraine cover and the narrow belt of terminal moraines is observed everywhere in Nordland county.

We also have similar moraine ridges in front of the glacier tongues in southern Norway. The outmost ones date from the large advance of the glaciers in the first half of the 18th century which culminated about 1750. In the following 200 years the trend of the glaciers in southern Norway has mainly been one of recession, though interrupted by minor advances during which the inner moraines have been deposited.

It is beyond doubt that the moraines in northern Norway date from the same time as those in the southern part of the country.

In the later stone age 2700—1500 years B. C. and the older bronze age 1500—800 B. C. the climate was dry and warm, up to 2°C higher than now, in the northern countries. At this time probably all the glaciers in Norway disappeared. But in the following years up to the birth of Christ they again reappeared.

It is obvious that the glaciers known to us in the middle of the 18th century had their maximum extent during the last 2000 years.

The terminal moraines are dealt with in the description of each glacier.

Frostisen.

The name Frostisen has been used with two different meanings: sometimes the name refers to the ice cap and its outflows, and sometimes it covers the ice cap and the surrounding small glaciers with their own firn basins.

In this paper the name Frostisen is used exclusively in the first-mentioned sense.

POSITION AND MAPS

Frostisen lies on the west side of the inner part of Skjomen, which is a south branch of Ofotfjorden, west of Narvik. The centre of this glacier is situated at 68° 14′ N lat. and 17° 11′ E long.

Frostisen is represented on two of the Geographical Survey's gradteigs map sheets: Skjomen, surveyed 1914—16, published 1919, and Tysfjord, surveyed 1909—15, published 1917. The scale of these maps is 1: 100 000. See also:

Norges geografiske opmåling (ed.), Topografisk beskrivelse til gradavdelingskart M 10 Tysfjord, Kr.a. 1922. — Norges topografiske beskrivelse H. I.

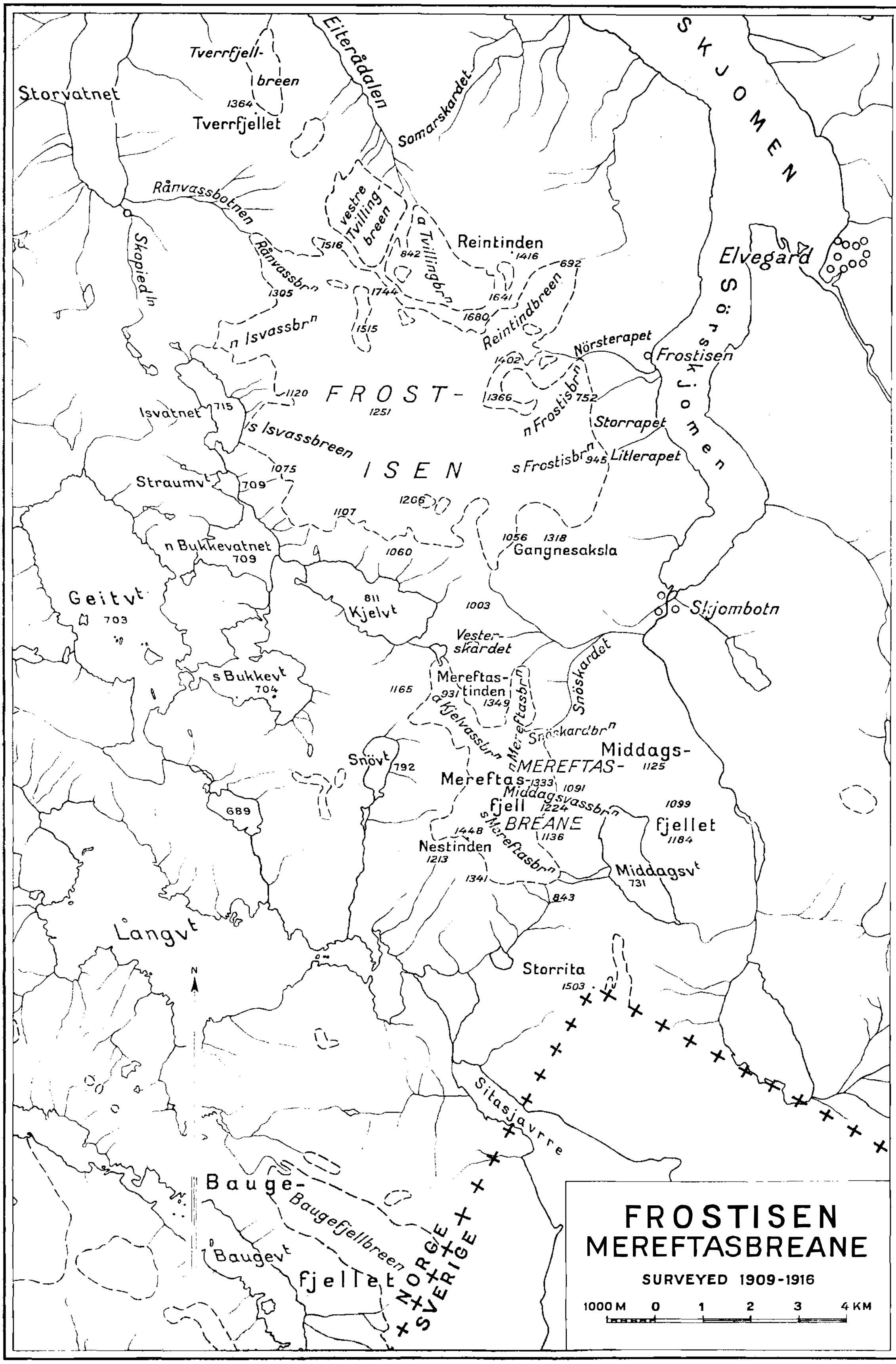
Storvatnet
Tverrfjell-
breen
1364
Tverrfjellet
Eiterådalen
Somarskardet
SKJOMEN
Rånvassbotnen
Skopiedln
vestre
Tvilling-
breen
a Tvillingbrn
Reintinden
1416
692
Elvegard
1516
842
Rånvassbrn
1305
1744
1641
Reintindbreen
1680
Sörskjomen
n Isvassbrn
1515
Nörsterapet
Frostisen
1402
FROST-
ISEN
1120
1251
1366
n Frostisbrn
752
Isvatnet
715
s Isvassbreen
Storrapet
s Frostisbrn
945
Litlerapet
1075
Straumvt
709
1206
1107
1056
1318
Gangnesaksla
n Bukkevatnet
709
1060
Geitvt
703
811
Kjelvt
1003
Skjombotn
Vester-
skardet
s Bukkevt
704
Mereftas-
tinden
1349
1165
931
Snöskardet
Snöskardbrn
Middags-
1125
Snövt
792
n Mereftasbrn
a Kjelvassbrn
MEREFTAS-
Mereftas-
1333
1091
Middagsvassbrn
fjell
1224
BREANE
1099
fjellet
1184
689
1448
1136
s Mereftasbrn
Nestinden
1213
1341
Middagsvt
731
843
Langvt
N
Storrita
1503
Sitasjavrre
Bauge-
Baugefjellbreen
Baugevt
fjellet
NORGE
SVERIGE
FROSTISEN
MEREFTASBREANE
SURVEYED 1909-1916
1000 M 0 1 2 3 4 KM

Fig. 81.

17

Norges geografiske opmåling (ed.), Topografisk beskrivelse til gradavdelingskart N 10 Skjomen, Kr.a. 1922. — Norges topografiske beskrivelse H II.

HISTORY OF THE NAME

(See the corresponding chapter in my paper on The glaciers of The Oxtindan Mountains.)

The material to the following account is in the main due to the courtesy of Pastor Kristian Nissen, authority on old maps, and the local secondary school teacher Mr. J. Norvik, to whom I would like to convey my best thanks.

In my paper on the glaciers of the Okstindan mountains I have mentioned that the oldest known name of these mountains dates from 1640. It is to be found in the Swedish surveyor Olof Tresk's paper "Relation över Fjällryggen mellan Sverige, Norge och Ryssland" (Relation up on the mountain range between Sweden, Norway and Russia.) Tresk was sent by his government to the Swedish Lappmark and had orders to survey this region and submit a proposal for a Swedish frontier with Norway and Russia.

He travelled in this region from 1635 onwards. His report is dated March 1640.

Mr. Tresk also worked in the region east of Frostisen.

At that time very few Swedes lived in those unhospitable boundary regions; his witnesses with regard to the course of the border line to be determined, were mostly Lapps, and therefore most of the names quoted are Lappish. He came into far less contact with Norwegians, if any. He seems often not to have known their place-names. For instance, he calls the Norwegian locality Børgefjell in Vefsen Bärgewara. It is therefore not surprising that he does not know the name Frostisen, but speaks of an Jissward (p. 24), i. e. Ice Mountain. The Lappish word ward or varre means mountain. The first element in the name (Jiss) is borrowed from the Nordic *is*, the genuine Lapp equivalent being jiekke. (See Qvigstad, Nordische Lehnwörter im Lappischen, p. 200.)

The name of Jissawara is to be found on Tresk's map of Torne Lappmark.

That Tresk's name refers to Frostisen, is beyound all doubt. The position of this place between the mountains of Pukewara and Uluckilswara is strong proof in support of this interpretation.

At a later date in the 17th century Nissen failed to find the name Frostisen mentioned by name in any form either in writing or on a map. Nor did it occur on any boundary maps from the period before or after the Treaty of Strømstad was signed in 1751.

About a hundred years later Major Peter Schnitler vas dispatched by the Norwegian government on the same mission as Olof Tresk, viz. to determine the border between Norway and Sweden. His boundary investigations extended from Dovre mountain i southern Norway to east Finnmark, and covered the period from April 1742 to November 1743.

He used far more Nordic names than did Tresk, even Lappish names of Swedish localities, e. g. Tresk's Nasawara is called Nasa-Field, and the lakes Virijaure and Vastenjaure are called Verri Vatten and Vastein Vatten. It is therefore not to be expected that he should use the name Isawara for Frostisen.

Schnitler made a topographic description of Ofoten based on the evidences he obtained in August 1743. His information on Frostisen runs as follows:

"I Skiomen Indfiord paa Vestre Side ½ Miil fra Botten er *Fraases* field, efter Længden ligger fra Nord-vest i Syd-ost ¼ Miil, halv saa bredt, paa den nordvestlige Side hvit med en Spidz Tinde ovenpaa, er paa Østre Side saa brat som en Muur, overpaa Vinter og Sommer med Iis tækket, dog Tinden bliver Snee-løss, paa Sidene snaut og bart."
(English translation: In the inner Skiomen Fiord on the west side ½ mile from Botten lies Mount Fraases, in lenght from north-west to south-east ½ mile, and half as wide, on the north-west side tall with a pointed peak on top, on the east side steep as a wall, its upper part covered with ice winter and summer, though the peak is sometimes snow-less, its sides are bare (Note: 1 Old Norwegian mile = about 6½ Eng. miles)).

