2. East-West Balance of the Quaternary Ice Caps in Patagonia and Scandinavia

By

Erik Ljungner

(With two plates

Preface.

This treatise has been referred to in my papers of 1943 a, 1945, and 1946. It literally agrees with the copies sent in to the Government in May 1946 as a qualification specimen for the chair of Geography with the following exceptions. As a consequence of my journeys 1946 § III C c has been added as well as the corresponding map fig. 34, fig. 10 d has been completed, and some footnotes have been added. Finally Mr. B. Norbelie has revised the text with regard to the language.

Acknowledgements.

My first personal contact with Andean problems was the fruit of my service in Argentine at the time when doctor José M. Sobral was Director General of Dirección General de Minas, Geología e Hidrología. Some of my observations go back to those years (1927—31). For due permission to publish them I am obliged to Director, Ingeniero Tomás Ezcurra. The chief results from Patagonia were obtained during my later expedition in 1932—34, by the aid of Swedish funds.

For a journey of reconnaissance in N. Scandinavia I received in 1938 half of the Otterborg scholarship. The opportunity to perform thorough comparative studies in the Scandes (see below) was given by my service in the Boliden Mining Company (1939—47). Its successive Directors Oscar Falkman and Erik Bengtsson as well as the leaders of its prospecting department Eric Wesslau, Acting Manager, and Dr Erland Grip, Chief Geologist, have manifested a great interest in my efforts to find out the history of the ice movements, although beyond the sphere of my original task. As nearly all my material from the Scandes and their foreland was acquired in the service of the Boliden Company, I will here express my heartfelt gratitude to the direction of the Company mentioned for their kind permission to publish these results.

I am much indebted to the redactor of this bulletin, Professor H. G. Backlund for his great interest in the publication of this paper and for his efforts to obtain the increased grants, by means of which the printing was made possible.

My assistant in the Scandes Mr Nils Marklund, a sharp and critical observer and the only student which hitherto learned my methods of analysis of rock sculpture, has handed me several observations on striae and local glaciation. He helped me in my boulder studies and constructed some of my boulder maps. He has constructed the stereographic maps of Peljekaisse pl. II and Snjärak fig. 15 as well as the sketch of Krappesvare fig. 12. From nature he has drawn some pictures and redrawn the map series, fig. 10.

1. Introduction.

A. Problems.

During my stay in Western Patagonia the question often presented itself: Why is the course of the Quaternary glaciations so different in Patagonia and Scandinavia, when the similarities in the geographical positions — save the latitudes — are so striking? Both regions extend N—S within the temperate zone's belt of the Westerlies. The dissimilarities in the eastern limitation would have been without consequences, if the Westerlies — as supposed — were prevailing also in epochs of glaciation. Near the western coast of both regions runs a high mountain range, the Andes and the Scandes respectively, which compel the Westerlies to deposit their greatest precipitation on their western slopes, and which divide the country into a narrow western part with a pronouncedly maritime climate, and a broader eastern part with a continental climate. In both ranges the glaciation limit (as also the firn line and the tree limit) inclines greatly towards the west. The Ice Age has left deep traces in both regions. Both the Andes and the Scandes are characterized by long deep fjords, and have a series of glacial lakes of the finger type running along the eastern side. Yet, there are great differences as regards the development and localization of the Quaternary inland ice.

In Patagonia the Quaternary inland ice caps did not — as far as is known — extend much beyond the mountain range, and the ice divide remained inside it.

The Scandinavian inland ice had a pronouncedly eastern position, extending a long way on the other side of the Baltic Sea. It is generally supposed that the nucleus region of the ice lay on the eastern side of the range from the first formation of an ice cap, the ice moving thence towards both the Atlantic and the Baltic. This eastern position has been explained by assuming that the precipitation on this side of the range is more extensively solid, due to the lower winter temperature (HÖGBOM 1885, p. 37); another explanation is that the west wind drives the snow over to this side (ENQUIST 1916, p. 34 et seq.). For ENQUIST this was a logical application of the important rule he discovered, that the glaciers lie on the lee side of the mountains. Just as the snow accumulates on the lee slope of a mountain, so must it also accumulate on the lee slope of a mountain range, and when a ridge of ice had formed here it in its turn gave rise to a greater accumulation of snow on its eastern side. In this way, according to ENQUIST, the ice divide was gradually shifted eastwards, so that already at an early stage it was far out on the lowland, probably along the Gulf of Bothnia.

The extramontane situation of the Scandinavian ice divide has influenced opinions as to the position of the divide of other glaciated regions. DE MARTONNE (1926, p. 919) writes of Patagonia's ice divide: 'Le faite de la calotte devait se trouver à l'Est de la crête principale de la montagne, comme en Scandinavie.' QUENSEL (1910, pp. 63, 64, 89) and CALDENIUS (1932, p. 132) nevertheless supposed the divide to follow the axis of greatest elevation.

As long as the position of the Patagonian ice divide was not definitely known, the difference in formation of the Quaternary ice caps in Patagonia and Scandinavia could be supposed to be one of degree. But after I had established a distinct western position for the ice divide in Northern Patagonia (Report 1, 1933, p. 647), a fundamental difference appeared between the picture I had myself obtained of the Patagonian Cordilleras and the one provided by the literature on the last Ice Age in the Scandes.

These are the problems treated in this essay. With the author's own investigations in Patagonia and Scandinavia as the basis, its aim is to show that the conditions in Scandinavia during important periods of the glaciations were in full agreement with those in Patagonia; further, that the inundation of the foreland, with an easterly position of the ice divide, was the consequence of the later climatical development, including Scandinavia in the Arctic zone of easterly winds. In those epochs the higher latitudes were of importance. The glaciation phases of Patagonian type recently discovered will explain some important features of Scandinavian morphology.

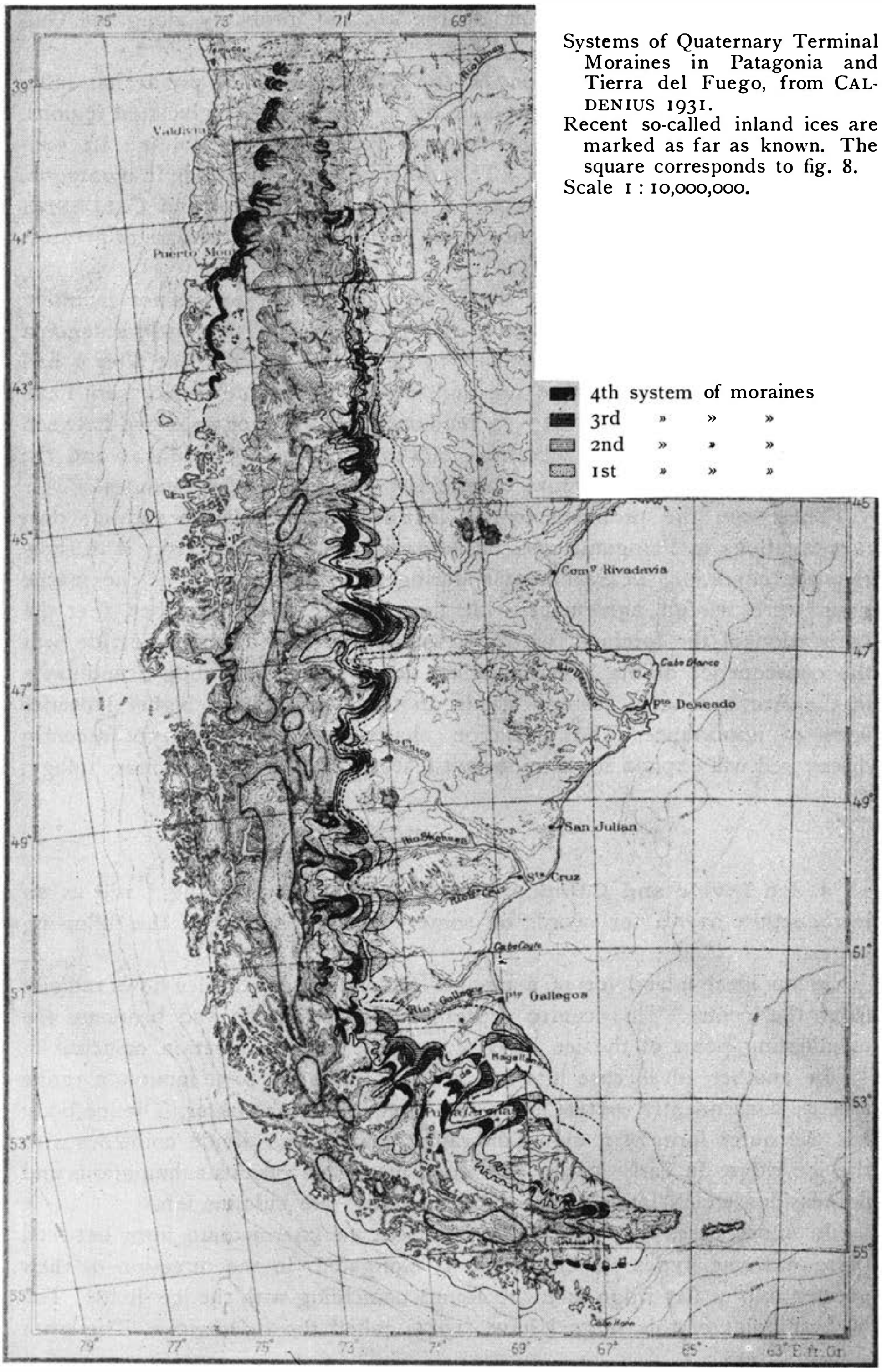
B. Some Terms.

a. Ice Divide and Culmination. To facilitate the reading I will as an introduction say a few words on some conceptions used in the following pages.

In an ideal inland ice of a circular circumference, the ice flows radially from the centre. This centre represents the ice divide and bears up the culminating point of the ice body. Ice divide and culmination coincide.

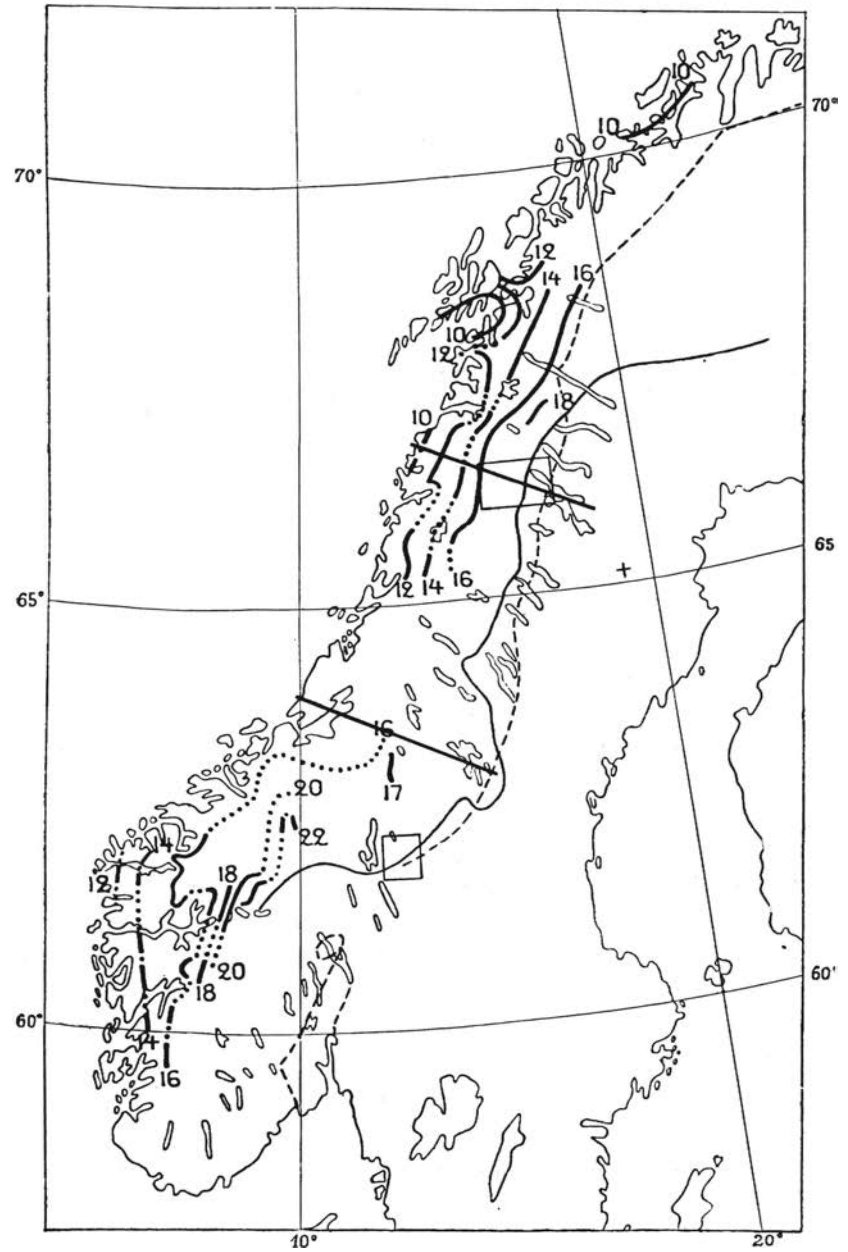
In another ideal case the inland ice is confined to a mountain range and is, consequently, extended in the direction of the latter. The ice body has the outer form of a mountain range, and its ice divide coincides with the ice ridge. In early stages this ridge may have various culminations and depressions which later on are substituted by one culmination.

In most cases the inland ices present an intermediate form between these extreme types. Their circuit is elongated. In the direction of their greater axis a flat ridge is to be found coinciding with the ice divide. The highest point of this ridge I have (1945) called the *culmination*. The latter



Systems of Quaternary Terminal Moraines in Patagonia and Tierra del Fuego, from CALDENIUS 1931.
Recent so-called inland ices are marked as far as known. The square corresponds to fig. 8.
Scale 1 : 10,000,000.

Fig. 1.



Flg. 2. The chain of the Scandinavian Piedmont lakes, some much enlarged, and the level of the actual glacial limit in hundreds of metres (coarse unbroken or dotted line) in photogr. reprod. from AHLMANN 1931, cf. 1943. The ice divide according to LUNDQVIST 1942 (fine unbroken line). Dash line surrounds the Silurian zone of Oslo and marks the east limit of the Silurian zone along the border of the Scandes. The sections in figs. 4 and 5 are marked. The squares correspond to the maps, figs. 10 and 34, the cross to Diagram B in fig. 11. Scale 1 : 10,000,000. Cf. fig. 35.

not only follows the ice divide in its migrations. It is also able to shift its position along the ice divide. The direction of flow has two components, one in the direction perpendicular to the ice divide, and another along the latter out from the culmination. The resulting direction of flow, as registered by the striae, might generally have been perpendicular to the isohypses of the ice surface.

The direction of flow is stated by mentioning the point of the compass from which the flow seems to arrive at the locality, just as in the case of the wind, contrary to the Norwegian practice. The scale of compass is 360°. The signs of ice flow on the maps symbolize the course of a particle, and the arrow head is placed upon the observation point.

b. Watershed and Iceshed. As watershed is the word commonly used in the sense of a drainage area, iceshed should consequently be used in the corresponding sense. Just as in Patagonia the Pacific and Atlantic watersheds meet in the water divide (or continental divide of the waters), so the Pacific and Atlantic icesheds met in the ice divide.

c. Fjell. In Northern Britain and Scotland we meet in several mountain names the old Scandinavian loan word *fell*, corresponding to the Norwegian *fjeld*, in modern orthography *fjell*, and the Swedish *fjell*, nowadays written *fjäll*. The Icelandic word is *fjall*. I have here used the most central form *fjell*. In the Swedish sense of the word, *fjell* is a mountain rising above the tree limit. Flat undissected areas are a characteristic feature of the Scandinavian fjells. Translated into *mountain* the word *fjell* would loose a part of its sense. In the form *fjeld* it was formerly sometimes used in international geographic literature.

d. The Scandes. Only some parts of the Scandinavian mountain range have old geographical names. For a short comprehensive term that cannot be misunderstood, I proposed *the Scandes* (1944 a, 1948 b). From a geological point of view the Scandes form the Scandinavian part of the Caledonides.