See Qvigstad og Wiklund, Dokumenter angaaende flytlapperne, I, p. 201. See also ibid. p. 246, which contains an account entitled "Riktig Mantal over fjeldfinner . . . i Ovenes Præstegield (Eng. transl.: Exact census of mountain Laplanders in Ovenes ecclesiastical parish) by a Lapp schoolmaster Henrich Ruuth, from June 15th 1743. This mentions a mountain in "South Sciumen" called "Fraasis".

Schnitler's name for Frostisen is strangely enough not to be found on his comprehensive map of Nordland amt 1743/44. On the other hand we find the name Isvand, (Isvatn) on the west side of Frostisen, which shows a certain knowledge of this region.

Nor did any name for Frostisen occur on the official frontier maps of about 1751. It is therefore understandable that no name for this glacier should be found on the Swedish Engineer Nils Marelius' meritorious map from 1772 of this region. His maps were much used from this year onwards as a basic source for maps on which the border between Norway and Sweden was marked off.

In 1938 Qvigstad published "De lappiske stedsnavn i Finnmark og Nordland fylker" (The Lappish place-names in Finnmark and Nordland counties), and there he also mentions (p. 207) Isa-varre, i. e. Frostisen.

The *farm Frostisen* is in the Norwegian vernacular called only Isen or punn Isen (up under the Ice). (Rygh, Norske Gaardsnavn. B. 16, p. 288.)

It is not to be astonished at when the Lapps call this farm Jiekke (Jøkul) or Jiedupa (the Ice).

The first time we meet with the name Frostisen is on P. A. Munch's map of northern Norway in 1852. (See the chapter The first map of the region p. 252.)

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Tresk, Olof, Relation om Fjällryggen mellan Sverige, Norge och Ryssland (1640). See Ahnlund, Nils.

TOPOGRAPHY

Frostisen is a typical ice cap situated on a comparatively flat mountain. Outflow glaciers radiate to the east, north-west and south-west.

To the east Frostisen is bordered by the inner part of Skjomen where a steep mountain rises to ca. 900 m. At the edge of the precipice this glacier ends with a c. 40 m high cliff. The surface of the glacier here is consequently approx. 940 m above sea level.

From Skjomen the glacier rises to the west, at first slowly then more steeply, and then once more gently.

Beneath the upper part of the Frostisen ice cap that culminates in a rather flat cupola about 1250 above sea level the under-lying mountain rises fairly steeply. The north side of the mountain appears in the form of a semicircular, perdendicular bare rock-wall 400 m high, on the top with a cover of snow and ice 40 m thick. A few glacier-covered ledges can be seen at intervals on this wall.

Similar conditions prevail too on the south-west side of the summit. See photo, fig. 6. From the highest part of the ice cap the glacier slopes gently off to the west.

To the north Frostisen is confined by extremely wild, steep, often vertical or even overhanging narrow walls facing the cirque at the upper end of Eitrådalen.

On the east side of Reintinden there are two cirques lying beside one another and facing Eitrådalen. They are occupied by glaciers. The knife-sharp edge south of these cirques culminates in the peak Reintinden, 1416 m high. The edge is highest in the western part, 1744 m and this is the lofties peak in the whole Frostisen region.

The ridge continues from this peak to the north-west, to point 1516 m. From here and to the south-west the edge is overhanging. This about five km long ridge is very narrow and rises 200—300 m above the surface of the glacier.

From point 1516 m the mountain curves to the north and declines gently as a broad ridge towards Eitrådalen.

To the southeast of this we have a steep short cirque glacier flowing to the north-east.

To the north-west the mountain area on which Frostisen is situated continues as a ridge with steep sides between Storvatnet and Eitrådalen. Its greatest altitude is reached in Tverfjellet 1364 m. It has on the east side a cirque glacier.

To the west and the south-west Frostisen is bordered by a shallow valley running north-south. In the bottom of this valley there are four lakes, Isvatnet (715 m) in the north, then comes Straumvatnet (709 m), Nordre Bukkevatnet (709 m) and Kjelvatnet (811 m). To the north of these lakes there is a valley running north to Storvatnet. The length of these two valleys bordering Frostisen to the west is 12 km.

From Skjombotnen a deep valley, named Vesterskardet, runs to the west. It ends in a cirque east of Kjelvatnet. Together with the eastern part of Kjelvatnet it forms the south boundary of the Frostisen area. The mountain slopes abruptly down into this valley and no glacier tongues occur here. It separates Frostisen from Mereftasfjellet. The distance between these two areas is c. 4 km.

EXPLORATION IN THE 19TH AND 20TH CENTURY OF FROSTISEN AND MEREFTASBREENE

The first thorough examination of Frostisen and Mereftasbreene was carried out by the author in 1906. This work was performed at the request of Amund Helland, Professor at the University in Kristiania (Oslo). He was the author of the monumental work Norges land og folk (Norway's country and people). The description of each county (amt, fylke) formed a separate part of the work. In 1905—06 he was ready to start the description of Nordland county, but in this part of Norway there was a large region about which only scanty information was available, viz. the area between Ofotfjorden and Tysfjorden.

Professor Helland asked me in 1906 whether I was willing to investigate this district and gather information concerning its topography, geology and glaciology. I expressed my willingness to meet his wishes.

I got a contribution of 400 kroner from a scientific fund to pay the expenses involved in this journey. I passed the whole summer of 1906 in this inhospitable region and had an opportunity to spend some weeks in an investigation of Frostisen and of Mereftasbreen to the south-west of Skjombotn.

Prior to my visit no glaciological investigations had been done of the glaciers between Ofotfjorden and Tysfjorden.

However, there exists a photograph of Reintindbreen taken by the French glaciologist Charles Rabot in 1883. A copy is to be found in the archives of the Geological Survey of Norway. See also p. 224.

The results of my glaciological studies are published in:

Hoel, Adolf, Frostisen. — Aftenposten, Oslo, 28. October 1906. No. 640 and 3. November 1906, No. 653.

— Frostisen. — Det norske geogr. selskaps årbok, B. 17, Kr.a. 1907. Contains a map of Frostisen and Mereftasbreene on a scale of 1 : 500 000).

— An unknown bit of Norway. — The Geogr. Journ. Vol. 34. London 1909. Pp. 59—61.

FLUCTUATIONS OF THE GLACIERS

As mentioned above Charles Rabot took a photograph of Reintindbreen from Elvegård farm on the east side of Skjomen on August 15th 1883.

The Norwegian botanist *Thekla Resvoll* took a photograph of the glacier about from the same spot as Rabot's, on 9 August 1906. It is reproduced in my paper on Frostisen, 1907. In the same year on 24 August I also took a photograph from the same position.

A comparison between these three photographs shows that the glacier had advanced considerably during the 23 years that had elapsed. The length of the glacier had increased by an estimated 200—300 m, while its width had in some places increased by a fourth. A few hundred metres above its front the glacier was almost twice as wide in 1906 as in 1883. The snow-cover in the mountains was also considerably greater in 1906.

In order to measure the fluctuations of the glaciers, *A. Hoel* in 1906 built cairns by three of the glaciers of Frostisen and Mereftasbreen. The distance between the cairn and the glacier front was measured with a steel tape. (See also The glaciers of the Okstindan mountains, p. 219.)

Reintindbreen. A cairn was set up below the large terminal moraine. This cairn stands on a tall slab of rock 10 m long, 5 m wide and 2.5 m high. It is situated between two glacier streams. The cairn is 1.5 m high and has a diameter of 0.75 m.

Nordre Mereftasbreen. A cairn was set up north of the spot where the glacier river commences, and is placed on a slab. The cairn has a diameter of 0.75 m.

Søre Mereftasbreen. A cairn 1 m high and with a diameter of 0.60 m was erected in front of this glacier on a small slab in the bottom of the valley.

It proved difficult to set up cairns in front of the other glaciers.

One of my assistants, Petter Olsen from Skjombotn, undertook to remeasure the distance from the cairns to the glaciers from 1907. The expences were defraied by scientific funds and private contributors. But after 1918 it was not possible to get subscriptions for this work. The results of the measurement were published by P. A. Øyen and myself in Norway and abroad.

In 1913 Captain *K. M. Søyland,* topographic surveyor of the Geographical Survey of Norway carried out ordinary topographic mapping of the western part of Frostisen.

According to the instructions of the Geographical Survey (see p. 22) he seized the opportunity of his topographic work in this region to hew crosses and erect cairns at the front of two glacier tongues of Frostisen, viz. Rånvassbreen and Nordre Isvassbreen.

Rånvassbreen. A cross was hewn into a large boulder approx. 4 m high, 4 m wide and 6 m long, 67.98 m from the glacier front. Two branches of the glacier stream run round the boulder.

A cairn was erected in the direction of the projected line of survey, approx. 300 m from the cross on the north side of the flat valley bottom, which is situated a little way below the glacier.

Compass bearing from the cairn was approx. 169° east of magnetic nord.

Nordre Isvassbreen. A cross was hewn into a vertical cliff face 2.5 m high, which faced the end of the glacier, 139.2 m from the glacier front.

A cairn was erected in the direction of the projected line of survey approx. 500 m from the cross. Compass bearing of the survey line from the cairn was approx. 75° east of magnetic north.

Frostisbreen. 19 July 1906 I took a photo of this glacier from the east side of Skjomen. This photo was reproduced in my paper published in 1907 on p. 136. It shows the vertical front of the glacier on the edge of the mountain's precipitous slope and the ice-cone down by the shore.

In 1916 *Kristian Nissen,* Inspector of reindeer pastures, in company with *Peder Kjerschow,* the Attorney-General and member of the Norwegian delegation, undertook a journey to the mountain district round Skjomen, during negotiations with Sweden on the question of reindeer. This journey was carried out on behalf of the Reindeer Pasturage Commission in order to study pasturing conditions in these mountains.

Nissen took a number of photos of Frostisen and Mereftasbreen. One was taken from the east side of Skjomen looking towards Frostisen from about the same point of my photo of 1906. Nissen's photo shows that the ice-cone had decreased in volume and height. It was now apparently 100 m lower. This was naturally due to the improvement in climate that had taken place during these 10 years.

The increasing temperature had augmented the ablation of the cone and diminished the supply of ice from the head glacier, that also had dwindled down during these years.

During the following years the improvement in climate continued at an accelerated rate, and as a result the ice-cone disappeared entirely in the late 1930's.

In 1916 *Steinar Foslie,* State Geologist of the Geological Survey of Norway, began geological investigating of Tysfjorden gradteigs map sheet. His investigations therefore included the mountains west of Frostisen and the actual glaciers (Foslie 1941).

Foslie endeavoured to find the cairns and the marks which Søyland had erected by Rånvassbreen and Nordre Isvassbreen.

At *Rånvassbreen* it proved impossible to find Søyland's marks. On the other hand Foslie succeeded in finding Søyland's cross at Nordre Isvassbreen and he measured the distance from this cross to the front of the glacier.