II. Patagonia.

A. Formations Attributable to the Ice Margin.

a. The Terminal Moraines. CALDENIUS gives a good map in colours (1931, pl. 1, 1932, pl. 42; reproduced in fig. 1) of the extent of the Quaternary glaciation in Patagonia and Tierra del Fuego. A belt of terminal moraines extends along the eastern foot of the Cordilleras. At the mouth of each major valley in the east border, terminal moraines follow close on one another in the form of concentric arcs: two distinct and more recent ones, and — in cases where they are preserved — two less distinct and older ones. The corresponding formations attributable to the ice margin on

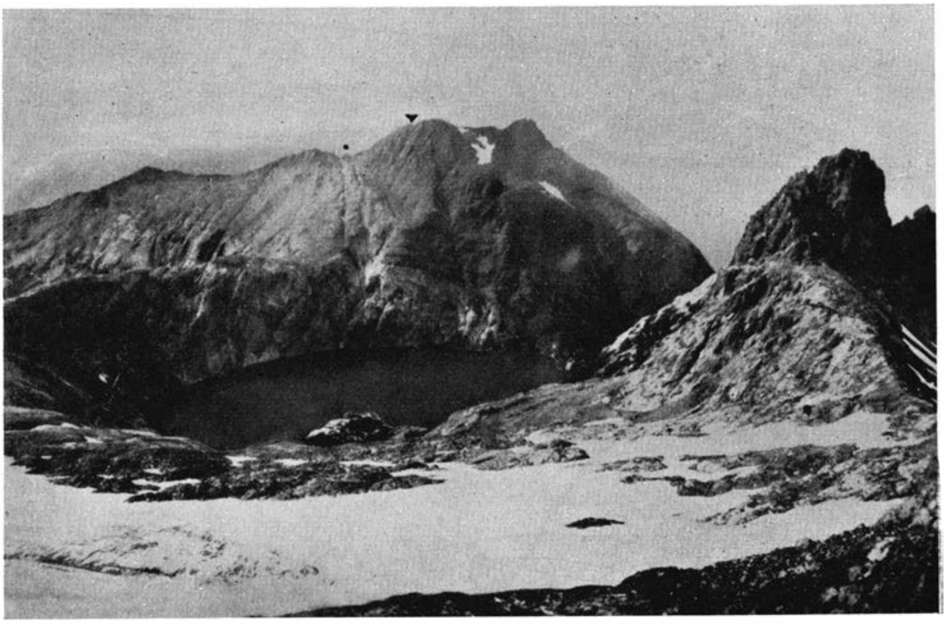


Fig. 3. A 4-facetted panorama by the author Apr. 29, 1933. Lake Anna, old cirque bottom found by the expedition (Mr RING and the author) in the mountains to the S. of Nahuel Huapi as seen from the Sierra Almenas (4 in fig. 6), looking ENE. Behind the lake arises Cerro Bonete 2310 m (5 in fig. 6). The lake runs off over a rock threshold to the right towards the Pacific. The ridge to the left, which is the continental divide of the waters and hides another cirque bottom on its Atlantic side, is well rounded by the inland ice overriding it from the right to the left. This threshold lies 1800—1900 metres above sea-level. On Cerro Bonete horisontal striae of the inland ice were found up to the saddle marked with the round point. Above the level of that round point, placed about 2200 m, the mountain was presumably a *nunatak*. In the foreground remnants of a small glacier. — A very hazy day.

the west side fall outside the coast, except furthest to the SE (in Tierra del Fuego) and furthest N (on Chiloë and in Southern Chile)[1]; according to CALDENIUS, the moraines of S. Chile correspond to those on the east side. Valuable data from S. Chile have been submitted by BRÜGGEN (most recently 1934, p. 170 et seq.).

b. Lakes and Fjords. Within the youngest of the terminal moraines there is usually a lake. This is only in part dammed up by the moraine; to a large extent it is a rock basin (fig. 6 : 16—17). The inner parts of the lakes resemble fjords (fig. 6 : 17, 18, fig. 7 and 8). The region round Puerto Montt is particularly instructive, giving an idea of the mutual relations of lake and fjord (fig. 7 and 8). The most southerly lake surrounded by moraine arcs in S. Chile is Lago Llanquíhue (19 on the cross section fig. 6). Lago Todos los Santos (18) formerly comprised part of it, but was separated from it by an eruption of the volcano Osorno (O) in late post-glacial times,

[1] In common parlance southern Chile does not include the Chilean part of Patagonia or Tierra del Fuego, which are considered as Colonies.

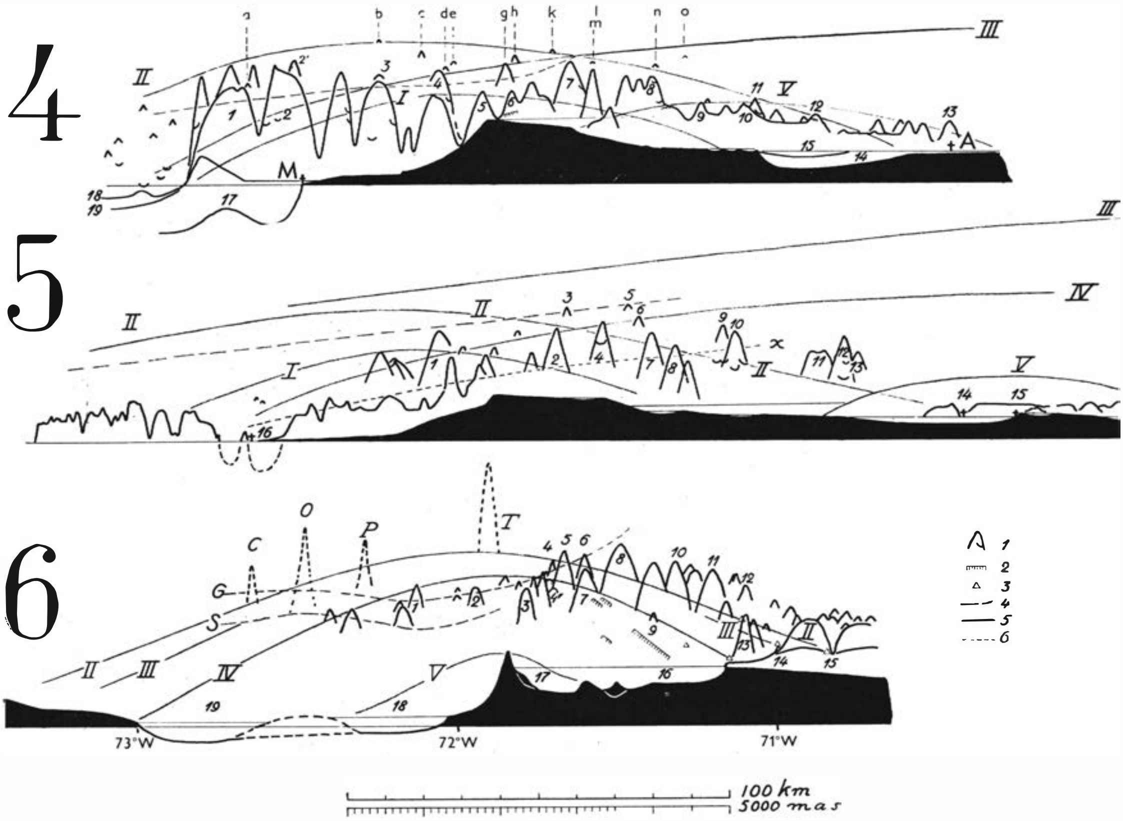


Fig. 4—6. Cross sections. Horizontal scale 1 : 2.000.000. Vertical scale 1 : 100.000.
1 = Mountain with cirque, 2 = marginal terrace, 3 = moraine,
4 = glacial limit, 5 = top surface of the ice, 6 = problematic surface.

Fig. 4. Section through the northern part of the Scandes. Line of reference marked in pl. II.
I = top surface of the ice during an intense alpine stage.
II = mountain ice sheet facing W.
III = part of the continental ice sheet.
V = the ice at the time of ice-dammed lakes.
Glacial limit from ENQUIST 1932 (dash line.) For letters and figures see pl. II.

Fig. 5. Section through the central part of the Scandes. Line of reference passes the Trondheim fjord 10 km SSW of Levanger, the boundary mark 163, and the northern end of lake Näckten.
I = the ice at an intense alpine stage.
II = mountain ice sheet facing W.
III = part of the continental ice sheet.
IV = part of the continental ice sheet at a late stage.
X = the highest possible level of an ice surface with the margin in 16, if the increased local glaciation belongs to that epoch.
V = a lake-damming ice.
1 = Fongen 1091 m, 2 = Snasahögarne 1463 m, 3 = Storsylen 1711 m,
4 = Bunnerstötarne 1554 m, 5 = Helagsfjället 1796 m, 6 = Herrångsstöten 1626 m, 7 = Åreskutan 1419 m, 8 = Ottfjället 1265 m, 9 = Lundörsfjället 1503 m, 10 = Anarisfjället 1426 m, 11 = Västerfjället 1159 m, 12 = Hundshögen 1372 m, 13 = Oviksfjället 1252 m, 14 = Östersund and Storsjön 292 m, 15 = Brunflo, 16 = Ekne by the Trondheim fjord (the depths of fjords refer to Ytterøn at Levanger).

and dammed up. The flooded forest trees are still visible in the lake bed, along the shores. Lago Todos los Santos (18) has a pronounced fjord character, as also Nahuel Huapi lying opposite, particularly in its western parts (17). The nearest southerly equivalent to Lago Llanquihue is a bay of the sea, for the bottom of the Chilean longitudinal valleys here falls below sea level. But in the east this bay, Seno de Reloncaví, joins a long fjord-arm, Estero Reloncaví. This is a genuine fjord, the most northerly one in Chile; at the same time it completely corresponds in position and morphology to the just mentioned Lago Todos los Santos (bathymetric map in STEFFEN 1919, pl. 3).

The east coast of the Island of Chiloë houses such terminal moraines as border new wide basins, flooded by the sea and joining fjord arms to the east (Estero Comau, over 500 m deep). But to the south of this, the terminal moraines disappear into the sea, and only the fjords subsequently testify to the vicinity to the west border of the Quaternary inland ice.

c. Relation of the Ice-Margin Formations to the Axis of Highest Elevation. The first noticeable narrowing off of the glaciation region southwards is in the eastern part of Tierra del Fuego, where the elevation of the Cordilleras sinks almost to nil. Northwards, the narrowing off is due to the rise of the glaciation limit towards the tropica circle.

It is extremely interesting to observe the relation of the marginal formations to the axis of highest elevation in the N, where the western formations are also complete. To this end I have constructed a map (figs. 7 and 8), where I have marked the volcanoes in one special way, and the area above 2000 m height of the older peaks in another. For 41° S the map is mainly based on my own investigations. Thus I have been able to establish that Tronador, N. Patagonia's highest point (T in the section fig. 6), is not made up of tertiary rocks, as was previously supposed, but consists of an interglacial volcano (see the history of exploration in Report 7 by LARSSON 1940, pp. 204—215). Further, when mapping out a region N of this, I found that an area appearing on older maps as 2386 and 2550

Fig. 6. Section through the Andes; line of reference = L 41° S. II—V = Ice surfaces corresponding to different post-Tronador stages. G = recent glaciation limit.
S = recent snow line according to PHILIPPI, REICHERT, and KÜHN.
C = Calbuco (active volcano) 2015 m, O = Osorno (active volcano) 2660 m.
P = Puntiagudo (old volcano, perhaps of interglacial age) 2490 m,
T = Tronador (interglacial volcano) 3470 m.
1 = Cerro Techado 1880 m, 2 = Cerro Esperanza, 3 = Cerro Frias 1812 m,
4 = Cerro Almenas point Mariscal 2200 m, 4′ = Cerro Capitan 1824 m, 5 = Cerro Bonete 2310 m, 6 = point 2270 m,
7 = Sierra Lopez point Lop 2090 m, 8 = Cerro Catedral 2402 m, 9 = Cerro Monje 1573 m, 10 = Cerro Utne 2170 m, 11 = Cerro Colorado 2073 m, 12 = Pico Quemado 1850 m, 13 = Cerro Carmen de Villegas 1474 m, 13 = 4th terminal moraine, 14 = 3rd terminal moraine, 15 = 2nd terminal moraine, 16 = Nahuel Huapi 767 m, 17 = the western fjord of Nahuel Huapi, Brazo del Viento, 18 = Lago Todos los Santos (= Esmeralda) 121 m, 19 = Lago Llanquihue 51 m. Cf. figs. 7 and 8.

m high has in actual fact a maximum height of 2041 m (my preliminary map published in Report 7 by LARSSON 1940, p. 235).

Consequently, if the volcanoes are left out of account, the axis of greatest elevation of the Cordilleras will be found to lie considerably further to the east than was supposed, *viz.* 71° $^1/_2$ W for the region 39° $^1/_2$ — 42° S.

This has very important consequences for the position of the lake zones and the ice divide. They do not lie symmetrically, but are pushed westward in relation to the axis of greatest elevation, the map showing clearly how the eastern chain of lakes in N. Patagonia lies completely under the axis; the western zone, on the other hand, is so far down the western slope that the most southerly lake falls in the longitudinal valley. This explains the striking morhological difference between the western and the eastern lakes, in that the former are wide lowland lakes, passing inwards into valley lakes, whereas the latter here in the north are exclusively valley lakes. Only the greater breadth of the glaciation region to the south permits the largest of the eastern lakes to extend in their outermost parts so far outside the actual Cordilleras as to correspond morphologically to the lakes of S. Chile.

The convergence northwards of the lake zones in accordance with the narrowing of the glaciation region provides the best proof of their glacial nature.

It is true that there are also structural lines converging northwards; on the one side the line NNW-SSE (Bio-Bio-Collon-Cura line) marked by rivers 10, 12, and 20 in fig. 7, and on the other the line NNE-SSW (the volcano line) marked by fissure valleys in granite, and volcanoes (abghjkmnorstuv) and hot springs in fig. 8, which are dealt with in more detail in my work 'Nahuel Huapi'. But the eastern lakes fall halfway between the two structural lines, and the western lakes fall west of the western structural line, between it and the longitudinal valley.

B. The Ice Divide.

a. Position of the Ice Divide. Thanks to the convergence of the lake zones northwards it is possible to make out the approximate position of the ice divide on the map in figs. 7 and 8. The fact that the eastern zone in N. Patagonia lies under the axis of greatest elevation of the Andes implies that the ice divide must lie west of this — a position that is retained also where the continental water divide is pushed eastwards. By field investigations concentrated on the summit levels on the western slope of the Andes I have also discovered at lat. 41° S in my section that the high mountains of this slope immediately east of the water divide in fig. 6 (3 etc.), were all overridden by ice from the Pacific to the Atlantic side. Here the ice moved from WSW, the ice divide culminating in the south. I go into this in more detail in my work 'Nahuel Huapi' (Report 6), which is being prepared for the press.

It is quite natural that CALDENIUS, who worked mainly along the east border of the Cordilleras, should have conceived the Patagonian glaciation to be a valley glaciation. During my work in the summit region of the western slope it transpired that the ice there may be likened to inland ice. During the glaciation's maximum there was probably no nunatak on the western slope S of lat. 40° 1/4 S.

b. Why Was not the Ice Divide on the East Side of the Cordilleras? The present glaciation in N. Patagonia is largely concentrated on the east side of the mountain peaks: this well confirms ENQUIST's theory of the influence of the wind (v. Report 7, LARSSON 1940, Pl. III). Considering the theories holding for Scandinavia (see Introduction), one would expect to find the Quaternary ice divide on the east side of the Cordilleras, this on account of a larger accumulation of snow.

The wind has an influence upon the position of glaciers during building as well as wasting actions. The influence of the wind on ablation is great (ÅNGSTRÖM 1933, SVERDRUP 1935) and therefore a selective ablation may play a rôle. The uneven distribution of falling snow is perhaps exaggerated (see SANDSTRÖM 1913 p. 15 and 1932 p. 240) and may partly be counterbalanced by the hoar frost which deposits on the windward sides. The observations of explorers do not coincide on the importance of the redeposition of drifting old snow (see discussion between LOEWE and WEGENER 1933).

Apart from the manner in which the wind exercises the greatest influence on the position of the glaciers, a mountain peak with its glacier is but a small detail in the section across the range. Experiences from a detail of this kind must not be thought to be valid for the whole section, least of all when the section connects two completely different climatic regions.

The great contrast in climate between the continental east side and the maritime west side in the S. Andes is found at all levels. The greater amplitude in the east between summer and winter temperature is expressed in the opposed inclination of the two forest limits (LJUNGNER 1939). And the marked fall westward (fig. 6) of the glaciation limit, due to the cooler summers and the greater precipitation there, is a direct indication of the predilection of the ice for the western slope. These circumstances imply that it must be here that the glaciation develops into inland ice. And here, too, must the ice divide arise. — As far as may reasonably be judged from the existing map material, the present-day so-called inland ices in Patagonia are mainly concentrated on the western slopes (fig. 1).

As regards the S. Andes there is no reason to suppose the direction of the wind to have been reversed during the Ice Age, as ENQUIST (1916, pp. 50, 54) does for parts of the Rocky Mountains in North America.

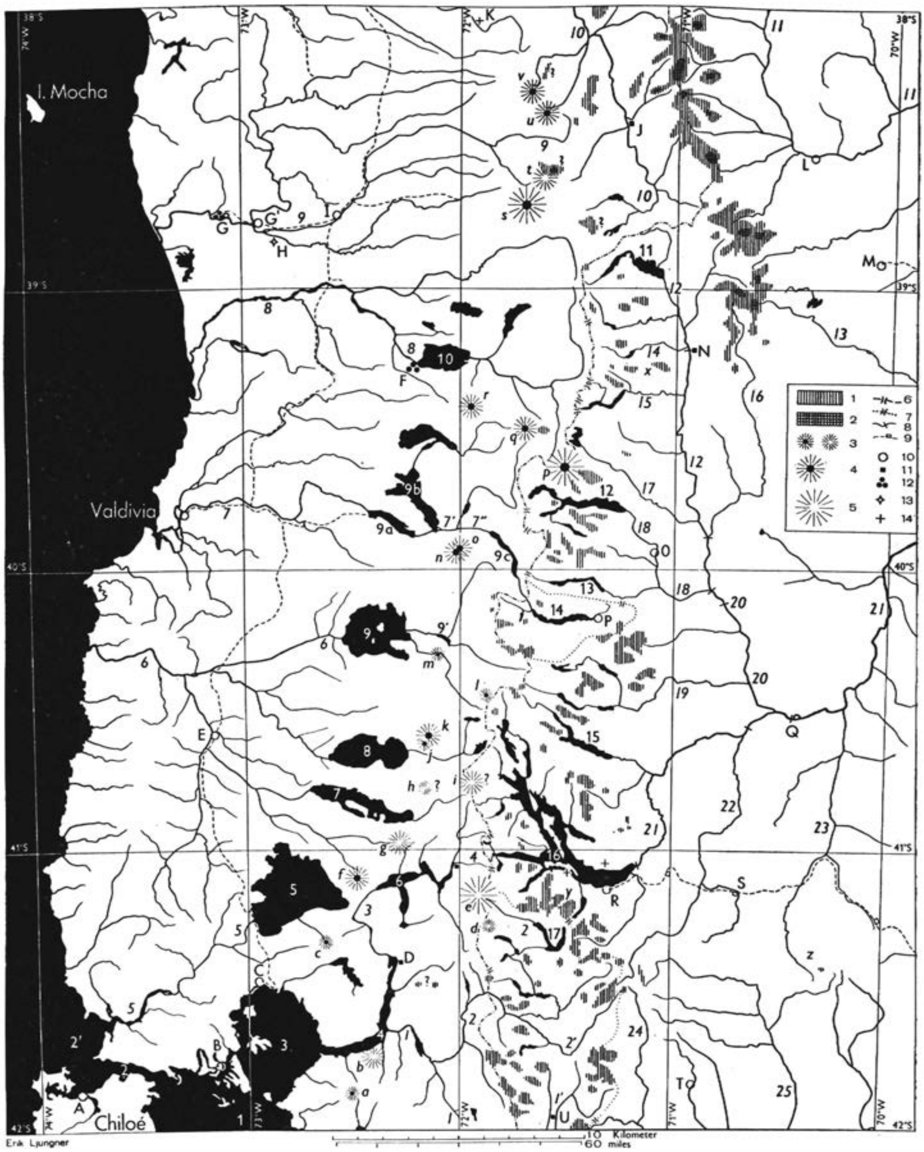


Fig. 7. Southern Chile and adjacent parts of the Argentine. Scale 1 : 3.000.000. Symbols:

1. Areas exceeding 2000 metres above sea-level.
2. » » 2500 » » » »
3. An active and an extinct volcano, altitude < 2000 metres above sea-level.
4. Active volcano, altitude 2000—3000 metres above sea-level.
5. Extinct volcano, altitude > 3000 metres above sea-level.
6. The Chilean-Argentine boundary, with a pass below 1200 metres above sea-level.
7. Continental divide, when not boundary, with a pass as in 6.