The result of Søyland's and his own measurements were co-ordinated by Foslie in the following table:

26 August 1913	139.2 m (Søyland)
28 August 1916	149.7 m (Foslie)

Thus, during these three years, the glaciers had retreated 10.5 m.

In order to investigate the conditions for further measuring and for drawing up new instructions required for surveying, I sent *Alfred Koller,* a Civil Engineer of Norges Svalbard- og Ishavs-undersøkelser (from 1948 Norsk Polarinstitutt) to Frostisen in the summer of 1934. (See the Glaciers of the Okstindan mountains, p. 219.) He worked here from 29 July to 9 August, visiting the glaciers surveyed by myself in 1906.

It was discovered that the fluctuations were so considerable that it was necessary to organize surveying in an entirely new way.

Reintindbreen. Koller only managed to find one of my two cairns, the one set up on the large slab. He measured a distance from the cairn of 470 m up towards the glacier and placed a new cairn here. But from this point the mountain was so steep and smooth that measuring with a tape proved impossible. From the old cairn a base-line was drawn up approx. at right angles to the direction used for the survey in 1906.

From it the new cairn's position was fixed by surveying in the following manner: A sufficient number of the Geographical Survey's trigonometric points were sighted, so that the terminal points of the base-line and the new cairn could be correlated to the trigonometric system of the Survey.

From the new cairn three points of the glacier front were tachymetrically surveyed. The front was by now in no way shaped like a glacier tongue, as the convex edge of the front no longer existed. It was proved that since 1906 the front of Reintindbreen had retreated 482 m. Koller also undertook a stereo-photogrammetric survey of the glacier from Elvegård.

Nordre Mereftasbreen. The state of this glacier, too, had altered considerably. The steep glacier tongue had disappeared. The new front was much farther back, high up the mountain side. It proved impossible to use a measuring tape, as the rocks were even steeper than those at Reintindbreen. For this reason it was necessary to measure a base line, and from this one of my cairns and two points on the glacier front were tachymetrically surveyed. In addition the front was surveyed photogrammetrically from a base line on the other side of the valley.

Søre Mereftasbreen. Here, too, the glacier had retreated so much that it proved necessary to carry out tachymetric surveys in order to determine the extent of the retreat. One of the cairns from 1906 was found. Two new cairns were erected near the front, and their positions were tachymetrically determined. Their position in relation to the old cairn was fixed. A number of points on the glacier were also tachymetrically surveyed. Rainy weather prevented the planned photogrammetric survey.

DESCRIPTION OF THE GLACIERS

Outflow glaciers

Without comparison the largest and the most interesting glacier of Frostisen is *Frostisbreen,* which runs to the east and the north towards Skjomen.

First it flows steeply down the highest part of the ice cap and then into a valley about two km wide. To the north of Gangnesaksla at a height of about 1050 m it divides into two branches, the *Søre* (south) *Frostisbreen arm* and the *Nordre* (north) *arm.*

The Søre arm. The southern arm now descends to a level stretch of the mountain and broadens out considerably. The area is saddle shaped. The direction of the saddle line is west-east. The glacier now slopes imperceptibly.

The mountain plateau at Skjomen is, as mentioned above, about 940 m high and the mountain side is very steep for a distance of about 2 km. Only in the extreme north there is a small stretch of flat ground, on which Frostisen farm is situated.

The glacier terminates at the edge of this mountain.

As the ice is situated at such high altitude ablation cannot keep pace with the accretion of ice, and as a result the ice inevitably tumbles down the mountain side to the shore of Skjomen.

Near Gangnesaksla the glacier plateau is lower than elsewhere, and here is a small lake, with no visible outflow.

Near its front the glacier is heavily crevassed. There are two main directions of crevasses, one running north-south parallel to the direction of the front, and the other perdendicular to it. The crevasses are as much as four m across. In this way the ice is divided up into parallelipiped blocks 10 to 20 metres long and wide. By August these blocks will, owing to ablation, which is strongest on the top of the blocks, attain the shape of pyramids.

Seen from the fjord the glacier appears as an uninterrupted wall, about two km long, similar in every way to the perdendicular fronts of the Arctic glaciers ending in the sea.

The Nordre arm flows to the north. All the ice north of the abovementioned saddle line flows to this glacier. It is about two km long and at the upper end its width is about the same. It is a real valley glacier. The front is situated west of Frostisen farm at an altitude of about 475 m. No other glacier in the Frostisen area reaches such low heights.

The mountain side and the glacier front have been photographed twice from approx. the same point on the east of Skjomen.

The first photo was taken by the author in 1906, and the second one by reindeer inspector Kristian Nissen in July 1916. Using altitudes and distances shown on the Geographical Survey's Skjomen map sheet and the photos, Civil Engineer W. Solheim of Norsk Polarinstatutt has computed the altitude of the upper edge of the glacier front in 1906 as being 1040 m, and the corresponding altitude in 1916 1000 m. During the course of these 10 years the thickness of the glacier has therefore decreased 40 m.

These figures are not entirely accurate, but they do at any rate show that the thickness of the glacier has decreased markedly during the course of the period in question.

In the years that have elapsed since 1916 the thickness of the glacier has also diminished considerably, as the temperature of the air has increased steadly.

There are falls of ice at three spots. One of these places is the front of Nordre arm. This spot is called locally Nørsterapet (litt. the northernmost fall). Only minor falls of ice occur here. The reason is that Nordre arm receives only small quantities of ice from the ice cap and also that the surface ablation is great here as the bulk of this branch is situated at a low level.

1.5 km further up the fjord the largest amounts of ice are carried down, and for this reason the place is called Storrapet (litt. the big fall). Another, 0.5 km further south, Litlerapet (litt. the small fall) is situated, and here falls of ice are infrequent and small. Both falls start at a height

Fig. 82. The east margin of Frostisen. To the right: the ice-fall of Nørsterapet; to the left: Storrapet with the big ice cone. The Skjomenfjord in the foreground. (Photo: K. Nissen. 1916.)

of 900 m. At Storrapet there is usually a fall of ice every day, although some times several days may elapse between each fall. The rumble of falling masses of ice can be heard almost constinuously. On one warm day, for instance, I counted six minor falls in the course of two hours. When the ice break loose from the edge there is first heard a noise like cannon shot; this is followed, in the case of major falls, by a thunderous sound which can be heard for miles around. This is another feature that recalls the Arctic glaciers. Several minutes elapse between the sound and the moment the ice reaches the shore.

On the narrow flat beach down by the water's edge the masses of ice from Storrapet form an ice-cone of considerable size. From the sea the cone looks small enough; but on climbing up it, one soon realize that it is some way to the top. The height of this cone was 190 m, and its width at its base 600 m in 1906. Its generatrices slope 25°, and it contains some 3—4 mill cubic metres of ice. At high tide the sea comes up to it. This was the southernmost place in the whole of Norway where glacier ice reached right down to the sea (68° 13′). The cone has now disappeared. (See the chapter Fluctuations of the glaciers.)

At the other falls no ice is accumulated at the shore.

The ice that has tumbled down makes white streaks on the cone which is dark with dust and rock. The ice of the cone is broken up, and the blocks vary from the size of a man's fist to half-a-metre in diameter.After a while these blocks freeze together, so that the cone consists of homogeneously compact ice, and may thus be regarded as a generated glacier.

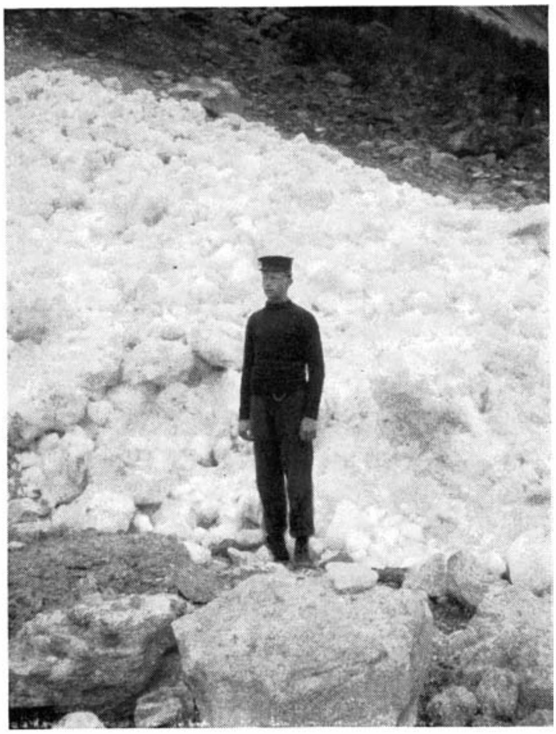

Fig. 83. Ice boulders on Storrapet after a newly ice avalanche.
(Photo: A. Hoel. 1906.)

The position of the cone is not always the same. It moves slightly north or south. This may be concluded from the following observation. On the north side of the cone there is a band devoid of vegetation parallel to the surface of the cone. It has a light colour. The owner of Frostisen farm told me that this band some years ago was covered by ice, but at the same time on the south side of it there was more bare ground than before and hay was cut here. The reason for this change in the position of the cone may be that the glacier breaks off rocks from the edge of the mountain.

At times very considerable masses of ice fall down. On 21 August, 1906, a large fall took place, and I had an opportunity of measuring the actual quantity of ice involved. This new white ice was easely to separate from the dark old ice. The new ice formed many stripes of different thickness. The average thickness was over 1 m, and in places 2—3 m. The cubic capacity of the ice was at least 7000 cubic m.

In summer these ice-falls involve no danger to Frostisen farm or to boats passing in the fjord. In winter, however, the position is different, as huge masses of snow crash down with the ice, and avalanches of snow also occur at other spots where there is no fall of ice. In winter, moreover, the avalanches are much swifter than in the summer, and the farm is often in danger. Nearly 150 years ago the farm buildings were swept into the sea by an avalanche, but there was no loss of life. The 2 kilometer-wide fjord is often unnavigable after an avalanche of this kind, as the snow often lies all the way across. Despite all this, and in spite of its perilous position beneath the menacing glacier, Frostisen farm is one of the best in Ofoten, and possesses lush fields and fertile corn land. Barley, oats and summer rye are grown only 200 m from the ice cone beneath Storrapet, and one year wheat ripened.

Just beneath the ice of Litlerapet a stream isues from the rock. This is probably the outlet of the little glacier lake, already mentioned, beneath Gangnesaksla.

On account of the rise of the air temperature these glaciers have dwindled away to such a degree that no ice tumbles down to the shore of Skjomen and the ice cone disappeared before the beginning of the last world war.

Apart from Frostisbreen there are no large glaciers emanating from Frostisen.

Rånvassbreen. This glacier is situated in the north-western part of Frostisen, south-east of Rånvassbotn and flows north. It is approx. 300 m wide, at its widest. The glacier has large crevasses and a slippery ice surface. The glacier tongue reached down as far as 850 m above sea-level.