8—14. Objects of human geography. See LJUNGNER: Nahuel Huapi (Report No. 6), fig. 4.

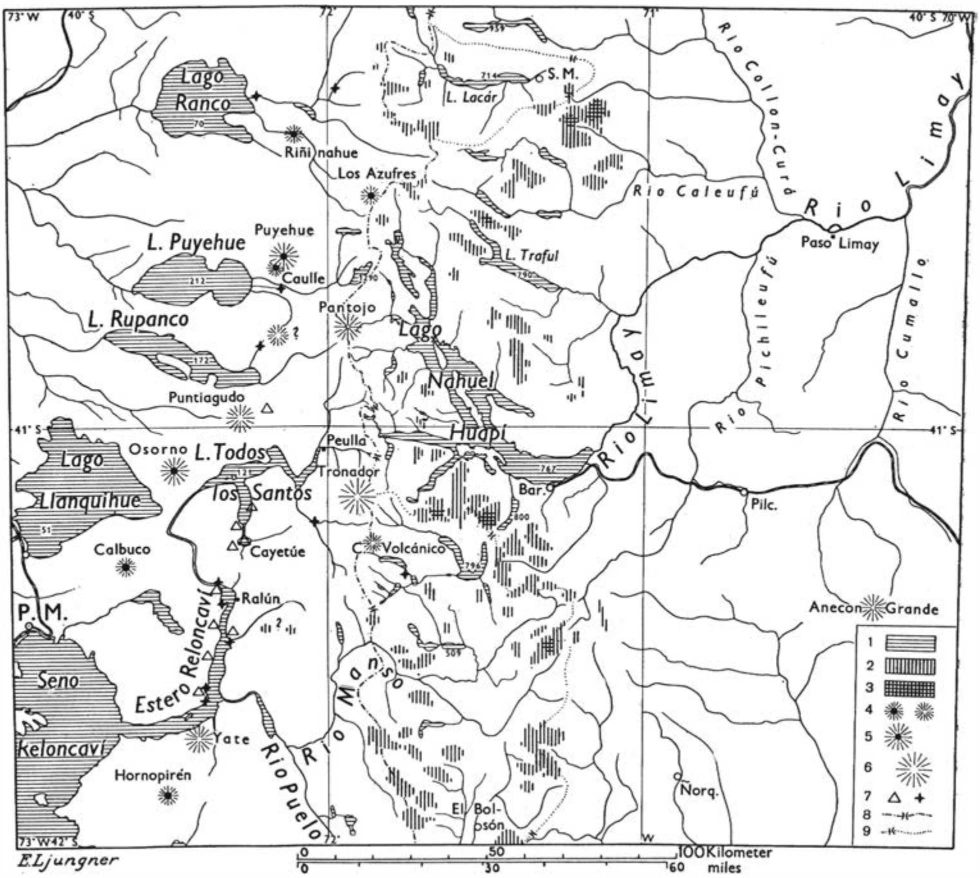


Fig. 8. Sketch map showing the orographical conditions of Sheet 72 Nahuel Huapi (1928) of the map of the Argentine Ordnance Survey, with corrections by the author. Scale 1 : 2.000.000.

1. Water surfaces (with the altitudes above sea-level).
2. Areas exceeding 2000 metres above sea-level.
3. » » 2300 » » » »
4. Active and extinct volcano, altitude < 2000 metres above sea-level.
5. Active volcano, altitude between 2000 and 3000 metres above sea-level.
6. Extinct volcano, altitude > 3000 metres above sea-level.
7. Eruption centre (according to Reichert 1917 and Steffen 1919). — Hot spring.
8. The Chilean-Argentine boundary, with a pass below 1200 metres above sea-level.
9. Continental divide, with a pass below 1200 metres above sea-level.

C. The evolution.

It is of interest in the following comparison with Scandinavia to see how the elements in the glacial landscape developed as the extension of the inland ice varied during different periods. The discovery of the interglacial pyroclastic formation, which I have called the Tronador series, has made it possible to discern a time sequence.[1] It has been found that the glacial morphology was completely developed already before the stratification of the Tronador series; many relics of it were found in the central part of the lake and in its western fjord-arm, as also in the mountains.

Well-developed glacial cirques have been observed in the central zone and westward in the vicinity of the water divide, with the lowest point a little below the present forest limit. So low a firn limit, about 400 m below the present one, may well have caused a valley glaciation affecting the proximal parts of the lakes. On the continental water divide S of Nahuel Huapi, immediately W of the axis of greatest elevation (between 4 and 5 in fig. 6), the wall between two glacial cirques belonging to the Atlantic and the Pacific drainage, respectively has been worn down into a threshold and polished by a Pacific ice stream, whose upper surface probably reached about 2200 m above sea level (fig. 3). Another ridge (7), just by Nahuel Huapi's southern valley side and more than 2000 m above sea level, has been rounded off by an ice stream about 2100 m above sea level. On this ridge an interglacial tuff has been deposited, in its turn overridden by an ice stream from the west. The formation of a glacial 'plate' (term by AHLMANN 1919, p. 128) by a firn glacier on the east side of the ridge subsequently restored the crest shape.

As QUENSEL stated, the lakes of Patagonia are rock basins. And as far as their position can be determined, it is usually the fourth moraine arc that marks their termination eastward — sometimes the third (counting from the outermost). At Nahuel Huapi the distance between the moraines is relatively large, and only the fourth one is distinct. Only an arm of the rock basin reaches possibly the third arc.

I have, however found several boulders of the Tronador series in both the fourth and the third moraines (the outer ones have not been investigated). As the lake basin, on account of the interglacial remains preserved in its central and western parts, must be regarded as older than the rocks of the Tronador series, it must be assumed that earlier glaciations or stages have also existed with the same extension as that marked by the fourth arc.

The position is the same on the west side of the Cordilleras. There the ice has made its way on to the lowland. The basins Llanquihue (more than 200 m deep according to bathymetrical curves on the international map of the world) and Seno de Reloncaví have there been formed by lobes projecting on to the lowland, but BRÜGGEN (1934, p. 171) discoverad two strata of Geschiebemergel further west, at the mouth of the River Maullin.

[1] LJUNGNER 1931, pp. 255—257; 1933, p. 646; 1935, p. 110 et seq. The geology of these deposits is dealt with in more detail in my as yet unpublished work "Nahuel Huapi", which in parts apposite here is reviewed by LARSSON (1940), where my maps are also published.

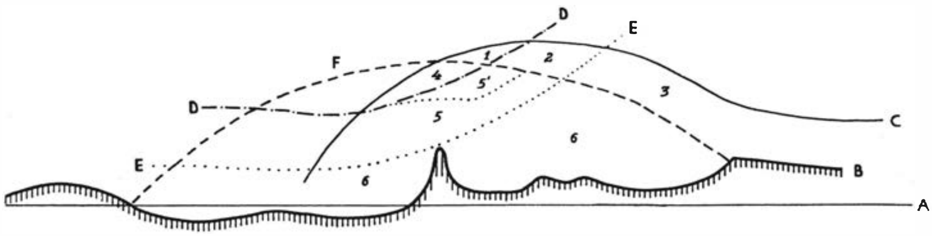


Fig. 9. Glacial-morphologic regions in a section 41° S (schematically).
The letters A—F refer to the lines of the profile. — A. Sea-level. — B. Bottom of valleys and lakes. — C. Maximum height of summits. — D. Recent glaciation limit. E. Glaciation limit of the ice age. — F. Surface of the Quaternary inland ice. Figures 1—6 refer to the areas of the section included within the lines B and C. — 1. Recent local glaciation. — 2. Cirques from the ice age. — 3. Glacial forms lacking. — 4. Recent local glaciation, and sculpture forms of the inland ice. — 5. Sculpture forms of the inland ice and, in 5', cirques from the advance and the regression. — 6. Sculpture forms of the inland ice only.

Thus, on the Chilean side, too, the lakes were renewed as far as younger glaciations extended.

If the position of the lake basins had been more uniform in relation to the border of the Cordilleras we might ascribe the former to an increased erosive effect at a certain point of the section. Without wishing to deny the importance of such an effect (particularly for the depths of some lakes), I would nevertheless like to point out that the map shows the lake basins to be clearly associated with a certain position of the ice margin. This position was probably held during large parts of various glaciations. Fig. 9 illustrates [schematically] the regional distribution of glacial forms in the Cordilleras.

III. Scandinavia.

A. Introduction.

In expounding the evolution of the Scandes during the last glaciations, I shall concentrate on two sections, whose positions are given in fig. 2.

The sections, figs. 4 and 5, show that in breadth and height the Scandes are fully comparable to the Andes in their Patagonian extent. Their maximum height is in the N. 2,125 metres (Kebnekaisse) and in the S. 2,468 metres (Jotunheimen).

In the Scandes the glaciation limit shows an inclination similar to that seen in the S. Andes (figs. 4, 5, 6, 2). Its height has been determined by ENQUIST (1916, 1933) and AHLMANN (1924, 1934) according to the so-called top method (ENQUIST 1916 p. 11 et seq.). The rise eastwards of the glaciation limit is due to the increasing continentality in the same direction; it must therefore be assumed that this rise would persist even if the glaciation limit sank low enough to touch the mountains of the eastern slope. I have dealt, in another work, with the glaciation limit and other elevation limits (1944 a). I shall be returning below to the circumstances of the Pleistocene (§ III B 2).

In Scandinavia we speak of two glaciations of Pleistocene Age, the 'great' one and the last one. In the following pages I will treat two glaciations, the first of which has hitherto been unknown but seems to be closely allied to the last one. There are reasons to include both in the last glacial age or glacial epoch (Eiszeit) of the Quaternary Ice Age.

Of the northern section, I have myself investigated the Swedish part up to some way past the water divide; I have also flown over the Norwegian part down to the coast (1939), which I have in addition studied during a coastal journey (1938). I have travelled over the Swedish part of the southern section (1920, 1944), as also through some parts of the Norwegian portion (1938), but only on excursions. In this section, therefore, the account is chiefly based on reports from the literature and studies of maps.[1] I have had the opportunity of making short field studies in some other sections, among them the Kiruna-Narvik-Lofoten one (1938). The ones here selected seem nevertheless to be most representative as regards position. Various flights in 1939 along the mountain range for reconnaissance or mapping and one in 1946 have made it possible to obtain bird's-eyeviews.

To the names of mountains and lakes referred to in the text and in the illustrations there are generally added in ( ) their letters or figures on pl. 1 and fig. 4.

B. A Section through the Northern Part of the Scandes.

1. Positions of the Ice Divide as indicated by Minute Sculpture Forms.

a. **Remarks as to Method.** Generally, it has not been considered possible that glacial striae and stoss sides should be extant from the earlier phases of the last glaciation (ENQUIST 1918 p. 23); even the existence, in central parts, of striae from the time of the maximum spread of the last ice sheet has been denied (SJÖGREN 1909 p. 111, TANNER 1938 p. 434, AHLMANN 1944 b). The varying directions of sculpture, therefore, have been regarded as caused by reduced ice masses of the latest phases of glaciation, if not — as in the case of the zone of the ice divide — as an expression of erratic movements. In order to determine the position of the ice divide — which only could mean the last one — that line or zone has been searched for, from where the predominant striae or sculpture show an outflow in two opposite directions. Difficulties have then arisen in the

[1] At about 1° to the S, however, a regional study was made in 1946, the results of which are added as § III Cc.

interpretation of existing striae, since the direction may easily be misread 180°, and an 'apparent' stoss side be confused with a 'genuine' one. Many investigators have emphasized this, and it has often lead to a reinterpretation of one's own and others' observations (examples below).

As in my regions of investigation the glacial forms as a rule are complex, I have tried (since 1935) to follow the evolution of the forms in each case, and it is evident that all outcropping surfaces of the region have a common history. One stage may be badly represented or lacking in some outcrop, but in another we can find it dominating the sculpture — the difference being mainly due to the difference of rock. In this science it is, thus, indispensable to observe also smaller "irregularities", bearing in mind that these may also represent features characteristic of their corresponding stages.

The science thus developed, which reminds of the analysis of a palimpsest, has by me been referred to as "hällanalys", i. e. analysis of the glacial surfaces of outcropping rocks. It comprises four parts. Directional analysis gives the direction of the streams; successional analysis gives their relative age; qualitative analysis gives their degree of plasticity, whence can be deduced their ice thickness; and quantitative analysis gives their relative durability.

It is evident that the science in question requires decisive and objective methods. All methods are not applicable to all cases. I have studied and tried out all existing methods, refused some, and added new ones. For each of the two first named parts of the analysis I have five. This is not the place to describe them. I have treated them in part in earlier works (1923, p. 12; 1930, p. 287; 1944 b, pp. 2—4, 15, 21).

It is obvious that in these evolutional studies the use of the predominant sculpture as an indicator of the ice divide must be refused, as must the average of the directions of striae.

b. The younger streams on the Bothnian slope. On the Bothnian slope of the Scandes I have made a study of the ice movements. The results are presented in the series of maps in fig. 10. I will commence with map *b*, as scratches belonging to that system, from the SE, have long been known in that part of the Scandes. Map *b* corresponds to a position of the ice divide on the foreland, also evidenced by the spread of granitic boulders from the foreland all over the mountains.

The map, however, demonstrates a further development of the ice flow. The direction from the east in map *c* implies a turning counter-clockwise, caused by a migration to the N of the culmination point of the ice divide, and this turning continues to the NW in *d*, indicating an ice divide situated about half-way between the border of the mountain range and the water divide.[1] I have often followed the boulder trains originating from known

[1] The striae of the western half of map *d* (fig. 10) were found in 1946. As the youngest striae of their tract they had to be placed here. They form a right or slightly obtuse

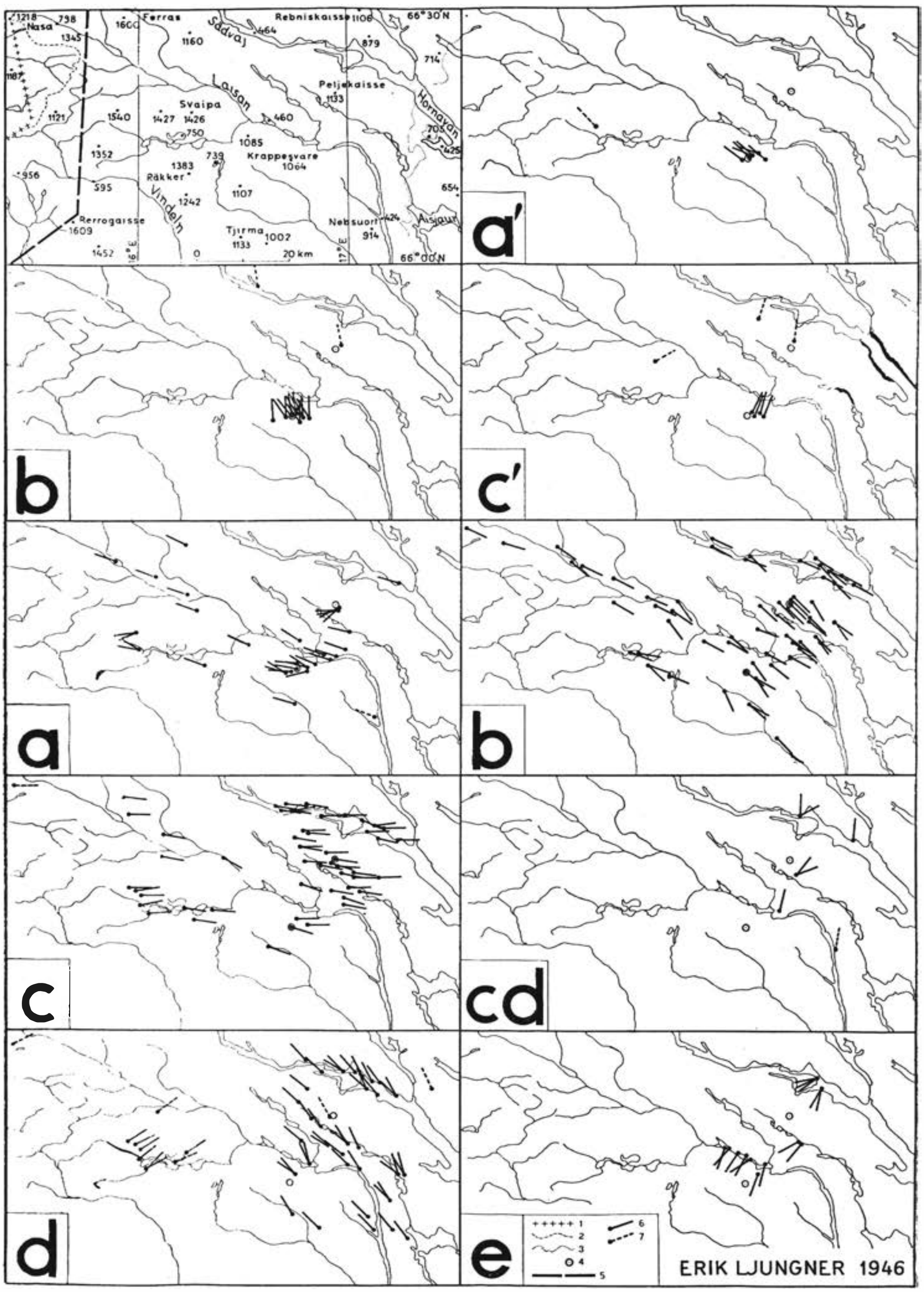


Fig. 10. Directions of striae from 9 epochs on the Bothnian slope of the Scandes, close to the S. of the Arctic Circle. For situation, see figs. 2 or 35 and pl. I. Scale 1 : 1.600.000. — 1. Frontier. — 2. Water divide. — 3. Axis of mass elevation, according to ENQUIST 1933. — 5. Limit between the rock series of the mountain range (to the left) and their granitic subdeposits (to the right). — 6. Glacial striae, the head of the symbol indicating the locality. — 7. As in 6, but the striae do not for certain belong to the epoch of the map in question.