The glacier is very steep in its lowest part. Near the front lies a terminal moraine. On both sides of the glacier the mountain slopes very steeply away, and is almost inaccessible.

Nordre Isvassbreen runs west down against the northernmost end of Isvatnet. The glacier has many crevasses.

In the front of this glacier there are some small moraines. Up to the distance of 50 m from the glacier front there are several new somewhat moss-ground moraines. The moraines beyond these are more broken up the farther the distance is from the front. The outermost trace of a moraine is found at 150 m from the front. (Foslie 1941, p. 258, observation 1916.)

Søre Isvassbreen. This glacier flows down to the southern end of Isvatnet and terminates in the lake itself, in a perpendicular wall about 20 m high. It is over one km wide, and occupies a shallow valley. On several occasions loud booms could be heard from the glacier. This occurred during calving, when large blocks of ice were detached. Many of these were floating in the lake. It is a very beautiful glacier.

The glacier was so heavily crevassed that I was unable to cross it. Instead I had to make my way across the rather treacherous ice which covered Isvatnet as late as 24 July.

By the south-west corner of the glacier there were three terminal moraines.

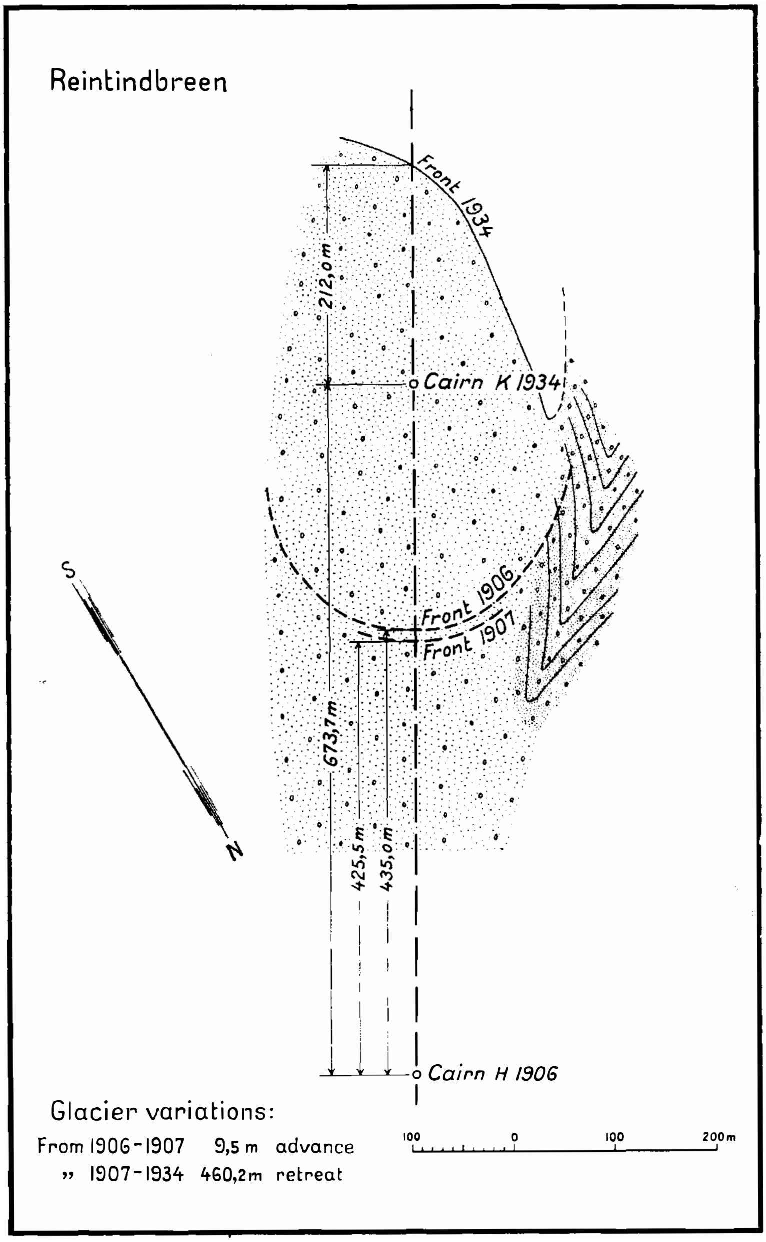

Fig. 84.

Bukkevassbreen is fairly large, being nearly one km wide. It runs down towards the lake Nordre Bukkevatnet and terminates at about 900 m above sea-level according to my observations in 1906. In front of it there are a number of considerable moraines.

Vestre Kjelvassbreen runs south-west down towards the western end of lake Kjelvatnet at the southern edge of Frostisen. The glacier

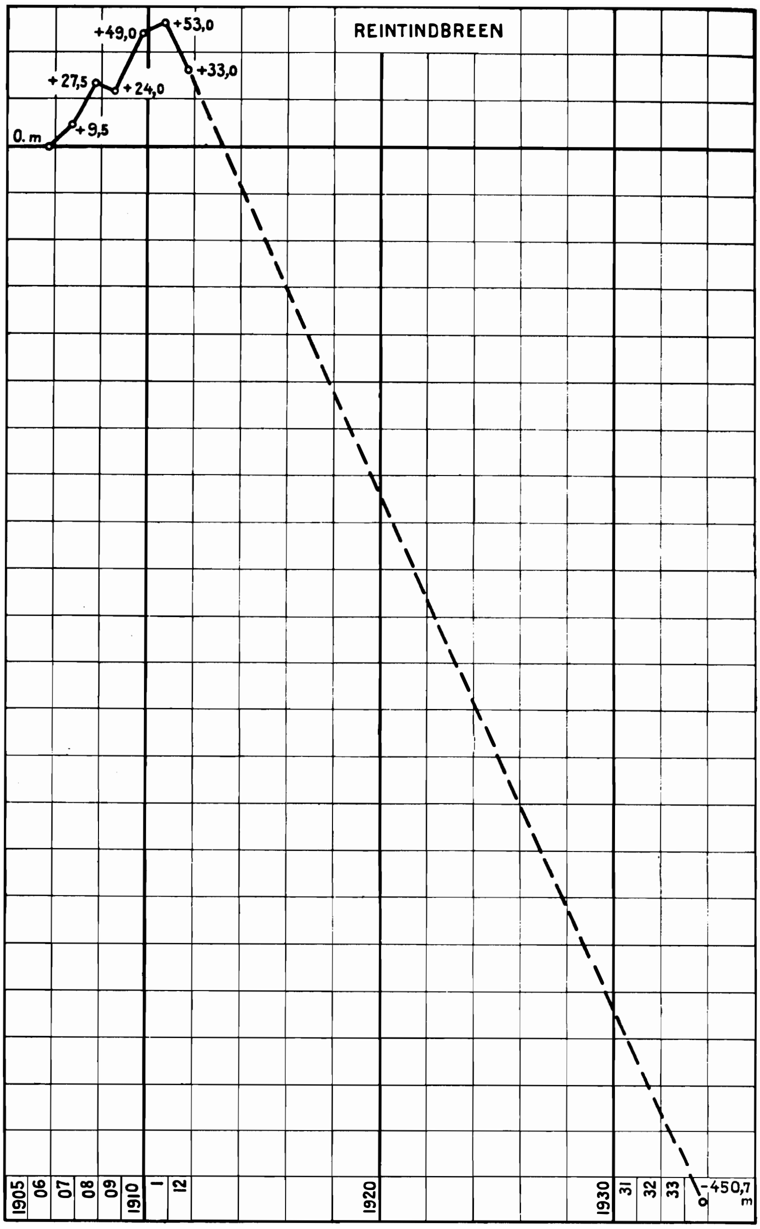

Fig. 85. The variation of the front of Reintindbreen.

terminated 130 m above the lake, i. e. 960 m above sea-level. It appeared to be increasing in size as it overlapped a terminal moraine.

Glacier with separate firn basins

Reintindbreen is situated to the south-east of Reintinden. Its firn basin is a large cirque. There is probably an ice-covered pass between this glacier and the ice cap Frostisen. It moves north-east. Its length is 2 km and the area 1.3 sq.km. Reintinden slopes very steeply down to the glacier, which terminated about 650 m above sea level in 1906 and 692 m according to the topographic map.

This glacier posesses unusually large terminal and lateral moraines near the glacier. They are probably the largest recent moraines in the whole of Norway. The lateral moraine on the north side is over 100 m high. The material of the moraine consists in the main of large boulders.

Outside these large moraines there were no traces of morainic material.

To the north of Frostisen there are three cirque glaciers. The two easternmost are lying close together divided by a narrow edge. They flow to the north towards Eitrådalen.

The eastern one is 2.3 km long and is about 2 km wide at its upper part. The area is 3.2 sq.km. The other is very steep and approx. square. Its length and width is 1.5 km. Its area is 2.9 sq.km. Both glaciers end at a height of 750 m above sea level. They have many crevasses.

None of them is named. I propose to call them *Tvillingbreene* (The twin glaciers): *Austre* (eastern) *Tvillingbreen* and *Vestre* (western) *Tvillingbreen.*

The third cirque glacier is situated on the east side of Tverfjellet. It runs to the north, is very steep and begins at 1130 m and ends at 680 m. It is 3 km long and 0.8 km wide at the middle. Its area is 0.9 sq.km. Enormous moraines are deposited in the front of the glacier. (Foslie 1941, p. 257.)

It had no name. I have called it *Tverfjellbreen.*

Mereftasbreene

POSITION AND MAPS

Mereftasfjellet is an isolated mountain area south-west of Skjombotnen. From Frostisen it is separated by the valley Vesterskardet. The distance from this valley to Nordre Mereftasbreen is only 700 m.

Mereftasfjellet is represented on the same gradteigs maps as Frostisen, viz. Skjomen and Tysfjord. See fig. 81.

TOPOGRAPHY

Mereftasfjellet is covered by glaciers and separated from the surrounding country by deep valleys, above which it rises 600—700 m. It slopes down precipitously in every direction, and access to the ice cover is not easy. In the east, from Snøskardet, it is only possible to climb the mountain at a point in the extreme north. From Vesterskardet and the valley to the west access is very difficult. From the bordering valley to the south it is possible to ascend by Søre Mereftasbreen. One

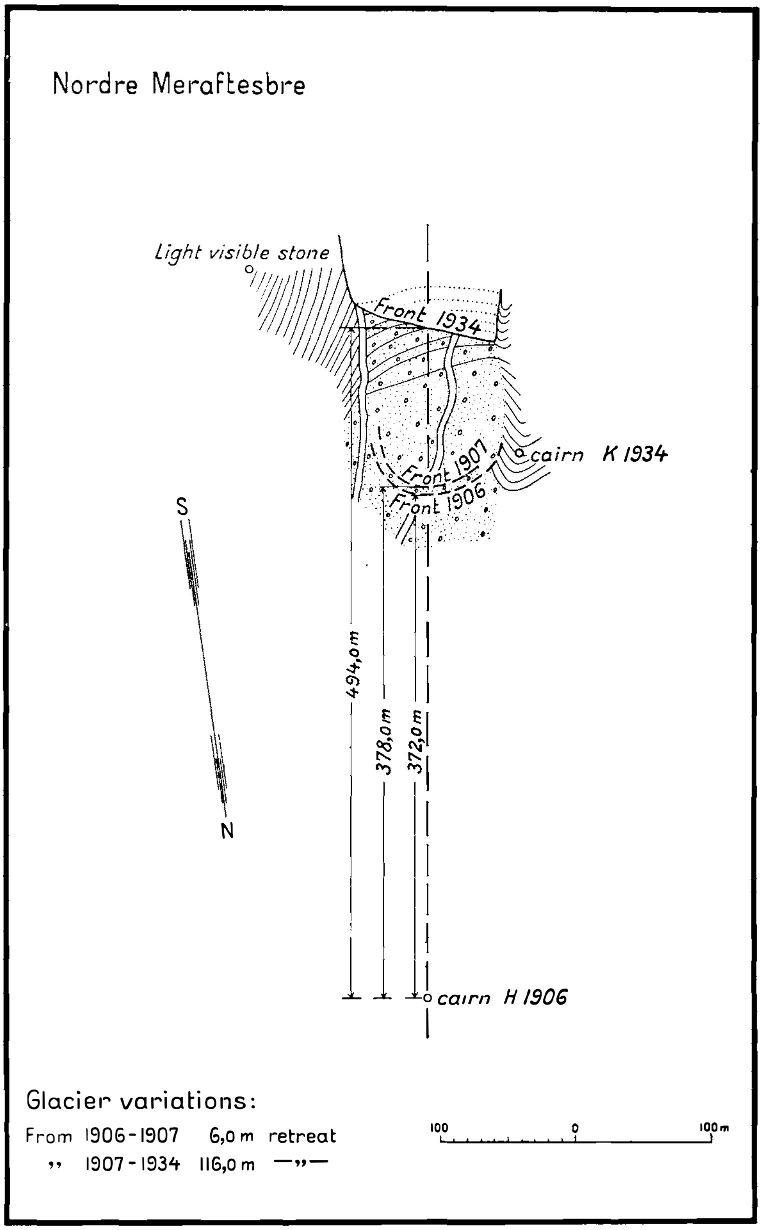

Fig. 86.

spot, however, from which access is easy is from the east end of Kjelvatnet.

The mountain is highest to the south-west, where a peak, Nestinden, rises to 1448 m. It is one of the Geographical Survey's trigonometrical points, and a cairn has been erected on the summit. Mereftastinden in the north-eastern part of the mountain rises to 1349 m. It has perpendicular walls to the east and the north, and looks very impressive when seen from the fjord to the north-west. From Nestinden, however, it looks rather insignificant, as it slopes gently to the south-west.

The glaciers of Mereftasfjellet consist of a central flat ice cap with a height of 1250—1300 m above sea level, and ice-covered mountain sides. The whole glacier area is called Mereftasbreen. The length of the glacier is 2.5 km (N—S) at the widest part it is 4.5 km. Its area is 8.24 sq.km.

Mereftasbreen feeds four outflow glaciers, viz. Austre Kjelvassbreen, Nordre Mereftasbreen, Snøskardbreen and Søre Mereftasbreen.

In the south-east corner of Mereftasbreen there is a glacier, Middagsvassbreen, with a separate firn basin.

From the summit of Nestinden runs a small steep glacier to the west, Vestbreen.

DESCRIPTION OF THE GLACIERS

Outflow glaciers

Austre Kjelvassbreen flows to the north-west between Nestinden and Mereftastinden. It starts up on the plateau, and is here 400—500 m wide. Soon after leaving the plateau it slopes steeply down, and considerable crevassing occurs here. It then narrows, until it is only 200 m wide; but lower down it broadens out considerably, and shows a number of longitudinal crevasses. It terminates at the bottom of Vesterskardet. The northern part of the front almost reaches the lake, and the southern part stretches as far as a small lake (847 m) south-east of Kjelvatnet. Near the front the glacier is very thin, and shows a blueband structure. A little way up the west slope of the valley is a terminal moraine.

Nordre Mereftasbreen runs from the plateau due north below the east wall of Mereftastind, terminating in the southern slopes of Vesterskardet at a height of 815 m above sea level. Where it stats it is 300 m wide, narrowing evenly as it descends. Its lower slopes are so steep (gradient about 40°), that on the east side the ice tumbles down the mountain side. The upper and central portions of the glacier are heavily crevassed, which makes it impossible to cross it here. At its front the glacier was very thin, but about 45 m from the end the thickness is considerable. Some 50—60 m from the front it was about 25 m thick. There appears to be an accretion of volume gradually moving down the glacier.

There are no actual terminal moraines, as the ground in the front of the glacier is too steep. Large quantities of gravel and ice blocks, largely brought down by landslides from Mereftastind, litter the ground in front of the glacier. Along the whole of the slope down to Snøskaret,

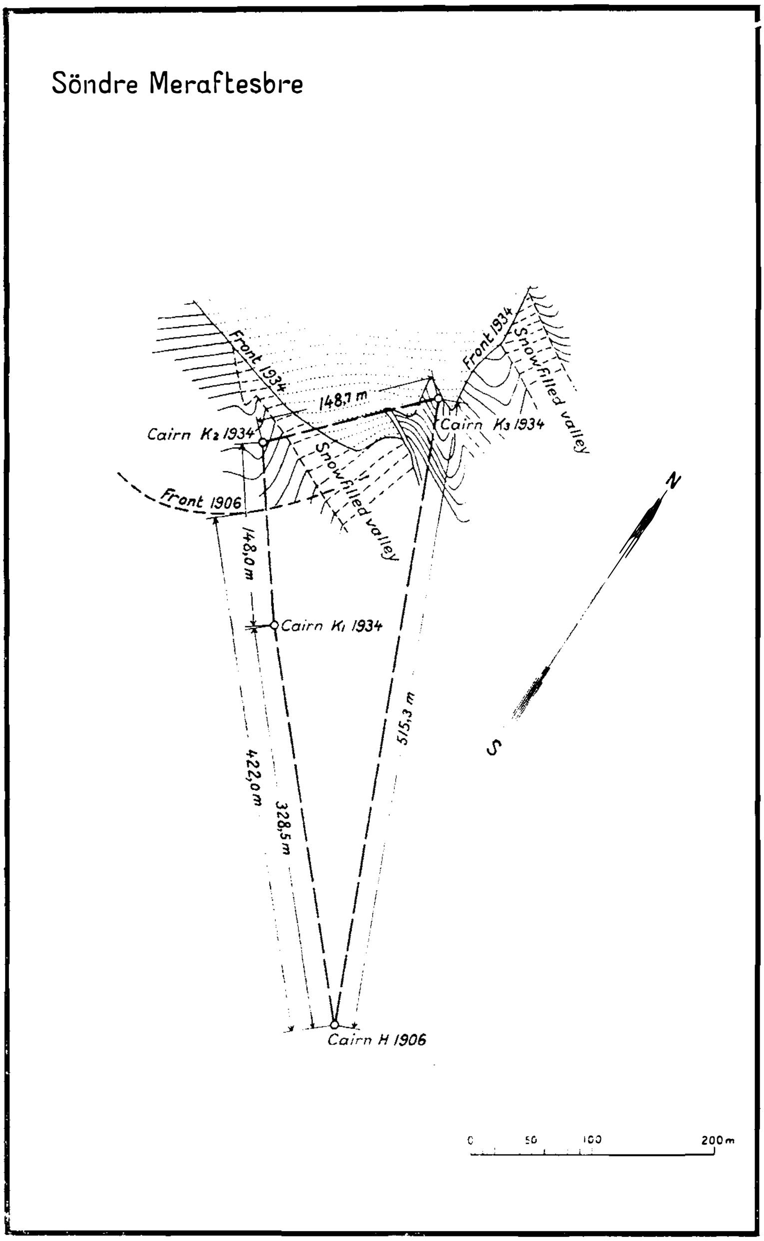

Fig. 87.

however, the glacier has a considerable lateral moraine. Making my way beneath the perpendicular ice wall, which is to be found on the east side of the glacier as a result of the falls, I was able to observe the fact that, between the ice and the rock, there was a lateral ground moraine cover, about 15 cm thick, cohsisting of clayey gravel. From the lowest portion of the glacier tongue a single glacier stream emerges.

Snøskardbreen runs to the east from the ice cap. It is very small, and is thus not visible on the topographic map (1: 100 000). A part of the glacier reaches the edge of the steep slope down to Snøskardet and occasionally some ice breaks off from the front and falls down to this valley.

Søre Mereftasbreen. From Nestinden to the north runs a wide ridge sloping gently to the north-east. The ridge and the mountain side are entirely covered with ice, which forms the firn area of this glacier.

It is also connected to the ice cap, but receives very little inflow from this. If an improvement in the climate should take place the glacier would be separated from the ice cap.

The glacier flows to the south-east in a shallow valley, and terminates one km west of Middagsvatnet (731 m above sea level). It is approx. one km wide and has very few crevasses. It possesses a fine blue-band structure. The front of this glacier was very steep on the occasion of my first visit on 23 July. The second time I saw it, on 19 August of the same year, a considerable ablation had taken place and it was consequently not so steep. In front of the glacier are three rows of terminal moraines. The nearest, 7 m from the front, was completely devoid of vegetation. The second is situated 81 m from the glacier, and the third 142 m from it. These are both overgrown with vegetation, and are about 20 m high.

Six glacier streams flow from the front. The bulk of the water runs into Middagsvatnet. The outlet of this lake empties itself into Skjomenbotn. The distance between Middagsvatnet and the fjord is approx. 4.5 km. But the water from the western part of the glacier runs into Leirvatnet, and from this lake it makes its way to the great Swedish river of Lule älv, which flows out into the Bay of Bothnia. The distance from the glacier to this gulf is 350 km.

Søre Mereftasbreen thus has the unique position of being situated along the main watershed of the Scandinavian Peninsula.

Vestbreen. I have never visited this insignificant glacier. I know nothing more about it than can be seen from the topographic map. It starts from an ice-covered ridge a little north of Nestinden, and runs to the west. It is very steep. Its length is about 500 m, and its width at its upper end is the same.

Glacier with separate firn basin

Middagsvassbreen. The topographic map of the part of the Mereftasbreene where this glacier is situated, is very bad, giving the impression that this glacier should be connected with the ice-cap.