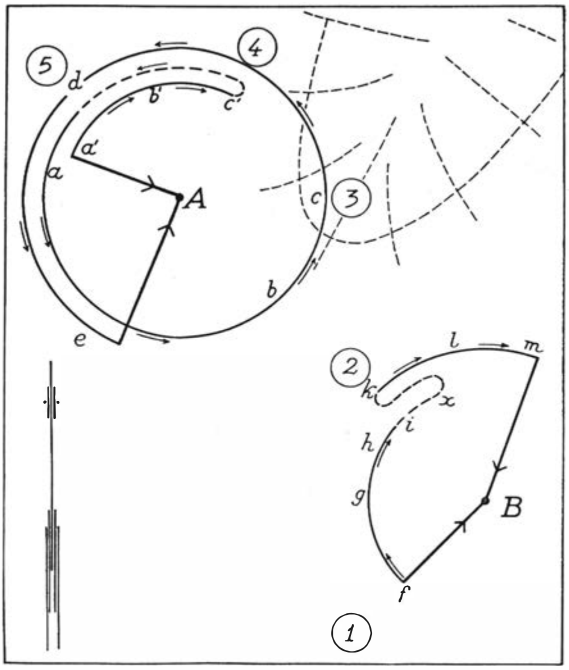


Fig. 11. Spiral diagrams of the evolution. All localities between 16° 30′ and 17° 30′ long. East on fig. 10 (i. e. the eastern half of each map) are placed in the centre A, but only the symbols of the oldest and the youngest directions are drawn. The turning from the oldest to the youngest direction is symbolized by a spiral. Dashed parts of the spiral are not represented by known striae. Diagram B refers to a tract on the lower foreland of the Skellefte-River, indicated with a cross in figs. 2 and 35. It corresponds to the epochs *b—d* in diagram A. The imaginary starting point of the ice flow was successively 1, 2, 3, 4, and 5 (see text). From *k* on the ice was in B rigid, indicating a smaller thickness and a more distant ice divide.

outcrops for a mile towards the SE. In some cases I have mapped them, where ground is known by outcrops and borings. In that position the ice divide gradually loses its importance. There are striae (*e*) implying a further turning counter-clockwise, but they belong to so late a stage that the higher mountain ridges dividing the great valleys had already begun to be ice free, and the melting on their southern slopes, accelerated by the insolation, caused a compensating movement of the ice remnants of the valleys from the south. A sometimes extensive plucking, i. e. loosening by breaking, but a very short transport of boulders was connected with that flow. An impenetrative field of ashlars showing one polished side and covering a polished rock surface was the result.

---

angle to the striae of the eastern half of the map. There was obviously a culmination on the polar side of the region — already proved by map *cd* illustrating the counter-clockwise turning. If the angle had been acute, the striae of the western half might hade been looked upon as traces of the ice divide itself. Now they must represent the opposite (western) side of the ice divide, the trend of which might have been N-S or NNE-SSW passing the centre of the map. — An interesting fact was the find, also made in 1946, of the traces of an ice-dammed lake occupying the environs of the actual lake-system of Bosjusjaure-Tjålmejaure and its tributaries, where also the striae in question occur, and at a level of 100 metres above the actual lakes mentioned. The nucleus of the ice body, which at this later stage dammed the waters, was consequently also situated to the east of the striae in question, probably a little to the east of the centre of the map.

Traces of a late local glaciation are common in this tract.

c. The Younger Flow in the Lower Foreland Connected with those of the Mountain Slope. Lake Hornavan on the map fig. 10 belongs to the river Skellefte Älv. Following this river more than half its way to the coast we arrive at a point of similar research. As demonstrated in fig. 11, the movements here registered (diagram B) are partly the reverse of those of the mountain range (diagram A), showing their reflected image. Station 1 is the imaginary starting point for the movements registered by the oldest scratches *b* (from SSE) and by *f*. Station 2 is the imaginary starting point of the flow corresponding to scratches *b* and *i*. Station 3 is the imaginary origin of the stream directions *c* and *x*. In 4 we see an imaginary centre for a short stage, when scratches of transition *c-d* were formed and scratches *x* were continued. Station 5 is the imaginary origin of the stream directions *d* as well as *k*. As the ice pressure from the mountain range diminishes at the coast, ice remnants in the northern part of the foreland and of the Bothnian Gulf have an increased influence in B, resulting in scratches *b* and *m*, which are generally of small importance, cf. paragraph E 3 i.

Stations 1, 2, and 3 mark together roughly the position of the part of the ice divide during those stages when scratches *b-c* and *f-x* were engraved, but at the beginning the ice ridge of the ice divide culminated much farther to the south. Stations 1, 2, and 3 give the imaginary positions of the culmination in its migration to the north as the ice cap was losing area in the south. To illustrate the relation of the imaginary positions of the culmination to the real ones, I have made a sketch in fig. 11, showing what may have been the real position of the culmination, when 3 was the maginary one. The real position of the culmination corresponding to 1 should be sought far to the south.

Diagram A as well as the series of maps in fig. 10 reveal, however, an earlier history than scratches *b* and *f*.

d. Older Streams of the Mountain Slope. In all parts of the profile through the eastern slopes of the Scandes and at all levels we find a sculpture older than *b* and in the opposite direction. This old sculpture is well developed, forming very great stoss sides. It is interesting to see the effect of the *b*-flow upon the initial surface formed by the older sculpture. It is more prominent along the water divide and to the west of the axis of mass elevation than in the eastern parts, which is to be expected principally because the cross-section area of the ice flow was much reduced here, above the threshold. Indeed, the only sculpture I found here at any levels was from the east. To the east of this part of the section the most conspicuous difference is, however, related to the altitude. In the valley-bottom double-facing stoss sides are characteristic, and for some distance the old sculpture can be wholly capped by the forms of the *b*-flow, as in the region of Svaipa (8), but at about half the height of the valley side the influence of the *b*-flow diminishes rapidly, and at greater altitudes it is

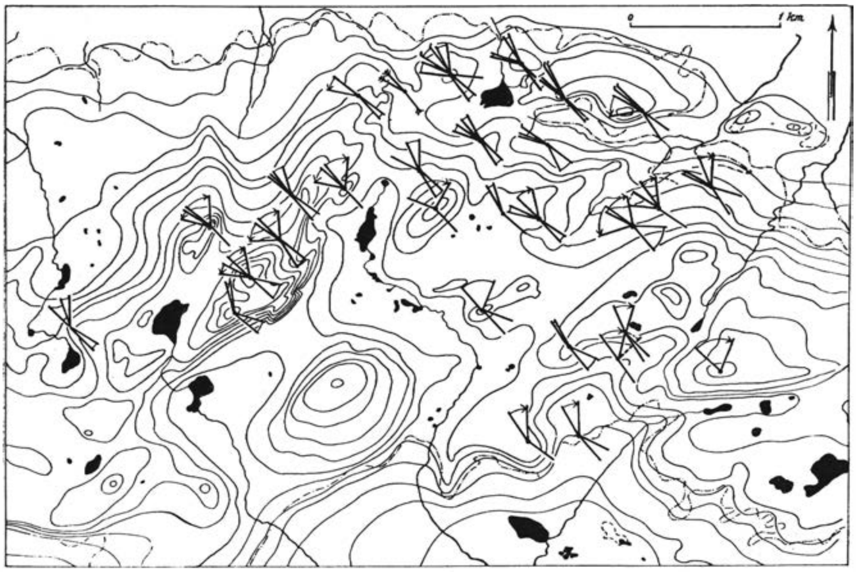


Fig. 12. The central part of Krappesvare (see fig. 10 and pl. I) with Kaissetjåkko (1064 m, to the left), from air photos. Scale 1 : 50.000. Lines of altitude sketched with an interval of 25 metres. Symbols of forest limit and striae (partly) as in pl. II.
From the NW there are striae from 3 epochs. A fan-shaped bundle of striae presenting a counter-clockwise turning belongs to the *a*-series. Older are the bundles showing a clockwise turning, which represent the prime-series; younger are the *d*-striae, marked as in pl. II. From the SE and E there occur normal *b*- and *c*-striae of the age between *a*- and *d*-striae.

difficult to find a trace of it. Consequently, high up we see the rock surface in the same state as it had before the continental ice sheet was established.

In Krappesvare (10) I found that the old sculpture from the axis is composed of two, see fig. 12. As the second had already been named *a*, I had to mark the first a' (*read a-prime*). The difference that helps us to tell them apart is that *a* turns counter-clockwise, as do all later ice flows in the mountain range, whereas a' turns clockwise, thus forming the "prime-series" a'—b'—c' with decreasing force. At these high levels in Krappesvare, where the *a*-sculpture has not destroyed the scratches and polish of the prime sculpture, it is easy to determine that the stoss sides were formed by the prime-sculpture. They are imposing. No yonger flow here had the power to form stoss sides.

There is no reason to believe that the sculpturing effect of the prime-flow was greater here than in any other part of the slope. The result of the erosion was probably smallest at Krappesvare, as a mountain glaciation requires a very great development to cover a fjell situated so near the border and, consequently, less time is disposed of here than in other parts. At about 300 m below the summit the polish of the prime-sculpture has generally been destroyed by the *a*-sculpture, but the stoss sides may be the old ones. It is possible that the stoss sides bearing *a*-striae in the valley bottoms developed from older stoss sides of the prime-sculpture.

e. An Early Deglaciation. The exceptional small result of the *a*-sculpture at higher levels in Krappesvare may possibly be due to a common decreasing effect of the glacial erosion with increasing level. This has been suggested but never proved. In this case we have to bear in mind the considerable altitude of Krappesvare in the profile of the sloping ice-cap just referred to when discussing the prime-sculpture. It is possible that the upper surface of the *a*-stream — or of the erosive part of it — capped the top region of this fjell only for a short time. There is, in fact, a circumstance to support such an opinion. That is the lack of all sculpture connecting *c'* with *a*. Here there seems to be a hiatus in the glaciation.

Let us consider the import of the varying directions of flow. The *a'*-sculpture shows a position of the ice divide to the WNW of Krappesvare. In view of the good development of this sculpture the distance to the ice divide was probably not less than at the time of the *a*-sculpture. Turning clockwise to NNW, we find the sculpture (now *b'*) to indicate that the ice divide culminated to the N. The sculpture develops gradually to *c'*. The flow now goes parallel to the mountain range, from NNE, crossing the direction of the great valleys and mountain ridges. It is obvious that this deviation of 90° from the direction of the natural slope was brought about by great masses of ice on the foreland. We may imagine the ice divide situated over Krappesvare. There would be no movement of the ice, unless an important culmination in the NNE or NE forced the ice to yield in the direction of the divide as supposed in the transitional stage *cd* (cf my picture of a culmination in fig. 11 between A and B).

The next map, *a*, is complete enough to displace the ice divide at least to the water divide. A locality of good stoss sides from the WNW lies close to the axis of the mass elevation. There were found in the surroundings many boulders of granite originating from the fjell Nasa (5 in fig. 4) in the NW corner of the map, fig. 10, demonstrating a still more westerly position of the ice divide, the more so as some bolders represent a type of rock known only from the Norwegian side of the boundary (LJUNGNER 1943, p. 207). These may have been transported by the *a'*-stream, and the stoss sides may partly date back to that time, but their scratches and friction markings — crescentic gouges as well as chatter marks — indicate the direction of *a* in spite of the very good topographic conditions here for a more northerly direction of flow, especially from NW.

I must state that at this locality the age of this sculpture in relation to *b*, which is here developed to about the same degree as *a*, was not determined by the sculpture. This is, however, not necessary, as the well preserved eskers and the westward dipping lateral erosion channels and lateral terraces as well as shore lines described by GAVELIN (1910 b) indicate that no ice has operated here since the melting away of the ice tongue from ESE, which dammed up a lake. This tongue originated from the ice divide corresponding to the *d*-flow in the lower slope and formed here the late continuation of the *b*-stream. The preserved sculpture of the stoss sides, indicating the flow from the water divide, must thus belong to *a*.

The shift of direction from *c'* to *a*, consequently, means the removal of the ice divide from the eastern border of the mountain range to the water divide or the western slope. The direction of flow is now consequent down the general slope as it was at the time of *a'*. That indicates that the ice masses of the foreland, which in the time of *c'* obstructed the natural run off of the ice from the mountain ridge, are now out of existence. The change from *c'* to *a*, consequently, was caused by a deglaciation. And the lack of sculpture at greater levels in Krappesvare between *c'* and *a* seems natural.

The deglaciation need not have been complete. There may have remained a (reduced) mountain glaciation linking together the two periods of advanced glaciation. As to the length of the interval, there is only one check. Provided that the mantle rock was not more important in the interval than in postglacial time, I must estimate the interval in the fjell Krappesvare to be shorter than the postglacial time, as we know of no instance of the prime-sculpture having been destroyed by weathering in the interval.

Summing up the results, we have found two independent advances of glaciation (or two glaciations) of the eastern foreland, separated by a short interval.[1] The mountain glaciation which was the starting point of the first foreland glaciation, seems to have been more important for the morphological development of the northern part of the Scandes than all the younger stages together. The nucleus of ice (*i. e.* the culminating point of the ice divide) formed by the advance was situated in the very northern part of Scandinavia. The posterior foreland glaciation also developed from an important mountain glaciation, but the nucleus formed took a central Fennoscandian position on the eastern foreland, far south of the region investigated. From here the nucleus (culmination) migrated towards the N. along the ice divide on the foreland. Finally, the ice divide itself migrated up the slope of the Scandes.

[1] "Advance" ("Vorstoss") is not the right word, as it signifies only the growing phase of a glaciation and, besides, is an indispensable term for also smaller changes in the course of development. For similar reasons also "stage" must be rejected. "Glaciation" ("Vereisung") seems to be the only appropriate term. To indicate their close connexion we might call the two glaciations treated 'the prime' and 'the posterior glaciation of the last glacial epoch or glacial age' ("Eiszeit").

2. Pleistocene Depression of the Glacial Limit according to Older Cirques.

a. Cirques of the Atlantic Slope. The imposing cirques on the west coast N. of the Arctic Circle have long attracted attention. The excellent topographical maps make it possible to differentiate a narrow, outer coastal zone, within which the landscape is wholly characterized by the forms of the local glaciation, and an inner coastal zone, within which these forms alternate with those of the inland ice, according to the elevation. The outer zone covers the large groups of islands, Lofoten and Västerålen, as well as a narrow strip of the mainland coast and of the large islands in the north.

Fig. 13. Cirques in South Ferras as seen from Peljekaisse (11). Picture from nature by NILS MARKLUND, Aug. 21st, 1943.

The topography of the Norwegian maps provides an idea of the situation of the glaciation limit during the time the older cirques were forming. Distinct, old cirques are to be seen on several of the lowest mountains on the coast, in spite of the fact that they were partly re-formed by the inland ice. These cirques must have a part above sea level sufficient to enable their nature to be demonstrated. There are several on the outer-most fringe of the islands. I confine myself, however, to two localities, chosen so far inside the coast line as to allow of the present glaciation limit being compared with the old one without extrapolation.

By the little Sagfjord, 68° lat. N., there is on the north side a cirque called Karlsöbotn, whose rock bottom goes down at least 60 m (the water depth to the clay) below sea level. It is framed in by mountains rising 276, 334 and 182 m above sea level. Opposite, immediately by the fjord, rises Veggfjellet, 1227 m, with glacier-free cirques. The difference of altitude between the highest point of the framework of one cirque and the other is thus about 900 m.

Now, even if the frame of the lower cirque may have reached 400 m before the total glaciation, the glaciation limit must have lain some hundred metres below this to produce a cirque 500 m deep. We can go as far as to say that, if Veggfjellet had had an equally good cirque form, it might now perhaps have had glaciers corresponding to a glaciation limit at 1200 or possibly 1000 m (both ENQUIST and AHLMANN set it at 1200 m). There nevertheless remains a difference of 900 or at least 800 m.

In the middle of Tysfjord, more than 700 m deep, Skarvbergsflåget rears up on a headland to 242 and 258 m above sea level. On the east side it has

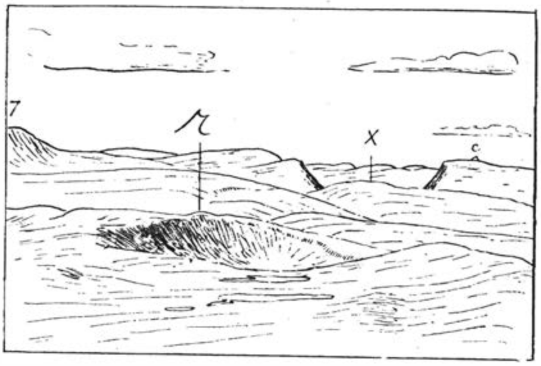


Fig. 14. Panorama from Peljekaisse (11 in pl. I), looking NW. North Ferras (7), Kaissatj (r) with a cirque, the valley of Lake Godejaur or Kujjaur (x) and, hidden by Godepakte, Ørfjell (c).

a cirque 2 km wide, with a tarn 600 m in cross section. The environs contain many high mountains with and without glaciers. If all the patches with the colour of snow given on the map represent glaciers, the glaciation limit is as low as 1 000 m, otherwise it is higher. (AHLMANN places it at 1 000 m, ENQUIST has not drawn it.) The difference will then be 700—800 m.