This glacier is a most peculiar one. Its lower portion consists of two tongues separated by a rock crest. The smaller of these runs east and terminates high up on the west slope of Snøskardet. The other runs south-east towards Middagsvatnet, but terminates at an altitude of

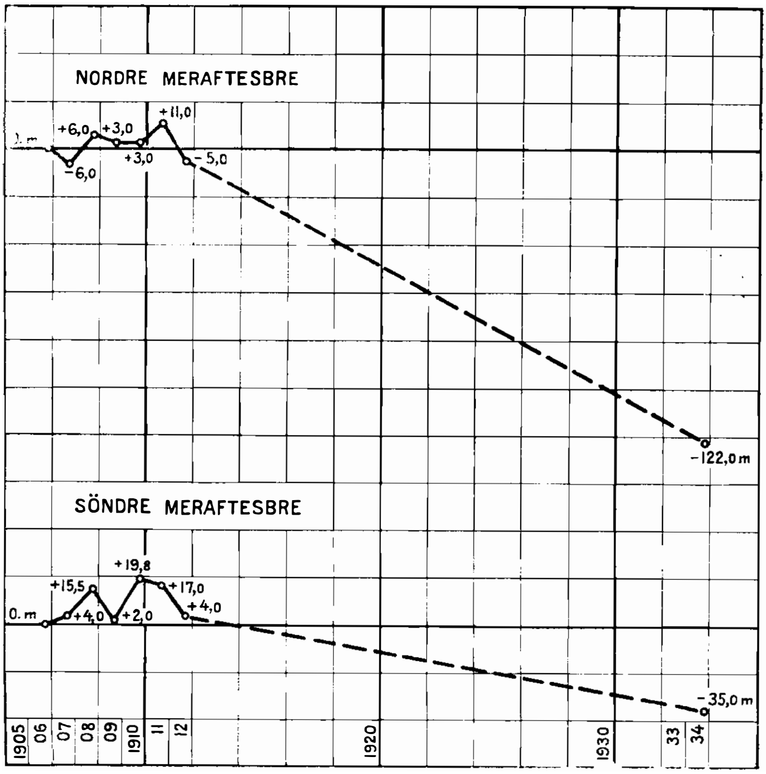

Fig. 88. Frontal variation of Nordre and Søre Mereftasbreen.

1125 m above sea level. Both glacier tongues hang down along precipitous granite walls, and from the larger one ice tumbles all the way down to Middagsvatnet. The end of the glacier showed a blue-band structure. The entire glacier is situated in a cirque 300 m wide, and with sheer walls. But the distance from the upper edge of the cirque down into the glacier is not more than 5 m. It cannot have been so long since this glacier was joined to the ice cap. Thus the excavation of this cirque must have started at a relatively recent date. It is now in the embryonic stage.

PLACE-NAMES IN FROSTISEN AND MEREFTASFJELLET

When I started my glaciological work in Frostisen and the glaciers of Mereftasfjellet in 1906, none of the glaciers in these areas had names except the Frostisen ice cap. It was therefore necessary to name the more important glaciers in my paper of Frostisen of 1907. Two cirque glaciers (Tvillingbreene) were indicated by a number. This was owing to the small scale of my map (1: 500 000) which prevented names being printed for these insignificant glaciers. The cirque glacier on Tverfjellet (Tverfjellbreen) and Vestbreen on Mereftasfjellet were not mentioned at all.

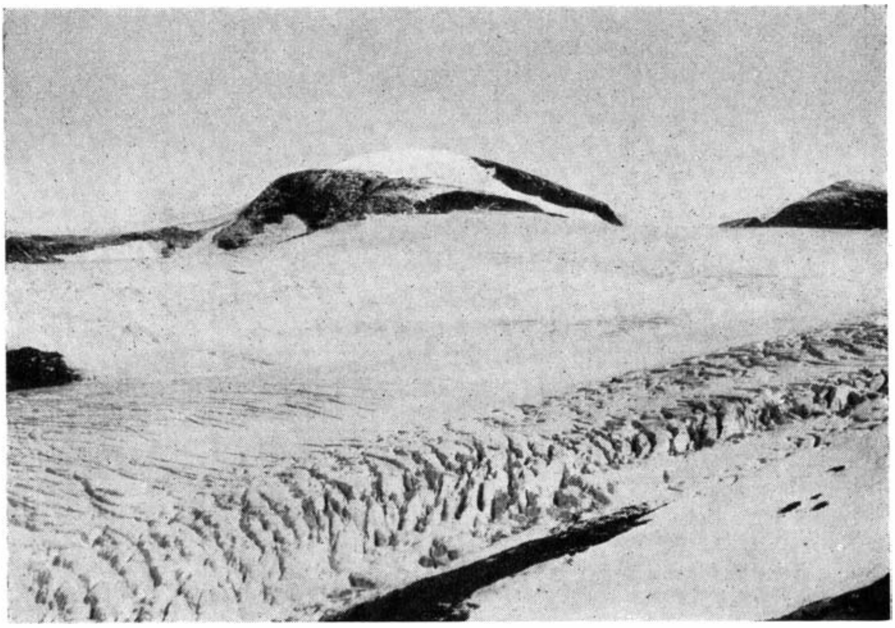

Fig. 89. Isvassbreen, Frostisen.

Below is a list of the glacier names on my map fig. 81 and the same names used in the present paper:

1907	1960
Vestre Kjelvasbræ	Vestre Kjelvassbreen
Straumvasbræen	Bukkevassbreen, named after Nordre Bukkevatnet
Isvasbræen	Nordre Isvassbreen
Raanvasbræen	Rånvassbreen
Reintindbræen	Reintindbreen
Frostisbræen	Frostisbreen
Søndre Mæraftesfjeldbræ	Søre Mereftasbreen
Østre Kjelvasbræ	Austre Kjelvassbreen
Nordre Mæraftesfjeldbræ	Nordre Mereftasbreen
Sneskardbræen	Snøskardbreen
Middagsvasbræ	Middagsvassbreen

To the 1906-names in the list I have added four others, viz. Tvillingbreene (Austre Tvillingbreen and Vestre Tvillingbreen), Tverfjellbreen in the Frostisen area and Vestbreen on Mereftasfjellet.

My map of 1906 contains not only glacier names but a great number of names of topographic features, such as lakes, valleys, etc., that have not appeared on any previous map, but were in common use among local inhabitants.

The spelling of the names from 1907 was in concordance with the official orthography of the same year. As will be seen from the list there is some disagreement between the spelling in 1907 and that of 1960. It is especially striking that the letter *æ* in the old names has been replaced by *e*, and *østre* by *austre*.

I must also mention other more important discrepancies between the two lists.

The name Mer*a*ft*e*s has been converted to Mer*e*ft*a*s. The first spelling is a blunder of mine.

In the name Meraftesfjeldbræ I have also deleted the word *fjeld*. The name in its new form will thus be Mereftasbreen. It is more convenient than the old one.

On the Skjomen gradteigs map sheet we find the highest peak on Mereftasfjellet, 1448 m. On this map no name is placed near this peak but we find a name Mereftasfjell in the middle of this mountain area.

The height of this trigonometric point was measured twice, in 1900 and 1915. The result of the first triangulation was that the height was 1442 m and of the second 1448 m.

In 1905 the director of the Geographical Survey, Per Nissen, published a map, to a scale of 1 : 1 000 000, of northern Norway. On this map is depicted a peak of a height of 1442 m in the Mereftasfjell region. This is the figure measured by the Geographical Survey in 1900. But Nissen called it *Nes Tind*. According to the spelling now in use the name will be Nestinden. From which source Nissen has got this name is not known.

I would propose that Nissen's name Nestinden should be adopted as the name of trigonometric point 1448 m for the following reasons:

1. The name Mereftasfjell does not occur on the map as a name of the summit 1448.
2. The name is only to be found in the archives of the Geographical Survey's Trigonometrical Section.
3. The name Mereftas enters into quite a great numbers of names of mountains and glaciers. It is therefore desirable to diminish the number of place-names combined with Mereftas.

In my paper of 1907 (p. 132) I described a glacier ending with a vertical cliff in the southern part of Isvatnet, called Isvassbreen. I also mentioned the glacier ending near the northern part of this lake. I described it in following words:

"The northern part of the glacier (Frostisen) forms a special tongue that does not reach Isvatnet".

But I gave it no name.

This has therefore entailed a certain confusion in the use of the name Isvassbreen.

I have therefore introduced spesial names for these two glaciers, viz. Nordre Isvassbreen for the northern one and Søre Isvassbreen for the southern one.

On the Skjomen and Tysfjord map sheets all the place-names are used in indefinite form, for example: Reintind, Kjelvatn. But according to the rules now in use for place-names they are with few exceptions, used in the definite form, viz. Reintind*en*, Kjelvatn*et*. In the present paper I have therefore followed the rule now in use.

The name Mereftasfjellet is of special interest because, like many other mountain names in Norway, it is connected with the position of the sun.

Mereftas means three o'clock in the afternoon in this part of the country. (In southern Norway it means 4—6 o'clock.) At this hour the sun is seen from Skjombotn in the same direction as Mereftasfjellet (fjell means mountain). The inhabitants of this place have therefore named it Mereftasfjellet. The people here take a meal (coffee, milk and buttered bread) at this hour of the day, which is also called Mereftas.

Glaciers between 68° 9′—67° 46′ N. LAT.

In 1912, 1914 and 1915 three of the topographers of the Geographical Survey carried out mapping on the Tysfjord sheat. They also, according to the instructions of the Survey (see p. 22) built cairns and hewed crosses in front of some of the glacier tongues and measured the distance between these marks and the glacier. They likewise made sketch maps of the glacier fronts and their surroundings, and took photographs of the places. Below are descriptions of the survey work of these topographers taken from the archives of the Geographical Survey.

Name of the glacier: *Kopisen*. N. Lat. 68° 8′. Surveyor: Captain O. Thue. Year 1914.

Near the west front two crosses were hewn into the rock at the edge of a precipice, on 4 August.

From the glacier flow two glacier streams. The distance from the outlet of the southernmost of these streams to the southern cross is 75 m, and from the outlet of the northern stream to the northern cross likewise 75 m.

A cairn was erected on a gently sloping scree consisting of large boulders approx. 100 m from the southern cross. Placing cairns at a greater distance from the crosses in a suitable spot was not considered feasible.

Surveying the east front of the glacier proved impossible owing to its steepness.

The line running through the southern stream outlet, the southern cross and the cairn, had a compass bearing (measured from the top of the cairn) of 54° east of magnetic north.

The line running through the northern stream outlet, the northern cross and the cairn, had a compass bearing (measured from the top of the cairn) of 74° east of magnetic north.

Name of the glacier: *Addjagčokka,* N. Lat. 67° 46′. Surveyor: First Lieutnant Kjell Bugge. Year 1915. (Map sheet Hellemobotn).

This glacier had already been surveyed, as there were two cairns sited in front of the glacier, marked on the sketch as first and second cairn. The distance between them was measured and a third cairn was set up further in, on rock, as the first two cairns were built on sand or heaps of stones, in or near the course of the glacier stream.

Name of the glacier: *Skårisen.* N. lat. 68° 8′. Surveyor: Captain O. Thue. Year 1914.

The survey of the glacier tongue (lowest, north-eastern portion) of this glacier was undertaken in August.