If it be taken into account that the precipitation in the fjord is probably lower than in the surrounding mountains, the difference will be greater in both cases. Lower cirque mountains than the ones used in this comparison seem to exist, though in that case it is no longer possible for the cirques to be established with certainty, e. g. Hamnen immediately N of the previously mentioned Karlsöbotn, with the bordering heights 200 m lower.

The submarine cirques were, then, formed at a glaciation limit which was with certainty 800 m below the one indicated by the present glaciation of the maps, and probably even lower than that.

b. **Cirques of the Bothnian Slope.** In the eastern slope the traces of old local glaciation indicate a low firn limit, of long duration, during the time *before* the maximum extension of glaciation. Of the glacier-free cirques in the Ferras group (7 in the section, fig. 4, and on the map in pl. I), Kåbrek's cirque (to the left in the picture, fig. 13) falls — according to my triangulation — in the range 1140—1440 m (cf. reports by GAVELIN, 1910, on cirques in mountains k and l). I have earlier (1943, p. 203) mentioned smaller cirque-like forms in Svaipa (8), with their beds at 1325 and 1057 m respectively, older than the wastage period.

In this still quite central part of the section, the growing valley glaciation must have prevented the local glaciation at lower levels. Counting from Ferras (7), and 40 km nearer the eastern border of the range, we nevertheless find the whole east side of the fjell Kaissats (r on the map), hardly 1 000 m high, to be made up of a cirque, fig. 14. The tarn at its bottom lies about 800 m above sea level. A probable cirque on Kåbrek of the group of mountains called Tjamort (s on the map) assumes the same place in the section. Its range of altitude is, according to the map, about 900—1 060 m. — Kåbrek is a not unusual Lapp name for mountains bearing cirques. Docent I. RUONG assumes that it is intended to bring out the concave surface (oral communication).

About 10 km further distal, near the border of the mountain range the weathered Peljekaisse (11, 1 133 m above sea level) reveals concave forms, shown in part on the topographical map, with its bottom at 775, 830, 850, 909, and 977 m; see pl. II. I am inclined to look upon them as glacial cirques. There has been no younger local glaciation.

The lowest traces of local glaciation in the eastern border are very valuable, as they provide a possibility of ascertaining how far below the present position the glaciation limit (or firn limit) had sunk before the ice inundated the foreland. As is common in the eastern border, there are no mountains along our profile sufficiently high to register the present level of the glaciation limit, but if we follow the eastern border somewhat to the north, such possibilities present themselves.

During flights along the border of the mountain range, and studies on stereograms made during this process, I have noticed concave forms which I consider to be traces of local glaciation on remarkably low levels, some down in the forest. In the NE corner of the map in pl. I, I have marked as such mountains: w = Kaissatjtjåkko (summit 1 063 m), v = Kaissavare (summit 990 m) and u = Snjärak (summit about 900 m). In fig. 15, I give a stereophotographic map of Snjärak's cirque, which faces NNE. The cirque is to be found, though without its true cauldron form, on the topographical map (at k in Snjära*k* or p in Kvikkjokk's ka*p*). The tarn at its bottom lies at about 711 m, and the rim reaches about 877 m. Birchwoods partly invest the lower parts of the cirque.

In very slight extrapolation in ENQUIST's map of the glaciation limit (1933, p. 184) — which is based entirely on interpolation — Snjärak will fall just below the curve for 1 900 m. Some new glaciologic data show, however, that ENQUIST's values for the rise of the glaciation limit are on the low side.

We find the curve for 1 900 m established by the glacier-free peaks 1 888 m and 1 934 m mentioned in my previous work (1944 a, p. 127, table), which lie in the SE slope of the Sarek group, and 25 km N of Snjärak. Not more than 20 km to the north lies the glacier-free Pårektjåkko, 1 790 m. The large glacier on the 1876 map in Tarrekaisse (q in fig. 9; 1 850 m), which formed an important support for ENQUIST's curves, does not exist any longer. Where it once stood, I found (5—18 July, 1939) only a cirque with a tarn, whereas the glacier in Staika (p; 1 799 m, seen at a distance) remains at any rate as a firn field. Where the glaciation is registered in peaks nearest to Snjärak — over 1 934 m 25 km to the N. and over 1 850 m 20 km to the WNW. — it is still in the process of rising towards the lowland. The present glaciation limit above Snjärak must then be considered to lie at about 2 000 m.

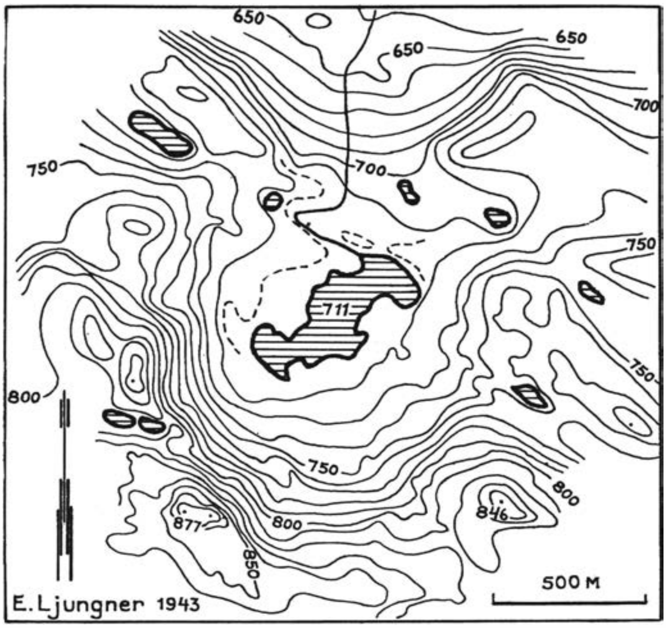


Fig. 15. Cirque in Snjärak (u in pl. I). Constructed from overlapping air photos with the aid of a ZEISS drawing parallax bar by Mr NILS MARKLUND and the author. Contour intervals 10 metres. Scale 1 : 25.000 (1 inch = 2 083 feet). From LJUNGNER 1945.

A control of this small extrapolation of the glaciation limit is possible to obtain by comparing its course with that of other climatic vertical limits which are low enough to cut Snjärak and the surrounding mountains. Such are the upper limits of the forest and the forest trees.

Many of the plant-geographical investigations mentioned in my previous work fall precisely in, or near, the region in question. Those of GAVELIN, HAMBERG, TENGWALL, ENQUIST, and WISTRAND fall within it, those of CLEVE-EULER and FRÖDIN immediately to the north. GAVELIN's and TENGWALL's reports, and the latter's map of the birchwood limit, provide us with what is necessary for Kvikkjokk's surroundings. In the previously mentioned glacier-free mountains in the north (Kåtoktjåkko and Pårektjåkko), it is at the same level as in Snjärak. The following section shows an interesting rise from the west (q, t, w and v are found on pl. I; the exposition is given immediately after the elevation figure):

Tarrekaisse's slope towards Tarraur (q)	Prinskullen (t)	Snjärak (u)	Kassavare (v)
660—670 m SW.	720 m	782 m SE.	788 m NW.
	725—730 m NE.	767 m WSW.	
	710 m SE.		

For conifers only a rather short section in the same direction can be obtained, from a point lying between q and t up to t:

	Points between q and t			t
	1	2	3 (Routevare)	
Spruce	440	500	585	637
Pine	410	—	500	—

Snjärak still lies on the west side of the birchwood culmination, which occurs about at v. The rise from the glacier-free Tarrekaisse amounts to about 110 m. In a small part of the same area the forest limit of the conifers rises by about 200 m. According to profiles drawn immediately to the north by J. FRÖDIN (1916, p. 58) and a little to the south by ENQUIST (1933, p. 162), the culmination point of the spruces is not encountered until 60 km further out on the low fjells of the foreland, and ENQUIST sets that of the pines even further east.

The plant-geographical data thus show a clear rise of the summer temperature towards the east, counting from the last glacier-bearing mountains, and the precipitation is clearly seen to diminish according to WALLÉN's map of 1923, and AHLMANN's of 1925.

It is thus on very good grounds that the height of the glaciation limit at Snjärak is set at about 2 000 m above sea level. This implies that at the time of the local glaciation in Snjärak, the glaciation limit lay at least 1 100 m below the present one. The lowland cannot as yet have been inundated, for on inundation the thickness of the ice in the border of the mountain range became too strong to allow of local glaciation at its lower levels. On the other hand, Lake Saggat (S. in pl. I, 303 m above sea level and 83 m deep, according to AHLENIUS 1901, p. 33) was probably filled up by a powerful tongue of ice from the higher fjells.

From the water divide on, our profile (fig. 4) lacks mountains high enough to enable us to register the actual glaciation limit. The lack (as far as known) of glaciers in Ferras (7, 1609) is remarkable, as, according to GAVELIN (1910 b), such are found in mountains k and l, S. of the profile. We can therefore take it that, on the whole, the glaciation limit lies high within the section. As, in addition, ENQUIST's adjacent tree-limit section enables us to conclude that the glaciation limit rises continuously eastward, we have no reason to expect the rate of the depression at the eastern cirques of the section to be lower than at Kvikkjokk.

c. **Conditions of Formation and Age.** There is a great difference in development between the old cirques of the western slopes and those of the eastern slopes. The former are well known, the latter have hitherto been unknown.

Conditions, however, are also different. The very initial orography was quite distinct. The Atlantic coast was the deeply dissected fault edge of

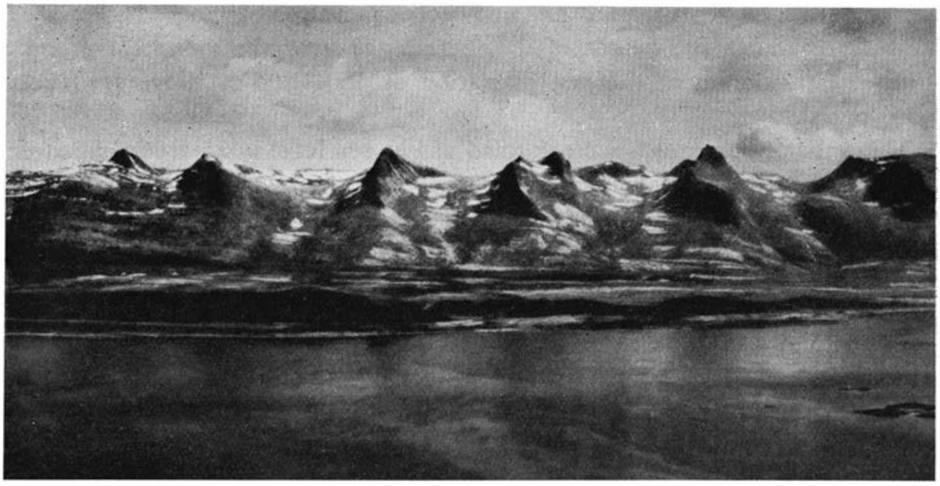


Fig. 16. The mountains Syv Søstre ('seven sisters') on the Norwegian coast at a lat. of 66° N. They were sculptured by local glaciation as well as by the inland ice, which according to ENQUIST formed the last ice cover there. Heights of the summits about 1 000 metres a. s. Air photo from NW. at a height of about 800 metres.

an old land block, the upper surface of which formed the eastern slope (cf. fig. 21). Below the level of actual glaciation young landforms were lacking on the latter, whereas along the coast crests and peaks at all levels afforded good shelter for firn and ideal conditions for its sapping action. The inclination of the glacial limit is an expression of a favourable climate in the west. In the eastern slope the formation of a cirque requires a considerable lowering of that limit and could therefore not start until late. The time at disposal was here also reduced from the opposite side: as soon as a continental ice sheet was established, the formation of cirques was stopped, whereas phases with continental ice sheets seem to have been of importance for the formation of low cirques at that part of the coast which was not invaded by the ice sheet. As ENQUIST pointed out (1918, figs. 14 and 34), the coastal zone of low cirques narrows and disappears rather suddenly to the south of the Arctic Circle.

The interference between the inland ice and local glaciers is interesting. REKSTAD pointed out (1910, pp. 34, 35) that low cirques at the Beiar fjord (lat. 67° N) have not been greatly altered by the inland ice; he therefore considers them to be relatively young. To the SW. (at lat. 66° 50′ N.) and NE. of that locality there are cirques housing local terminal moraines. S. of the Arctic Circle (lat. 66° N) the mountain group Syv Søstre is well known to every coast traveller (fig. 16). Its geology and morphology have been dealt with by VOGT (1900, pp. 26—28, 65) and ENQUIST (1918, pp. 42—44, 96), cf. the topographical map Mosjøen. The fine cirques, whose bottoms lie at 450—500 m above sea level, have, according to ENQUIST, been covered by the inland ice and subsequently not housed glaciers. GRØNLIE estimates the height of the ice surface over the mountain group during the maximum of the last glaciation at 800—900 m above sea level (1940, p. 21).

The submarine cirques were formed at low sea level in an arctic climate, partly before the last inland ice and partly interfering with it. Their formation must have been completed before the recession of the last inland ice from the region, as in late glacial time the land was submerged.

The rates of depression here found are not astonishing to modern opinions. MILANKOVITCH's theoretical calculations (1938), based on radiation, give 1 800 m for the deepest points of the curve. Starting from geological data, KLUTE (1928) assumes for the border of the North European inland-ice a depression of 1 200 m. In the Sierra Nevada and the Cascade Mountains, during the last ice age, local glaciation reached 1 000—1 400 m lower than now, according to BLACKWELDER 1933, pp. 865—922. SOERGEL's temperature calculations based upon ground frost action in Germany (1942) are also of interest.

The rate found here for the Atlantic coast is, however, only a part of the total amount, as the glaciation limit, when lowest, was below the sea level and could not be registered. The rate found at the eastern slope, on the other hand, corresponds to the time of mountain glaciation only, and would therefore have seemed unlikely, had not the study of the ice-movements shown the great importance of an independent mountain ice sheet glaciation.

If depression reached the same rate on the western slope as on the eastern, 1 100 metres, the glaciation surface would already within the fjords have sunk to the sea level or below that, and at the mouth of the fjords certainly below the sea level. As seen in figs. 2 and 4, the inclination of the glaciation surfaces towards the Atlantic is rather steep. The question now arises whether that gradient was greater or less in the time of mountain glaciation.

In Chapter III E 3 b we will show that the contrast between the maritime western slope and the rather continental eastern slope must have been sharpened during the development that led to the mountain glaciation. The causes of the inclination of the glaciation surface must thus have been greater. Furthermore, unanimous experiences from all parts of the world show that the Quaternary depression of the glacial limit was always much greater in maritime climates than in continental ones, about double where the contrasts were pronounced. Consequently, the glacial limit surface was probably some hundred metres below sea level at Lat. 68° N, and as the rise of the actual limit surface to the south is only about 200 m rom Lat. 70° N down to Lat. 60° N along the coast (fig. 2), we may assume that at the time of the mountain glaciation the glaciation limit surface along the Norwegian coast finally lay below the present sea level. Whether it also lay below the sea level of that time, depends mainly on the mutual vertical relation of land and sea.

3. Studies on Glacial Valley Sculpture.

a. **The Atlantic Slope.** To be able to discuss the ice balance between east and west it is necessary to get an idea of the thickness of the ice during the various phases in the various parts of the section. In so doing it is important to know the upper limit of the erosion, and also the distribution of traces left by total and local glaciation. The inclination of the terraces throws much light on the shrinking phases.

I shall first show some valleys which bear the fresh forms of passing ice streams, and try to deduce others from older phases.

The excellent Norwegian maps often enable us to make out the dimensions of ice streams from a period when the ice on that side of the Scandes was in part confined to valley streams. The finest valley trough sculptured out in that manner is probably Skjomdalen, a little to the south of Narvik (Sheet N 10 Skjomen, of 1919). The valley continues at Skjomen's chapel in the Skjomen fjord and, like the latter, runs NW. (fig. 17). The inundating inland ice from the Swedish side (the vicinity of Kebnekaisse) has here been compressed between the Storstein group (max. 1 901 m) in the NE. and lower groups in the SW. The stream was originally about 15 km broad and comprised four parallel valleys, three of which debouch in the appendix-like Sørskjomen. Two of the ridges, γ and δ fig. 18, separating the valleys, partly stuck up above the ice, forming nunataks, and these have become as thin as fishfins. During the whole of the sculpture period in question, however, the valley-separating ridge β, reaching 1 019 m above sea level was inundated by ice. The great valley forms a perpendicular wall (α) in the high plateau. Some of the hills and peaks standing on the precipitation seem to be only halves. The other half was planed away by the sapping activity of the valley stream.

During the greater part of this time the stream's surface 10 km before Skjomen's chapel was about 1 100 m above sea level. After that time the ice surface may have sunk rapidly, since the 1 019 metre ridge β bears no trace of sapping erosion; the lack of traces of local glaciation here also indicates that already at that time the glaciation limit exceeded this height.

The valley erosion described represents a period when the ice surface was so low that it generally speaking touched the mountain range, fig. 21. Owing to the inclination of the ice surface towards the Atlantic this did not take place at the axis of greatest elevation, but along a line to the west of it. Fjells becoming ice-free here began to divide up the ice into

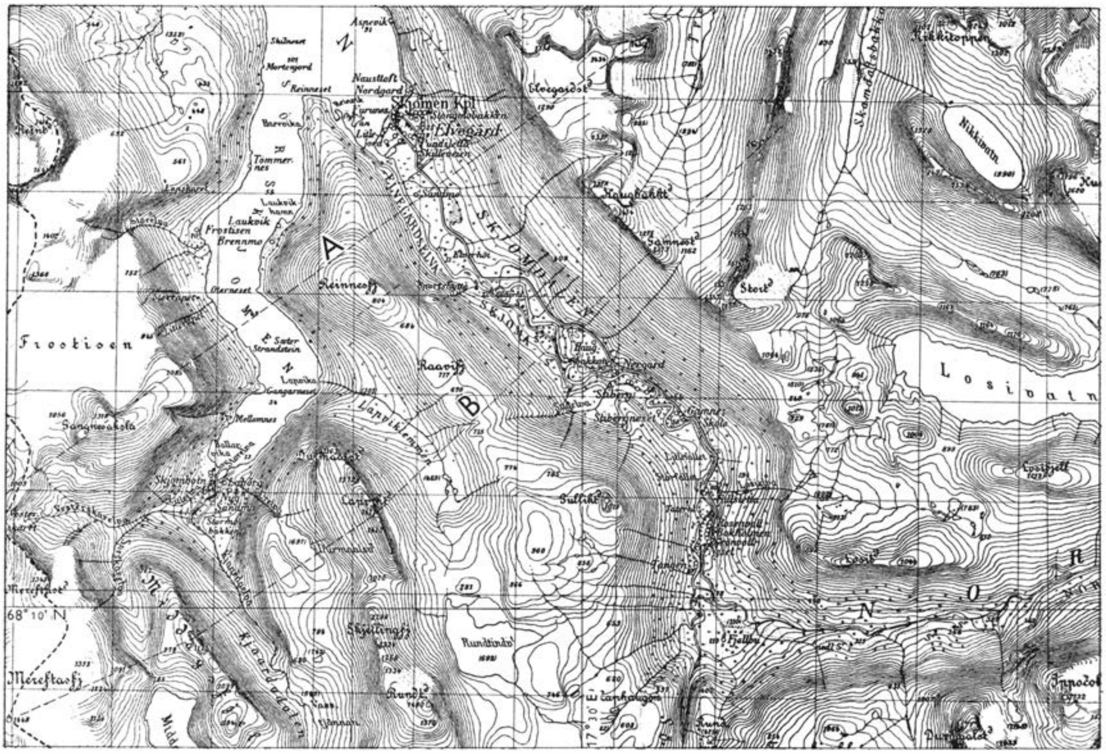


Fig. 17. Part of the topographic map of Northern Norway, sheet N 10 Skjomen. Situation 68° 8'.5—16'.5 lat. N. and about 17° 13'—45' long. E. Scale 1 : 150 000 (1 inch = 12 500 feet). Each square 2 km. For profiles, see fig. 18.
The glacial forms may be interpreted by assuming the following stages of glaciation: A. Local glaciation, very old, old, and recent. — B. Valley ice streams of local origin (I in fig. 4). — C. An ice cap (mountain-ice sheet) having its divide here (II). — D. An ice-cap having its divide in the SE (III), but in this zone partly divided into valley streams moving rapidly NW with a great sapping action, forming steep valley sides and nunataks of a back-fin type. The NE:ern part shows hardly any influence from D.

separate streams, which further down the slope were in part again united to form a large surface.

We find another example quite close to our section and in the northern part of the map in pl. I. Immediately SW of Sulitelma (67° 10' N)

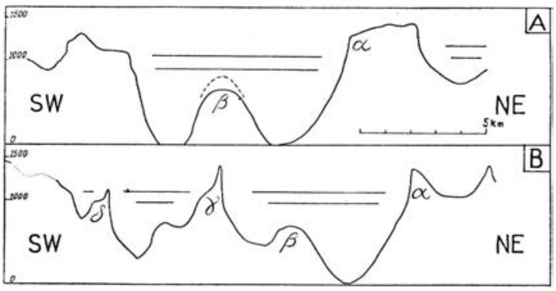


Fig. 18. Profils drawn on fig. 17. Vertical scale = 3 ⅓ × horizontal scale, which is 1 : 300 000. Dotted line = show surface.

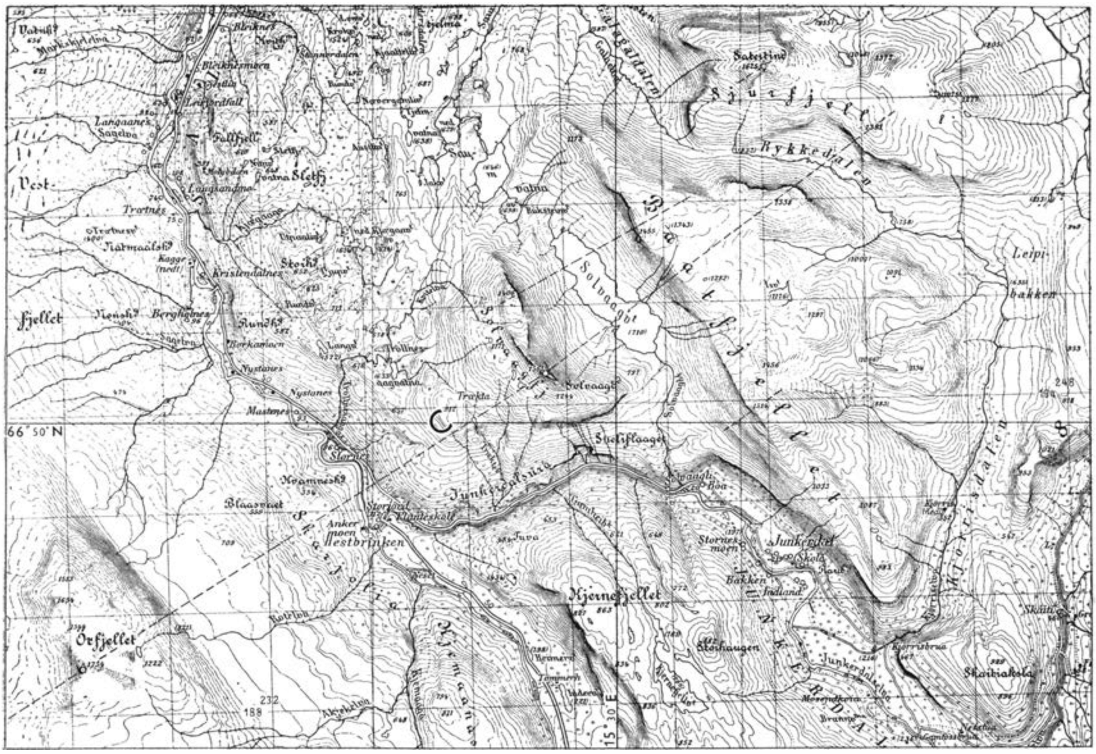


Fig. 19. Part of the topographic map of Northern Norway, sheet L 14 Junkerdalen. Situation 66° 46'.5—54'.5 lat. N. and about 15° 13'—43' long. E. Scale as in fig. 17. Profile in fig. 20.

The glacial development is the same as in fig. 17. The forms of C cover a greater area. Lake Solvågsvand was probably a cirque bottom, cf. Lake Nikkivatn in fig. 17. The valley Rykkedalen surely conducted an old ice stream from Sjurfjell. The effect of C is seen on the straight and steep valley sides of Båtfjell and Ørfjell, a straightening of the Solvågfjell and the forming of its "back-fin".

the ice flowed unimpeded during the period in question towards the NW., with a breadth of 30 km. Not until in the SW. of this part (approx. at e) does the level of the plateau rise, so that for a short course the ice was divided up into parallel valley streams, figs. 19, 20. Of these the one most interesting to us is that flowing right beside our section, whose left 'shore' consisted of the Örfjell ridge (c in fig. 4, 20 and pl. I; with Ör- or Ölfjell, fig. 28, 1 764 m). Båtfjell's plateau (f 1 514 m) can be taken as the right

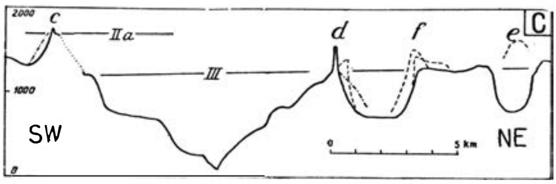


Fig. 20. Profiles drawn on fig. 19. Scales as in fig. 18. Dotted line = snow field. Dash and dotted line = reconstructed preglacial slopes.

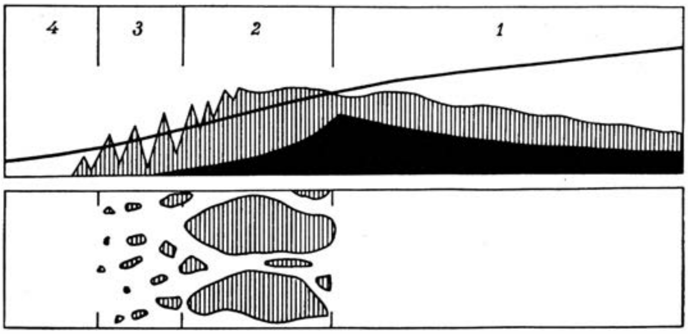


Fig. 21. In NW Norway the ice of stage III could only in some gaps pass the threshold formed by the mountain range. The idealized profile and plane illustrate the manner of passage.

1. Zone of free ice surface.
2. Zone of valley streams.
3. Zone of *nunataks.*
4. Zone of foreland ice.

bank, figs. 19, 20. This broad ice stream was, however, partly divided into two, since the dividing ridge (d), sculptured to a fish back (1 200 m), bears a long, high back-fin (Solvågstind 1 561 m, figs. 22, 23), visible from the border of the mountain range. This fin projected up above the surface of the ice and was sculptured by sapping. Båtfjell's plateau slopes throughout from the valley, figs. 19, 20. Its highest points lie exactly on the margin of the valley, indicating an important enlargement of the valley's cross section by sapping. During this phase the surface of the ice lay about 1 250 m above sea level at Solvågtind. As the distance to the actual coast is only slightly greater than from Skjomen, the relatively stationary ice surfaces here and there may well be contemporaneous. — Some of the valleys here show a complex section, whose origin require a closer study. The Solvåg valley possibly once formed a cirque facing NW., its back wall broken down by glacial erosion.

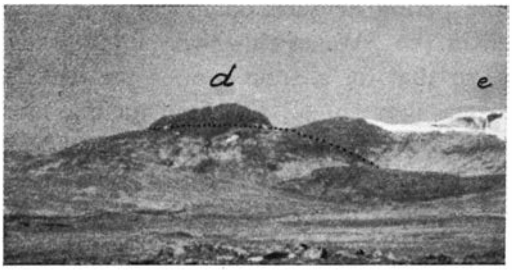


Fig. 22. Solvågfjell with its "back-fin" Solvågtind (d) at a side-view from Nasafjell (5) looking N. Between Solvågtind and the flat-topped Satertind (e) we see a part of Båtfjell forming a steep valley side facing Lake Solvågvand, cf. figs. 19, 20. Telephoto with infra-red light by the author, Aug. 8th, 1942.

Fig. 23. Solvågfjell with its "back-fin" Solvågtind (d) from Junkerdalen looking WNW. From "Norsk Reisebok".

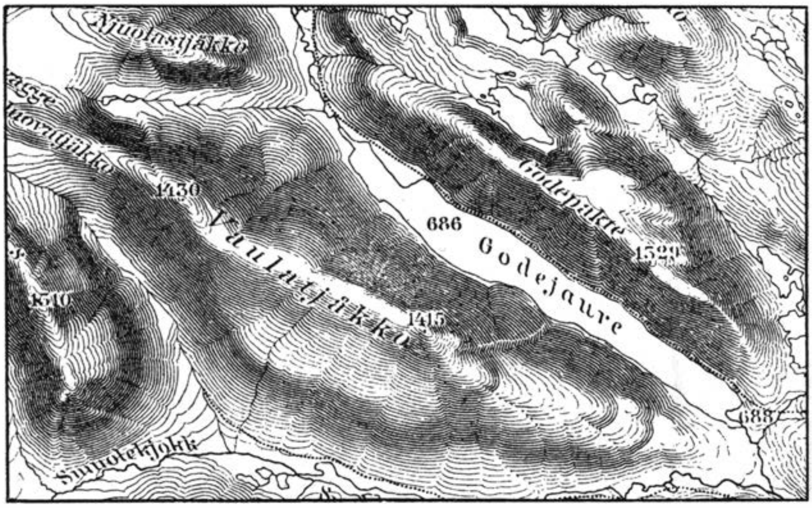
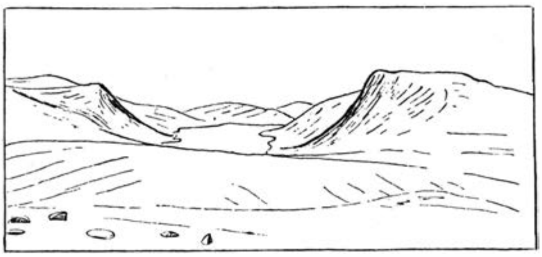


Fig. 24. Lake Godejaur or Kujjaur (i. e. 'the Lake of the wild reindeers', x in Pl. I). From the Swedish map, sheet 18 Merkenes (1875—76), Scale 1 : 150.000. (1 inch = 12.500 feet). The lower limit of the map is the Arctic Circle.

b. The continental Slope. The sculpture described shows the morphological effect of a valley ice stream. In the Northern Scandes, consistent valley streams on the eastern slopes were absent during the period of wastage, except for very late ones in the border of the mountain range, where they were fed by a very much reduced inland ice. If, however, as I have desired to show here, an unbroken covering of ice invested the high mountains and the western slope during the time the ice was developing, it must nevertheless have been possible for the valley streams running from these towards the Swedish foreland to effect an erosion anologous to the one described above, although the far less marked initial relief did not allow of equally imposing results. The sharpness of the forms has naturally been worn down during later phases.

I should like at this point to mention Kujjaur (Godejaure), a lake lying immediately north of our section and opposite the valley streams last described on the Norwegian side, pl. I x and figs. 24 and 25. Its water level, 686 m and with unknown depth, lies, like that of Solvågvand, about

Fig. 25. Lake Godejaur from a photo by G. EDIN, looking NW.



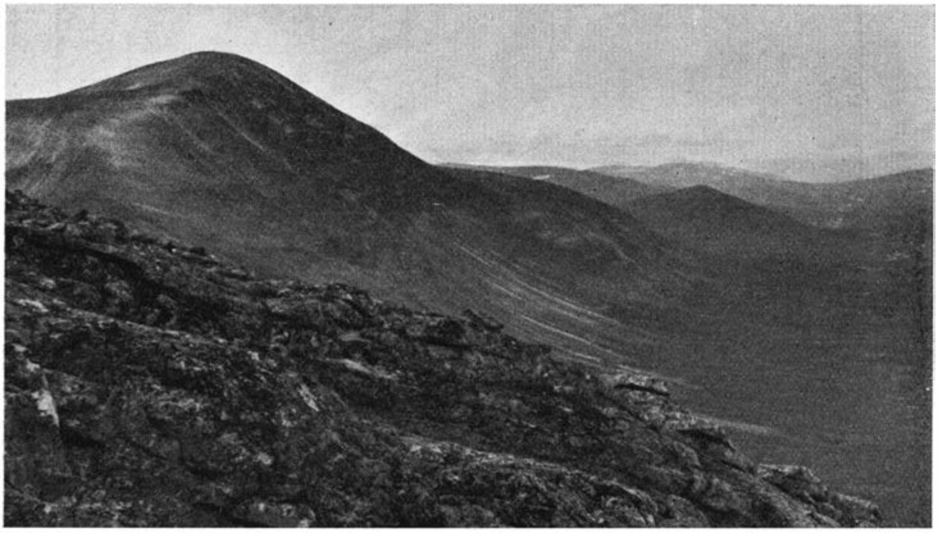


Fig. 26. Part of the Laisan Valley, looking WNW. In the middle Ertektjåkko, in the foreground the trough edge of Svaipa.
Photo by the author, August 19th, 1942.

700 m below the plateau height. The U shape means that the valley sides are steep up to the margin of the plateaux; the latter's great height, with its inclination partly away from the lake, indicates a sapping activity by a valley stream, just as at the Skjom, the Solvåg, and the Saltelv valleys.

Kujjaur is not far from the water divide. In the Laisan valley, which our section follows, a great valley trough occupies a more easterly portion of our section. I have made some observations there concerning the glacial erosion (cf. LJUNGNER 1943, with map).

The Laisan valley displays two generations, as the section (fig. 4) in part shows. The older one, which corresponds to broad plateaux at the elevation 650 m (above the fig. 14 in fig. 4) round the outlet of Lake Storlaisan (15), still forms the valley bed for Laisan's uppermost course (between 5 and 7). The younger valley generation has reached an eastern longitude of $15^{\circ} 55'$, where the river makes a marked descent (under 7). It has widened into a trough. At certain places in the main valley this trough has, probably by sapping, engulfed the older generation, as in the imposing precipice of Ertektjåkko (W. of 8 fig. 26). At other places, however, the older, flatter valley appears like a shoulder above the margin of the trough, as the case is at Svaipa (8) or at Tjäksa (9).

At Svaipa (8) the trough margin lies at about 960 m (on the map diagram 1943, fig. 1, below location 9). It is visible on fig. 26, in the foreground, and in fig. 27. The fjell consists of hard, white, partly micaceous quartzite, which is well fitted to preserve the sculpture of older phases. Two ice movements are registered: an earlier one from WNW, and a later one from ESE.