A cross was hewn into the rock 100 m from the spot where a stream flows out from the glacier.

A cairn consisting of flat stones was erected 100 m from the cross. To set up a cairn at a suitable spot further away from the cairn was not considered feasible.

The line cairn-cross has a compass bearing (measured from the top of the cairn) of 23° east of magnetic north.

Name of the glacier: *Fonnisen.* N.lat. 68°4′. Surveyor: captain Harald Hjort. Year 1912.

Survey was undertaken on 27 August.

A cross was hewn into a small perpendicular rock face, 62.8 m from the glacier front.

A cairn, in the direction of the projected line of survey, was set up on a small mound just west of the north end of lake Storelvvatnet. Another cairn was also built in the same line on the other side of the lake, some way up the slope.

The compass bearing, from the cairn to the glacier, is approx. 48° west of magnetic north.

Name of the glacier: *Norddalsisen.* N. lat. 68° 8′. Surveyor: Captain Harald Hjort. Year 1912.

Only four glacier tongues have been measured, viz.
The north-eastern,
The south-eastern,
The north-western,
The south-western.

At the *north-eastern glacier tongue* a cross was hewn into a soft pale-brown cliff-face on the upper edge of a slope, 69.4 m from the front of the glacier.

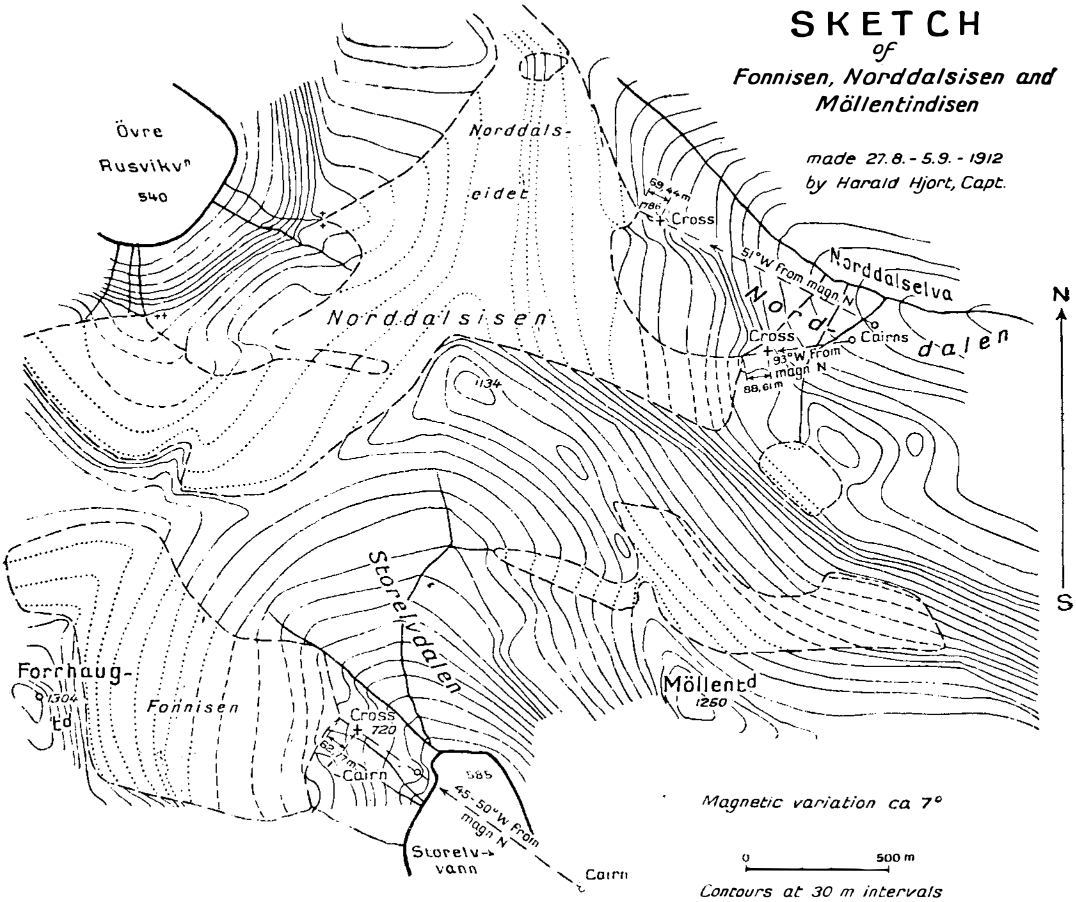

Fig. 90.

A cairn was erected in the valley at a distance of approx. 800 m from the glacier in the projected line of survey. It proved impossible to place the cairn closer to the glacier owing to broken ground in between.

The compass bearing of the line of survey from the cairn is 51° west of magnetic north.

The survey was undertaken on 4 Sept.

The south-eastern glacier tongue. A cross was hewn into the cliff face on the upper edge of the rocky slope facing the valley, approx. 88.6 m from the glacier front.

A cairn was erected in the valley about 300 m from the projected survey line. The compass bearing from the cairn was 93° west of magnetic north.

Survey was undertaken 4 Sept.

North-western glacier tongue. It proved impossible to carry out a survey according to the Geographical Survey's instructions for two reasons, viz.:

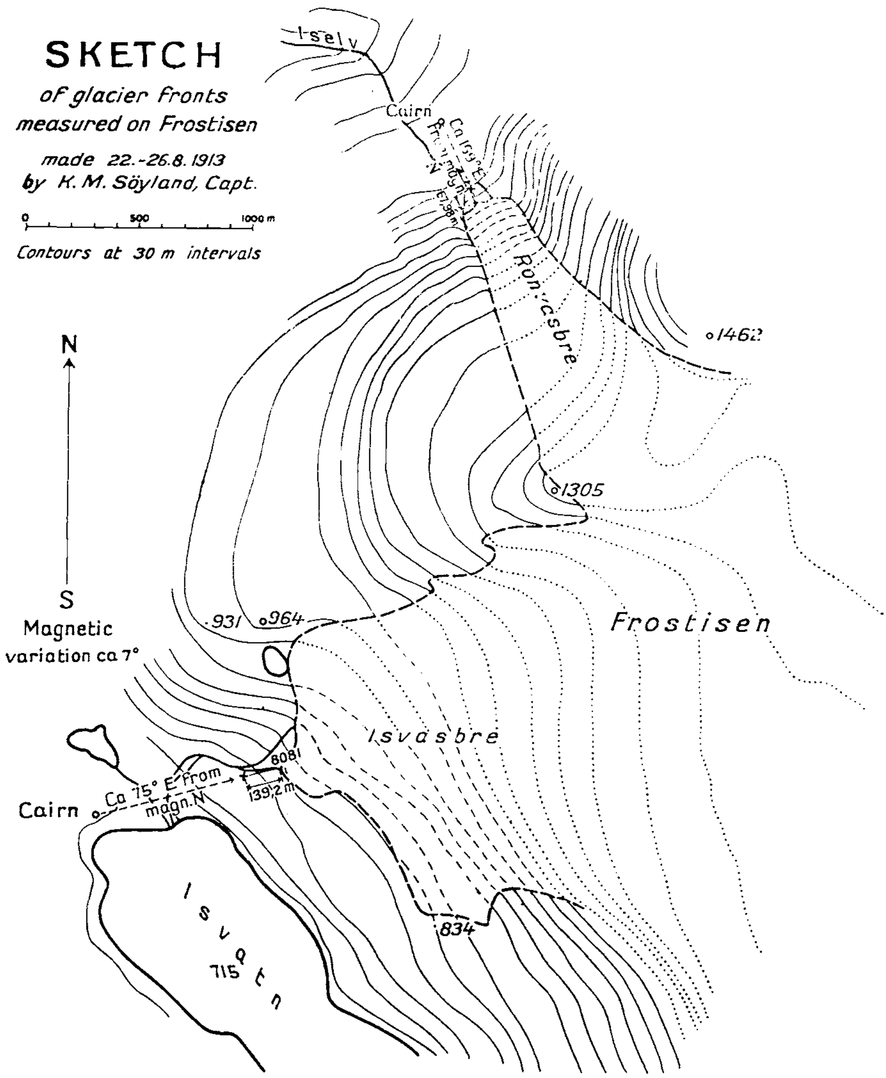

Fig. 91.

1. Approx. 20 m from the glacier tongue the rock face plunges almost perpendicularly and inaccessibly down to lake Rusvikvatnet. Circumventing the precipice in order to carry out a survey would haven taken more time than it was possible to devote. It would have meant that we should not have completed our two topographic surveys in Norddalen, etc. from Strømmen before the work for that summer had been brought to an end by a spell of bad weather.

2. Local conditions were quite unsuitable for surveying with the aid of cross and cairn placed along the direction of the glacier tongue. For this to have been done the cairn would have to be placed at the west end of lake Rusvikvatnet (approx. 1700 m above sea level), and the cross

would have had to be less than 20 m from the glacier tongue.

Another system was consequently adopted, viz. placing two marks on the rock, one on each side of the glacier tongue.

1. Approx. three m south of the foot of the glacier and three m higher, on a vertical cliff face, a mark, 12 was hewn into the rock.

2. Approx. 10 paces north of the glacier front a cross was hewn into the flat rock. The sharp flat foot of the glacier lay in a straigth line between these two marks.

The survey was undertaken on 2 Sept.

South-western glacier tongue. Conditions here were almost exactly the same as those on the one mentioned above, viz. a few metres from the glacier tongue there was an inaccessible precipice down to lake Rusvikvatnet. Furthermore the ground between the foot of the glacier and the precipice consisted entirely of deep, loose sand, gravel, and pebbles, which made it a hasardous or impracticable task to approach the edge of the precipice to try to discover a spot futher down where a cross could be hewn into the rock. In any case, the cross and the foot of the glacier would almost certainly have been invisible from any cairn that might have been erected.

Here, too, a survey system across the glacier, more or less in an east-west direction was used.

As will be seen from the sketch map, two streams run down into lake Rusvikvatnet from the glacier front. (There is also another stream further west.)

Two marks were cut into the rock at two points close to the streams.

Approx. 57 paces east of the eastern stream we hewed a cross into a north-facing corner of a cliff.

Approx. 14 m from the cross, but closer to the glacier, stood a huge boulder, which it is highly unlikely that the ice will ever reach and which is bound to remain standing in its present position for a long time. There was no other rock surface into which the cross could be hewn. Here two crosses were cut close to one another, one a little to the left of the nearest point of the glacier (approx. 43 m from the cross), and the other to the right of the furthest glacier point to the left of the two streams.

Survey was undertaken on 2 Sept.

On the sketch map a glacier is also to be found on the north side of Møllentinden. This proved, however, impossible to survey. The glacier tongue hangs over a nasty, precipitous rock face over 100 m high, and it will probably never move down it, but instead break up into fragments and send blocks of ice down the rock face, judging by the mass of ice blocks which was seen under the glacier front immediately below.

Additional enclosure to sketch map, scale 1: 12 500.

Name of the glacier: *Presttindbreen.* N. lat. 68° 19′. Surveyor: Captain Harald Hjort. Year 1912.

The glacier is situated between Presttinden and the lake Svartvatnet.

Referred to as the *Presttindbreen* by the author.

A cross was hewn into a flat rock beneath the steep moraine mound above the glacier tongue. The distance from the cross to the glacier is 76.6 m. It is measured with a rope across broken ground.

A cairn was erected in the projected direction of the line of survey on the other side north of Svartvatnet. The line of sight is almost tangential to the west end of the small island in the shallow east end of the lake.

Compass bearing, taken from the cairn, is between 1° and 2° west of magnetic north.

Survey of the glacier tongue was undertaken on 11 Sept.

Captain K. M. Søyland of the Geographical Survey carried out in 1913 the same kind of survey work at Frostisen. It is dealt with in the description of this glacier, p. 263.

APPENDIX

New glacier names

Many glaciers in our country, both large and small, lack names, especially in the sparsely inhabited districts of Northern Norway. But as a rule the mountains upon which the glaciers are situated will have their proper names, and other localities in the neighbourhood may also have their own names. We had originally intended to identify these nameless glaciers by indicating the names of the mountain upon which they are situated, or the name of some conspicuous place in the neigbourhood. For instance, a glacier on Reintind would be identified as "Glacier on Reintind". A glacier lying on a nameless mountain, but near a lake by name Bogvatn, might be called "Glacier at Bogvatn".

It would, however, clearly be an improvement if these glaciers could be given their own names. This can easily be achieved by combining the name of the locality, where they are situated, with the appellative bre. Instead of writing "Glacier on Reintind" we introduce the name: "Reintindbreen", and instead of "Glacier at Bogvatn" we get "Bogvatnbreen".

We have submitted this proposal to professor Alf Sommerfelt, adviser on place names to Norges Geografiske Oppmåling. He has declared that the proposal ought to be accepted. The authorities of N.G.O. are also agreed that these names should be accepted as official names of the hitherto nameless glaciers, and that they will be introduced on the new maps following their publication.

The administrative districts of Norway

We consider it to be of some importance to present an account of the division of Norway into administrative districts.

The country is divided into 20 main units. Two of these are county boroughs. By an act of August 14th, 1918, the old designation for these units, *amt,* was changed to *fylke,* corresponding to the English county. The actual names of these divisions have also been changed. As both new and older names often occur in the text, the following table may be useful.

Old names:	*New Names:*
Akershus amt	Akershus fylke
Bergens by	Bergens by
Bratsberg amt	Telemark fylke
Buskerud amt	Buskerud fylke
Finmarkens amt	Finnmark fylke
Hedemarkens amt	Hedmark fylke
Jarlsberg og Larviks amt	Vestfold fylke
Kristians amt	Oppland fylke
Lister og Mandals amt	Vest-Agder fylke
Nedenes amt	Aust-Agder fylke
Nordlands amt	Nordland fylke

Nordre Bergenhus amt	Sogn og Fjordane fylke
Nordre Trondhjems amt	Nord-Trøndelag fylke
Oslo by	Oslo by
Romsdals amt	Møre og Romsdal fylke
Smaalenenes amt	Østfold fylke
Søndre Bergenhus amt	Hordaland fylke
Søndre Trondhjems amt	Sør-Trøndelag fylke
Stavanger amt	Rogaland fylke
Tromsø amt	Troms fylke

Fylkene are in turn divided into 680 units, called *herred,* corresponding to the English term district.

The southern part of Norway, comprising the two counties of Aust-Agder and Vest-Agder, is generally called *Sørlandet.* The area comprising the counties of Rogaland, Hordaland, Sogn og Fjordane and the southern part of Møre og Romsdal (up to 62° 30′ N) is called *Vestlandet.* The country east of Sørlandet is named *Østlandet.*

The total land area of Norway is 324 222 sq.km.

Names of research institutions mentioned in this publication with English translation

Universitetet i Oslo	The University in Oslo
Universitetet i Bergen	The University in Bergen
Norges geografiske oppmåling N.G.O.	The Geographical Survey of Norway
Norges geologiske undersøkelse N.G.U.	The Geological Survey of Norway
Norges vassdrags- og elektrisitetsvesen	The Norwegian water course and electricity Board
Norges Svalbard- og Ishavs-undersøkelser N.S.I.U.	The Norwegian Institute for Research in Svalbard and other Arctic regions
Norsk Polarinstitutt N.P.I.	The Norwegian Polar Institute
Norsk Meteorologisk Institutt	The Meteorological Institute
Statsarkivet i Bergen	The State Archiv in Bergen

English translation of Norwegian words in common use of glacier names

Å	river, torrent
Åga	river
Aust	east
Austre	eastern
Bekk	brook
Berg	rock
Blå	blue
Botn	cirque
Bratt	steep
Bre	glacier
Brei	broad
Bukk	reindeer buck
Dal	valley

Elv	river
Fager	fair (beautiful)
Fjell	mountain
Fjord	fjord, firth
Fonn	snow-field
Foss	waterfall
Gjuv	ravine
Geit	goat
Grå	grey
Grov	torrent
Halvøy	peninsula
Heim	home
Helle	slab
Hest	horse
Hol	hole
Hø	rounded hill
Høg, høy	high
Hytte	hut, shelter, chalet
Ille	bad
Is	ice
Jøkul	glacier
Jotun	giant
Juv, see gjuv	
Kamp	hill
Klett	steep hill
Klump	rounded hill
Kvit	white
Lang	long
Leire	clay
Lille	little
Liten	small
Mark	field
Middag	noon
Nord	north
Nordre	northern
Nos	nose
Og	and
Ø, øy	island
Ost, øst	east
Øystre	eastern
Pigg	peak
Pytt	puddle the name is used in certain parts of Hardanger in the meaning cirque, for instance in Pytbreen (cirque glacier).
Raud, rød	red
Rund	round
Rygg	ridge
Seter	small summer transhumance farm in the mountains with cowshed and accommodation for milkmaids.
Sjø	sea, lake
Skavl	snow-drift

Skog	forest
Slett	even, flat
Små	small
Sne and snø	snow
Sør, syd	south
Søndre, søre	southern
Sten and stein	stone
Stor	great, large
Storm	storm
Stul, see seter	
Stygg	ugly
Svart	black
Tind	peak
Tjørn, tjønn	tarn
Topp	peak, summit
Tverr	transverse
Vatn	lake
Vesle, vetle	little
Vest	west
Vestre	western

Lappish glacier names

In the three northern counties of Norway the interior highlands have been almost exclusively used as pastures for the semi-domesticated reindeer herds of the Lapplanders. Accordingly most of the place names are Lappish. Generally they are easily explained. But the names may have rather deviating forms in the different dialects and the spelling of the Lappish names on Norwegian topographical maps may be incorrect. This makes the explanations doubtful in many cases. Furthermore some names cannot be explained at all.[1]

We are indebted to Dr. Knut Bergsland, Professor of Finno-Ugric Languages at the University in Oslo, for revising the list, correcting the spelling, and adding some explanations.

Some common Lappish appellatives:

čokka, čåk'ka	summit
čorro, čårro	ridge
gaissa, gai'sa, gai'si	peak
jiekŋa, jiegŋa	glacier
oalgge, oal'gi	shoulder
varre, varri	mountain

[1] See Qvigstad, J. De lappiske stedsnavn i Troms fylke. 1935. De lappiske stedsnavn i Finnmark og Nordland fylker. 1938. — Printed in the publications of Instituttet for sammenlignende kulturforskning, Ser. B. Vol. 29 and 33. Oslo.

List of Lappish place-names

Names on the present maps	Modern spelling[1]	English translation
Agjagvarre	Addjatvarri	Spring Mt.
Akjek	Azek	Thunder
Alappen	Allatgai'si	Snow-bunting Hill
Argaladeičokka	Ar'galađeičåk'ka	
Baldoaivve	Bal'doai'vi	Halibut's Head
Bassečokka	Bassečåk'ka	Holy Summit
Bæssegčokka	Bæssetčåk'ka	Burdh bark Summit
Bierdnačokka	Bier'dnačåk'ka	Bear Summit
Bolna	Bål'dna	
Čainhačokka	Čaihnačåk'ka	Woodpecket Summit
Čaučasgaissa	Garanasgai'si	Raven Peak
Čoarvvevarre	Čoar'vevarri	Horn Mt.
Gammeloffjell	(Gamalåptvarri)	Shoe Ledge Mt.
Gaskačokka	Gas'kačåk'ka	Middle Summit
Gietnagaissa	Jettanasgai'si	Giant's Peak
Gicceçokka	Gic'cečåk'ka	Young goat Summit
Gieddoaivejiekŋa	Gied'doaivejiegŋa	Meadow Hill Glacier
Govlekečokka	Guoblekečakke	Snowdrift Summit
Gussavarre	Gussavarri	Cow Hill
Ippovarre	Ippovarri	
Isogaissa	Isogai'si	Great Peak
Jovaskjøris	Juovvačåruš	Boulder Ridge
Juovavaras	Juovvavaraš	Boulder Hill
Karrejiekna	Garrajiegŋa	Hard Ice
Læigastind	Læigasčåk'ka	
Likkavarre	Liggavarri	
Madagaissa	Maddagai'si	South Peak
Nikkitoppen	Nikkeoal'gi	Nicholas's shoulder
Njuorjovarre	Njuor'jovarri	Seal Mt.
Njunnesvarre	Njunis(varri)	Mountain Spur Mt.
Oallačokka	Oallačåk'ka	Main Channel Summit
Olmaiallojiegŋa	Ålmaiallojiegŋa	
Rapisflåget	Rappisbak'ti	Steep bare Cliff
Raskavarre	Ras'kavarri	
Ridoalke	Rid'doal'gi	Landslide Ridge
Sepmolfjell	Sebmulvarri	Mossgrownd Mt.
Sipmeken 57 B: čokka	Sibmekečakke	
Siidasjiekŋa	Siidasjiegŋa	
Skuŋkivarre	Skuŋkivarri	
Slædovagvarre	Slæddovagvarri	Bare Rock Hill
Slædočokka	Slædočåk'ka	Moraine Summit
Smaasorjusvdne	Unna Sår'jusajavražat	
Snjaškavarre	Snjaš'kavarri	Spur Mt.
Sælkačokka	Sælkačåk'ka	
Sorjusčokka	Sår'jusačåk'ka	
Sulitjelma		

[1] Orthography henceforward used by Norges geografiske oppmåling.

Names on the present maps	Modern spelling	English translation
Tjorrofjell	Čårrovarri	Ridge Mt.
Unnariepasvarre	Unnarieppašvarri	Little Gap Mt.
Vaššavarre	Vaššavarri	
Veikekčorro	Væikikčårro	Copper Ridge
Viermafjellet	Viermečakke	
Viskis		

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