The details of the NW. sculpture are very well preserved above the trough margin, where I have not hitherto seen traces of the SE. stream, which was

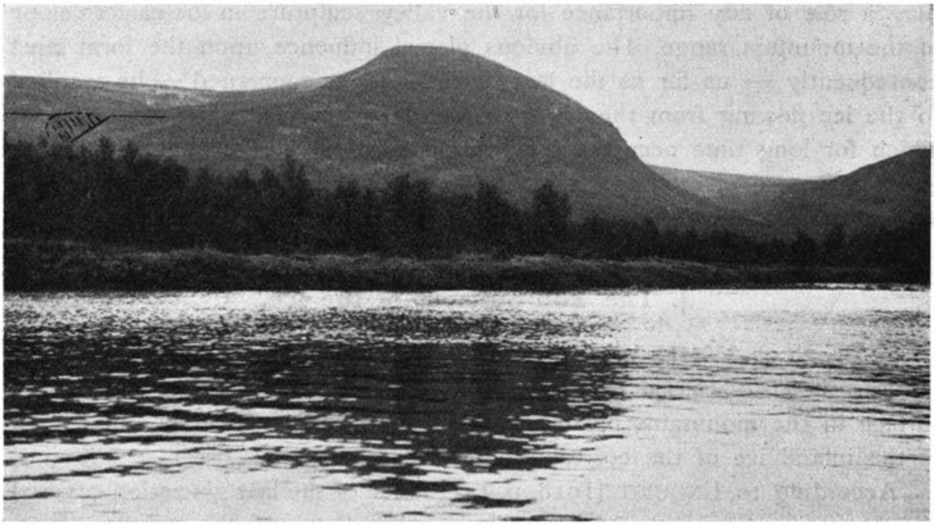


Fig. 27. Svaipa from the river Laisan,
looking SSW.
Photo by the author, August 18th, 1942.

more recent and had left a collection of boulders on the top (see 1943, p 208). The sculpture of the SE stream increases extremely quickly under the trough margin, however (cf. 1943, p. 203). At 950 m above sea level (about 10 m under the margin) careful searching revealed traces of the stream in the form of cross fractures or a faint rounding of small edges; at 900 m one can find stoss sides, 1 or at most 2 m in length, formed by the SE. stream in the more exposed lee sides of the NW. stream; at 850 m the SE. sculpture reigns supreme, the NW. sculpture having been eroded by the SE. stream. Below 800 m the rock is covered by drift and gravel. Outcrops of quartzites at 565 m show SE. sculpture only (location 8). The river flows at 498 m. On the other side of the valley, which does not reach the height of the trough margin, SE. sculpture also prevails (for closer details see 1943, p. 202, Plassavardo). In more easterly sections (Tjäksa and Krappesvare, 1943, p. 203) the upper limit for the noticeable SE. sculpture drops somewhat, so that it more or less follows the level of the trough margin.

The erosion of the flow from SE. was obviously very much greater in the valley trough than at higher levels. But the change in effect mainly takes place within the upper 100 metres of the valley trough.

The question whether the stronger erosion in the trough was brought about successively by the retreating short tongue moving from the SE. or was due to a greater amount of morainic matter at lower levels — which according to LUNDQVIST (1940, p. 17) should have the opposite effect — or to a third cause (possibly one of a greater velocity), will be discussed in a special paper on the glacial erosion. It is enough to establish here that the ice flow from the foreland in the last glacial stage was not able to play a rôle of any importance for the valley sculpture in the eastern slope of the mountain range. The obvious glacial influence upon the form must consequently — as far as the last glacial stage is concerned — be ascribed to the ice flowing from the water divide and especially to the alpine glacier which for long time occupies the trough. — We will return below to this great difference in eroding effect of the SE. flow on the eastern and western slopes (Chapter III B 4 c).

4. The Top Surfaces of the Ice.

a. Previous Works and Opinions. It is natural that the question has hitherto been discussed only from the point of view that the highest ice surface in the mountains must belong to the time of the maximum spread of the inland ice of the corresponding glaciation.

According to ENQUIST (1918, p. 14) the ice of the last glaciation covered all mountains S. of the Arctic Circle, also those of the western slope. AHLMANN (1919, p. 214) assumes the surface of the inland ice in the region round Saltenfjord (67° 1/4 N.) to have lain about 900 m above sea level. TANNER (1930, p. 415) is of the opinion that the whole mountain range, and perhaps the Lofoten Islands also, were covered. The ice sheet calved at Haveggen (the edge of the continental shelf). GRANLUND (1936) has drawn a section through the maximum ice surface in the vicinity of the Arctic Circle. In addition to a couple of peaks in the "skjærgaard" (archipelago), he considers as nunataks several peaks on the mainland. In my section fig. 4 and my map, I have marked the nearest ones. To the south of our section he mentions Lukttinderne (a) and Okstinderne (b), to the north Solvågtind (d), the latter according to HOLMSEN (1932, pp. 22, 28) who cites REKSTAD (1917, p. 16). GRØNLIE (1940) made an interesting attempt to distinguish between the "great" glaciation and the last one. Especially noteworthy is the discovery of glacial boulders from the "great" glaciation upon the plateau remains of the outer islands such as Vaeröy (p. 6). This "great" inland ice calved at Haveggen, but the last one reached, according to GRØNLIE, only half the way from the mainland, terminating at the outer rim of the island group of Lofoten—Vesterålen. The "great" inland ice left only the highest peaks of Lofoten free, whereas the last one was overlooked by several nunataks, also on the mainland and to the south of the Arctic Circle. In our section the surface of the last glaciation is said to have reached only 400—450 m above sea level in the "skjaergaard", and about 1500 m at the water divide. — GRØNLIE, who mainly supports his opinion on the maps, seems to have had his eyes fixed on the same sculpture forms of valley streams to which I made reference above, and assumed these to have represented the highest ice surface; this view seems to have been shared by AHLMANN (1919, p. 214).

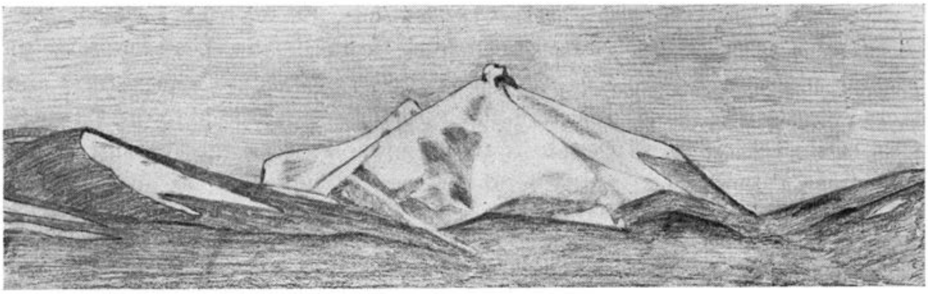


Fig. 28. Ørfjell (c) from S. 10° E. Drawn by the author from his telephoto taken on Aug. 8th, 1942, from the top of Nasafjell (5). The mountain has patches of old snow and a thin snow cover fallen the previous day but no shades. It was unknown up til 1916

The opinions cited above are founded on boulders, striae or land forms. As regards boulders of high mountains, there seems to be no possibility of deciding whether they have been left by the "great" or the last inland ice, for a boulder of a resistant rock must be able to survive an interglacial epoch. The boulder found 100 m below the highest peak of Okstinderne (fig. 30) therefore, constitutes no evidence that the mountain group in question was overridden by the *last* inland ice. As early a scholar as HOEL (1910, p. 24) assumed it to have formed nunataks.

Glacial striae from another glacial age, on the contrary, would be unable to remain, at exposed localities, unto the present time. Only very occasionally might it happen that striae appear because a covering was recently removed. Consequently, ENQUIST's discovery of glacial striae of the inland ice in several high positions cannot be neglected. As the most important localities I would mention Lukttinderne (a), on the ridge immediately north of the summit 1327 m (ENQUIST 1918, p. 15), Örtfjellet (3) in three localities of the top plateau (ENQUIST, p. 14 and plate I), Stormdalsfjellet (between 2 and 3), and Svartisen (1 and 2), where older striae from the SE. could be distinguished from yonger ones from the S. (ENQUIST p. 100 and plate).[1]

At first sight we should find it natural for the older flow to belong to the time of the greatest spread of the last continental ice sheet in Europe, the second one to a later stage of long duration, such as the Ra-stage.[2] From a more northerly part of the Atlantic coast there are, however, older observations, which do not seem to permit of such an interpretation.

[1] In Glomådalen (between 1 and 2) ENQUIST (map) has turned the striae of MARSTANDER (1911 a map, 1911 b p. 38) 180°, presumably by an inadvertancy.

[2] Ra (= line) is a local word for terminal moraine ridge. The Ras of southern Norway are supposed to represent the same stage as the so-called Mid-Swedish moraines and the Salpausselkä-ridges in S. Finland, formed at the limit between Gothi- and Finiglacial time. Ra-stage is the shortest expression for this advanced position, which lasted about 700 years in Finland, according to SAURAMO.

According to GRØNLIE 1931, *Cyprina* deposits were at Tromsö overridden by a great valley glacier protruding from Balsfjord, and outside its terminal moraine *Yoldia*-clay was deposited. GRØNLIE (1914, 1931) and others consider the remarkable terminal moraine to correspond to the Ra-stage of the Oslo region (cf. TANNER 1930, p. 399). Tracing the ice surface up to the water divide, GRØNLIE found its level to have lain at about 800 m at the frontier, where he later on (1940) estimates the level of the upper

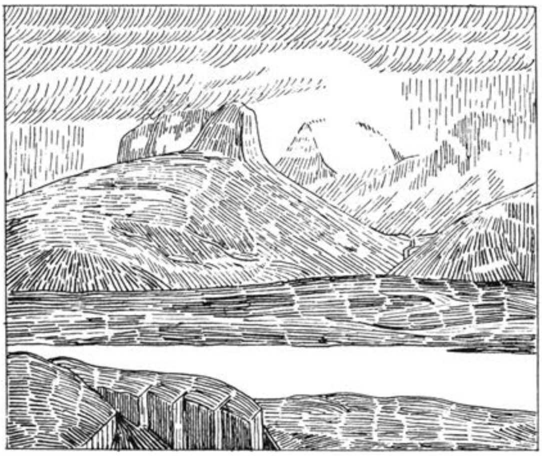


Fig. 29. Bortind 1080 m at a lat. of 67° 7′ N. as seen from Rønviksfjell near Bodö, looking SE. across the Sa ten fjord.
Drawn by the author from his stereotelephoto on July 7th, 1938, in rain. Immediately to the right o Bortind the snow-covered Lurfjell-tind 1286 m. The base of the nunatak of Bortind is at a level of 850 metres a. s. Here passed the ice masses from the region of fig. 19.

limit of valley sculpture at about 1200 m. — In his latter work (1940, pp. 26 and 66) GRØNLIE considers the *Cyprina* deposits at Tromsö to be interglacial. Such an interpretation contradicts his statements that the ice surface of the last glaciation at the frontier had a level about 400 m higher than that corresponding to the terminal moraines at Tromsö, as that thick ice would probably have swept away the clay. The *Cyprina* clay may be of Alleröd age.

A reconstruction of the ice-surface of the Ra-stage would have been of great interest for our section. For that purpose I sought in the literature for geological data indicating the position of the terminal moraines of the Ra-stages. But opinions disagree on these matters.

REKSTAD's discovery of *Yoldia* clay above *Cyprina* clay at Fagerviken at the mouth of Rana fjord (VOGT 1900, p. 85 et seq.) was considered by BRØGGER (1900, p. 130) to indicate the climatic deterioration at the beginning of the Ra period. This view was supported by TANNER (1930, p. 400). A 10 m long shore-line within solid rock here (VOGT 1900, p. 71) was also supposed to have been developed during the Arctic climate then prevailing (VOGT 1900, pp. 66—67). But as, at that time, no higher shorelines corresponding to the subsequent transgression were known, BRØGGER (1900, p. 31) was inclined to conclude that the deposition of the *Yoldia* clay here in the north had continued on even during the maximum of submergence. When GRØNLIE (1908, pp. 42—48; 1910, p. 155; 1911, p. 101) had found the fjords and valleys to show the terraces corresponding to higher isobasic surfaces which BRØGGER advertised for, all requirements for the presence inside the fjord or fjord valley of marginal formations from the outer Ra-stage seemed to be satisfied — provided the first-named biological interpretation were correct. These formations might have been looked for right into Bjellånes (i. e. 20 km inward the fjord valley). There one meets a very great moraine with a shore terrace, which (VOGT 1900, pp. 151, 153) sets on the same isobase as the Fagernes shore-line. Still higher terraces are found by GRØNLIE (1908; p. 43). We find, however, a moderation of such views. On the basis of comparative studies into the coastal stretch of terminal moraines, VOGT (1913) and GRØNLIE (1927, p. 58) were contented to set the outer Ra unto the inner part of the fjord. VOGT placed it at the thresholds of Ranen and Holandsfjorden (17 and 18 in the section). But in the nearest more northerly valley GRØNLIE (1927, p. 58) placed the Ra in the vicinity of the water divide. GRØNLIE based his decision on comprehensive stratigraphic and faunistic investigations both north and south of the fjord (Sjonbotnet and Korgen).

In 1940 GRØNLIE published a new compilation of the recession history, based on the epeirogenic spectra according to TANNER's method. The result is in complete conflict with earlier views. The ice margin (G-G on Plate III) corresponding to the Tromsö-Lyngen and outer Ra-stages is here placed on the outermost skerries.

Terminal moraines are not known where the more important lines are now drawn.

b. Stages of Mountain Glaciation (and Atlantic Sheet Glaciation). To clarify the possibilities of the view presented here it has been necessary to construct sections through the mountain range including the ice surface for different stages, even though reliable data are still too few to give these lines anything but a provisional value. To start with, I will treat the mountain stages, i. e. the time of the ice divide's stay in the mountain range. And herewith I include the two glaciations registered by the minute sculpture forms, since the development of their mountain stages with respect to the cross section has been parallel, and the greater sculpture forms such as valleys and cirques my derive from both glaciations (if not from earlier glaciations, too).

Such trough valleys as those of Kujjaur and Laisälven at Svaipa (see Chapter III B 3 and figs. 24—27) were formed by valley streams from the west contemporaneously with the formation of cirques in Ferras, Kåbrek, and Svaipa (see Chapter III B 2). At that time, we must imagine a still more intense glaciation on the upper western slope: a dense network of mighty valley streams often spreading out to even ice fields, and principally fed by plateau glaciers. It was now that the most projecting ice tongues

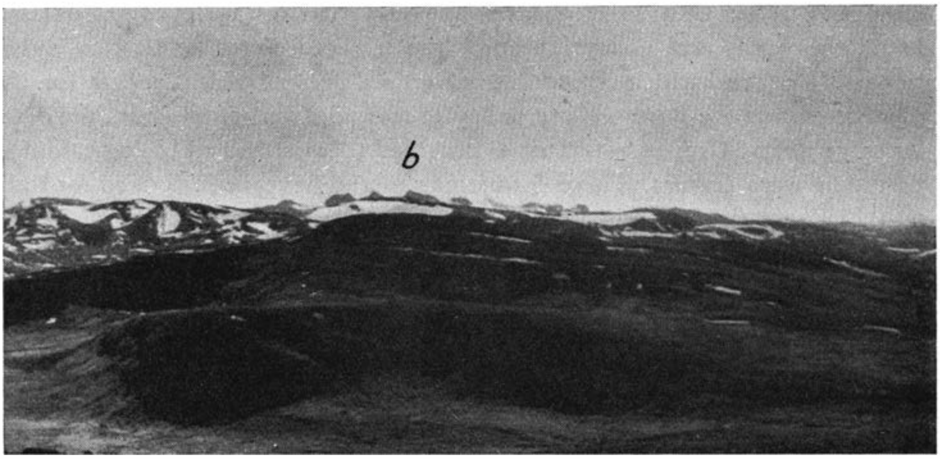


Fig. 30. The mountain group Oxtinderne (b, 1912 m) seen from Nasafjell looking S 42° W. Basal parts hidden by Junkerfjell 1335 m, showing a firn-filled cirque, and this fjell again by Andfjell 1204 m above sea-level. Streaks of snow on the slope of the latter fjell probably mark lateral drainage channels dipping NW.

Telephoto by the author, Aug. 8th, 1942.

carried out a great part of the fjord sculpture (partly brought into existence already by earlier glaciations). Between these tongues cirques were formed, and Piedmont glaciers concluded the glaciation on the coast. The formation o cirques went on in central parts of higher peaks also.

The reciprocal pressure between the ice masses of communicating valleys established a common top surface of the ice streams ("Eisstromnetz"), which we can call Stage I. A corresponding development of the glaciation in British Colombia was called by KERR (1934, cf. 1933 and 1936) "intense alpine stage". In point of fact, the present stage of glaciation in some northern parts of British Columbia, such as the St. Elias range, comparable in breadth with the Scandes, can serve as an illustration of our stage I. But the present glaciation of the St. Elias range is due to the great height of the range, and not to a low glaciation limit. Therefore, the glaciation of the fjords is small. In this respect Spitzbergen and Graham Land offer better possibilities for comparisons. But in all cases the marked Alpine forms are obstruent of a complete comparison.

As stated in Chapter III B 1 and 3, the old ice flow from the NW. on the eastern slope reached far greater heights than those of the valley streams referred to Stage I. There must have been stages of more intense glaciation of the mountain range than those of I. They are called II. The maximum height of the corresponding ice surface is drawn in the section. As at Svaipa (8, 1426 m) the striae from the NW. (*a*-striae) are still found at 1000 m on the valley side (at higher levels frostweathered) and the top (dip of structure to the NW.) is well rounded, as by an ice stream from the

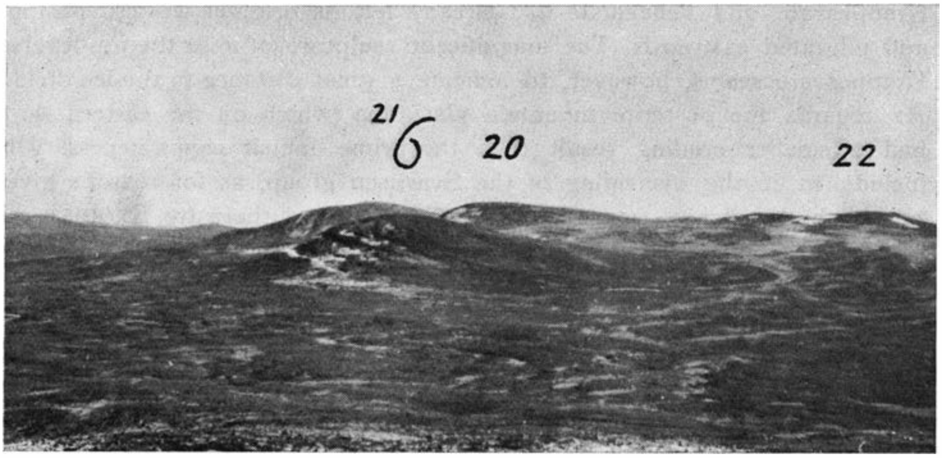


Fig 31. View from Nasafjell (5, 1210 m) looking ESE. showing the old peneplain and the west-dipping lateral drainage channels and terraces on almost all mountain slopes, very conspicuous in 6 and perceptible in 22.
6 = Kargasatåive 1219 m, 20 = Ballonåive 1343, m, 21 = Skertasåive, all together forming the southern side of the Laisan valley, seen to the left.
Photo by the author on Aug. 8th, 1942.

NW. (fig. 27), I have drawn the ice surface above the top. — Krappesvare (10, 1064 m) was totally overridden from the NW., because it shows a beautiful sculpture of the a'-series up to the top plateau, and striae of the a'- and the a-series. Krappesvare, therefore, yields the most important data for the construction of the minimum height of the mountain ice sheet. — In Peljekaisse (11, 1133 m, pl. III), where the petrographic conditions (micaceous schists of the Seve-group) hardly permit of the conservation of an a'-sculpture, I was able to establish (in addition to the main b-striae from SE) a-striae in doleritic knobs at four localities on the slopes to the S. at the levels 938—1050 m above sea level. As the directions of these older striae are from N 85—90° W at the lower levels, and from WSW. and SW. at the uppermost level (partly due to topographic diversion), and a stoss side at 1085 m in schists without striae faces WSW., it seems possible to interpret a set of indistinct chatter marks from about S 35° W on the doleritic point of the summit as a true indicator of ice flow a. If so, the continued counterclockwise turning as the level increased would indicate that the ice surface of the a-flow possibly did not reach the summit until the moment when the flow was about to shift to the b-direction. The lack of rounding W. and SW. of the summit (not so to the NW.) is partly due to the structure of the schists (dipping to the E.). As in Krappesvare the a'-flow was much more important than a, it must have capped the summits of Peljekaisse.

Starting from the data yielded by the eastern slope we can estimate the probable level of the ice surface at the ice divide. There is, of course, a theoretical possibility that the ice divide at the time when the ice capped

Krappesvare and Peljekaisse had already left its original western position and migrated eastwards. The magnificent sculpture of *a'* at the top level of Krappesvare seems, however, to indicate a great distance to the ice divide. As regards the posterior mountain glaciation (which on the eastern slope had a smaller eroding result than the prime one) it seems necessary to include in it the overriding of the Svartisen group, as for reasons given below the scratches from the SE. and S. found there by ENQUIST can hardly be connected with the posterior eastern foreland glaciation. That requires a considerable ice level also for the western slope at the time of the *a*-sculpture.[1]

When the ice surface was still rising from position I to II the glaciation limit sank enough to permit the cirques near the eastern border of the mountain range to be formed (in Kaissatj, Peljekaisse, etc., see Chapter III B 2). Contemporaneously, the most advanced ice tongues sculptured Piedmont lakes. The outermost cirques, as that of Snjärak, for example, may belong to the time of the maximum height of ice surface II before the inundation of the eastern foreland. The glaciation limit had then sunk 1100—1200 m below its present position in the east, and probably even more in the west (Chapters III B 2 c and E 3 b).

At this stage (II) the glaciation may have reached about the same development on the eastern slope as it had at the earlier stage (I) on the western slope. As a whole, we must consider the ice to have formed a sheet. In the glacial history of British Columbia KERR (1934) has assumed stages which he called "mountain ice sheet stages". But he did not find anything to prove conclusively that the higher eastern peaks were overridden by the ice moving from the Pacific.

---

[1] Of great interest for the altitude of the ice surface II in the Norwegian part of the section are two data from the neighbourhood.

One is the find of an erratic boulder at 100 m below the highest summit of the fjell Oxtinderne (b in the section), which was referred to in the former paragraph. The other is the form of Ørfjell (c), drawn in fig. 28. Upon a flat conical groundform, dissected by local glaciers, there stands a short pillar (or a steep-walled ridge) reminding of a *nunatak*. Considered as such, it would indicate an interesting stage of ice-sheet glaciation with a surface level at 500 m above that of the valley-ice stream (stage III), indicated by d. Possibly the maximum ice level at stage II was not higher here.

As the group of mountain peaks Oxtinderne (b in fig. 4) is situated at 65 km from the profile line on its equatorial side and Ørfjell (c) at 35 km from the same line on its polar side (pl. I), they can only very cautiously be compared in the same cross-section. Their mutual relations must have been rather different at the mountain ice-sheet stage (II) of the prime glaciation, when the culmination of the ice divide was on the polar side, and the corresponding stage (II) of the posterior glaciation, when the culmination was on the equatorial side. The data here in question are most likely related to stage II of the posterior glaciation. The ice surface is consequently drawn too low with reference to the trace of b, and too high with reference to the trace of c. Quite in accordance, the ice surface III is drawn too high with reference to the trace of d.

Fig. 32. SE-dipping lateral terraces on the SW. slope of Valle, a plateau-like ridge projecting from Peljekaisse. Looking NNW., towards Rimopakte, cf. pl. II.
Photo by the author, Sept. 12th, 1945.

Above I have performed a calculation of the possible level of the glaciation limit at the coast at the time of the most advanced mountain glaciation (Chapter III B 2 c) and found that that limit surface, even if the position of the coast was more elevated than now, possibly was below the sea level. It thus seems probable that the western ice front in that advanced stage had crossed the strandflat and advanced a considerable tract of the shelf as far as depth conditions permitted. In such a case the inclination of the top surface of the ice to the west may have been rather small, and the position of the ice divide to the west of the water divide and of the axis of mass elevation — as shown by the facts — would be a necessary consequence.

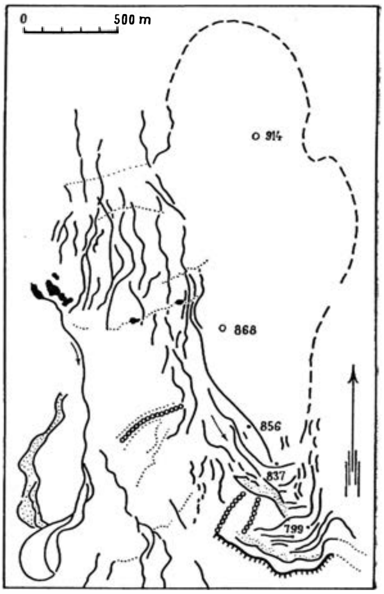


Fig. 33. SE-dipping lateral terraces and drainage channels on the W. and S. slopes of Nebsuort (12). From non-overlapping airphotos. Scale 1:40.000. Dash line gives the outlines of the *nunatak* at a certain stage.
Symbols as in pl. II. On the NW. slope the lateral formes have been destroyed by solifluction. The E. side was too steep for such forms to be developed.

In fact, I can see nothing contrary to the presumption that the top ice surface, which in northern Norway has been ascribed to the "great" ice age, is identical with those of the mountain ice sheet stages (II), which then might better be called western or Atlantic ice sheet stages. Especially Stage II of the prime glaciation would suit the interesting and valuable observations made by GRØNLIE in the northern regions (Tromsø and environs). Here we are already on the coast of Barent's Sea, the whole of which belongs to the shelf and which possibly played a rôle for the extension of the ice cap in later stages of the prime glaciation.

As the Atlantic ice sheets were dependent on the shelf as a vehicle, the relation of this shelf to the sea level must have been of great importance, especially at times of advance. Leaving out of consideration the climatical causes, the great development of the prime Atlantic ice sheet in the northern tracts presupposed an exceptionally high level of the shelf. As, however, the isostatic submergence caused by that glaciation was greater in the north than in the south, and probably was not wholly compensated when the new cycle set in, the latter glaciation may have started on some better conditions in the more southerly districts. It is also clear that a considerable isostatic submergence would be dangerous for an Atlantic ice sheet formed.

We will later on return to this subject.

c. Stages of Continental Glaciation. During the prime eastern foreland glaciation of the last ice age the ice surface above the top of Krappesvare (10; 1064 m) must have lain at a level sufficient to permit the ice to overflow the water divide. We could hardly suppose a smaller height above the summit than 500 m. The direction of flow to the SSW across all great landforms also requires a considerable ice thickness.

The period of the posterior eastern foreland glaciation is represented by glacial sculpture from the foreland on summits such as Peljekaisse (11; 1133 m) and Nasa (6; 1218 m), and by the deposition of boulders originating from the eastern foreland on top plateaux such as Svaipa (8; 1426 m) and Nasa (6) (LJUNGNER 1943, p. 207). In the eastern part of the slope we distinguish the directions of striae *b* and *c*. In the surroundings of the water divide such a subdivision is difficult, all the more as here also the time of the *d*-striae was represented by a flow toward the Atlantic coast. In the passes by Nasa (6), where all sculpture is young, GAVELIN observed striae from the E. and the ENE. (1910 b). They were introduced with dash lines on map *b* and *c* in fig. 10.

True *b*-sculpture is represented on the very summits of Peljekaisse (11, 1133 and 1122 m). As a characteristic *c*-sculpture is found on summit 894 and corresponding striae on summit 950 of Kaissatj situated 10 km NW of Peljekaisse (11), some indications of the weathered dolerite on the very summit of Peljekaisse (1133 m) also seem verified. These are a few fractures of the type chatter marks from an easterly stream (S 80° E) accompanied by a shallow furrow. (The summit 1050 in Krappesvare was overridden from S 72° E.)

The sculpture sometimes reveals a somewhat diminished plasticity of the ice of the *c*-flow as compared with that of *b*, indicating a greater thickness of the sheet producing the *b*-sculpture, and consequently a greater height above Peljekaisse.

In the section fig. 4 I have drawn a line III illustrating an important stage in the time of the *b*-sculpture, when Solvaagtind formed a nunatak cf. fig. 20. Indeed, it is not unlikely that this latter level represents the maximum of ice level of the posterior continental glaciation. That would coincide with the opinions of REKSTAD, AHLMANN, HOLMSEN, and GRØNLIE, cited in the first part of this chapter.

But a consequence is then that the striae on the Svartisen Group found by ENQUIST belong to a mountain (Atlantic sheet) glaciation. As the direction of sculpture is from the SE., turning clockwise to the S. as the thickness of the ice decreases, the only conceivable stage is the posterior mountain (Atlantic sheet) glaciation.

Here I will call attention to the examples given in Chapter III B 3 on the valley sculpture of the western slope. Characteristic of that sculpture are the steep walls, which form a sharp limit between the plateau and the dissecting valley if the plateau reaches a sufficient height. On the coast the plateaux are often reduced to peaks rising above a flattened surface corresponding to the valleys of the interior, fig. 29. Obviously, we have here the trace of an ice surface. The excellent Norwegian maps of recent date permit us to follow that surface. It shows a considerable dip towards the coast and a slight fall along the mountain range towards the NNE. The direction of the main inclination, consequently, is here to the NW. Towards the S., the surface seems to rise so that only a few summits are left above it when it passes the Arctic Circle. That is the surface which REKSTAD, HOLMSEN and GRØNLIE — and at the coast AHLMANN and GRANLUND — have referred to as the maximum ice surface of the last glaciation.

A serious objection can be raised against this interpretation. If the *b*-flow on the eastern slope at higher levels left only some striae and even in the valley bottoms generally could not remove the stoss sides of the mountain stages, how was it able to effectuate a sculpture on the western slope important enough to stand out as a remarkable feature on maps on a small scale?

This would seem to be ambiguous, but I propose the following explanation.

First, we must remember that the steep-walled plateaux-dissecting valleys as the Skjomen and the Solvåg valleys of the Atlantic slope (Chapter III B 3) have certain analogies on the eastern slope (as the Kujjaur valley) and that consequently part of the sculpture in question must have been brought about during mountain stages; the latest of them, the *a*-sculpture, was characterised by a rising level to the SSW.

Secondly, the *b*-stream must have had a much greater effect when passing the threshold formed by the mountain range along the line or zone where the upper ice surface touched the section, fig. 21; that line is not the water divide but a line somewhat to the W thereof — just where the sculpture in question is most developed. It might be called the tangential zone.

Thirdly, according to my experience from the foreland the greater distance from the ice divide and the thinning out of the ice sheet involves a strongly increased eroding power.

During the time of the formation of the *d*-sculpture the ice sheet was much reduced. Lateral drainage channels were formed, fig. 30. Finally, the water divide was ice free, and ice-dammed lakes were formed on the Bothnian watershed. In the section I have marked the level of this latter stage. In the uppermost part of the Laisan valley, i. e. near the peninsular water divide, there are in both valley sides a couple of west-dipping lateral terraces and drainage channels, definite traces of the surface of the successively shrinking ice body, fig. 31. Already GAVELIN observed them (1910 b). In the eastern part of the section I found the corresponding east-dipping lateral formations in the SW. slopes of Nebsuort (fig. 33) and Peljekaisse (fig. 32 and pl. II). The concentration of these formations to SW. slopes (i. e. NE. valley-sides) at the eastern slope of the ice-ridge is of double interest. First, it is in good relation to the *e*-scratches (Chapter III B 1 b) and secondly, it reveals a climate of the continental type permitting an important insolation; on the western slope there is nothing to forbid us to suppose a maritime climate causing melting mainly by convection.

Although MANNERFELT (1945, p. 213) denies a pronounced radiation climate during the down-wasting stages in the southern part of the Scandes, his table on p. 213 reveals a clear exception with regard to the Transtrand Fjells, the only district in his treatise situated at some easterly distance from the ridge of the ice divide.

Here MANNERFELT also found an exceptionally high gradient of the ice surface as measured from the marginal formations, 7/100 to 10/100 (1945 p. 133 f). In the opinion of the present writer this may be due to the importance of insolation, causing a more frontal ablation (see below p. 67). In Peljekaisse the gradient varies greatly but reaches 7/100 on the best developed terrace.

C. A Section through the Central Part of the Scandes.

a. Position of the Ice Divide. Nowhere has the ice divide been the object of so much research as in Jemtland. Extensive observations of glacial striae had been made there even before the investigators were willing to ascribe the erosion phenomena to an ice (DUROCHER, 1846, and HÖRBYE, 1857).

DUROCHER, who farther S. (between Fæmunden and Dovre) had established for the first time a movement towards the water divide, thought he had found striae running from WNW. and NNE. on Åreskutan (7) and in the region of Kall NW. of it (1846, pp. 34—40, and map). The movement from ESE. was established for W. Jämtland and Härjedalen by HÖRBYE (1857, pp. 22, 23, and map). According to TÖRNEBOHM (1872) and HÖGBOM (1885), this movement is the sole one there. TÖRNEBOHM's diary, published by HÖGBOM, has a partly different tale to tell on p. 13 (movement from NW had been noted in two localities near the frontier). HÖGBOM (p. 16) stated that the methods used when interpreting glacial striae are very liable to subjective judgments, since in most cases a stoss-side cannot be found, but his 'unshakeable opinion' as to the uniformity of the movement is at the back of this statement. He abandoned this opinion in 1894, when he even went as far as to cite DUROCHER's above-mentioned observation at Kallsjön and that of HOLST at Marby on the NW. side of Storsjön (see below) as proof of the position of the ice divide far to the west (p. 74). HÖGBOM's just quoted statement is an honest admission of the great difficulties in the interpretation of rock surfaces, which a later generation has also had to grapple with; see, for example, for Jemtland CARLZON-CALDENIUS (1909) and G. FRÖDIN (1913 and 1925), for Lappland J. FRÖDIN (1914).

Although the question of an older sculpture from the NW. demands a modern analysis of the rock surfaces, I have nevertheless wished to see what the literature would lead one to expect.

According to the table in HÖGBOM's diary (1885, p. 12) he himself observed in 14 cases an ice movement from the NW., which he interpreted, when publishing it, as a movement from the SE. These 14 cases make 33 % of the number of localities. He has in the same way re-interpreted the original reports for 9 (50 %) of SVENONIUS's localities, 2 (25 %) of GUMAELIUS's, and 2 (100 %) of LINDSTRÖM's. Some of these belong to the region for the last ice divide where, when making a control of the field, CARLZON-CALDENIUS (1909) considered the alterations to be justified in most cases, but not in others. Uncontrolled localities NW. of the ice divide nevertheless remain.

G. FRÖDIN seems wholly disinclined to consider that glacial striae and stoss sides have been preserved from the earlier phase of the last glaciation. He has not been able to find DUROCHER's stoss sides, and does not consider them to be genuine, but due to the structure. When visiting HOLST's above-mentioned locality (FRÖDIN, 1913, p. 2) he could 'only confirm that unmistakeable northwesterly stoss sides were present here'. But he considered the striae probably to be formed by a younger SE. stream (1913, p. 2), and the locality is not mentioned later. Thanks to the hardness of the quartzite, this rock surface distinctly imparts the valuable information that, at any rate for the locality in question, the stream from SE. was only able, at most, to form striae, where the NW. stream had produced stoss sides. Later on, FRÖDIN has found several localities (by 11 in the section), another 10-15 km NW of his last ice divide Härjedalen-Storsjön, that had stoss sides and striae from the NW stream, and younger striae from the SE stream (1925, p. 133, 159). But as the older sculpture, too, is referred to the wastage period, the implication is that the ice divide mentioned migrated eastwards, whereas the ice divide north of the transverse valley migrated westwards. FRÖDIN is consequently no longer able to apply his simple and attractive picture from 1914 b (p. 544; cf. 1916, p. 76) of the palaeo-, meso- and neo-Scandinavian ice divide (cf. LIDÉN, 1913, Pl 6).

On the other hand, HÖGBOM's theory (1920, pp. 89, 91, 92), which he supports on the extention of the Rätan granite boulder, is that the Härjedalen-Storsjö ice divide, too, had an extramontane position; if we work from this — a procedure which FRÖDIN (1925, p. 120) does not consider impossible — then several localities with older rock sculpture from the NW. can be referred to the oldest ice-divide position.

According to this survey there is in Jemtland, W. of the last ice divide, an outcrop (Marby) with ice sculpture from the NW. which is acknowledged to be older. As it consists of quartzite, and as in the previous section it is primarily quartzite that preserves the oldest sculpture, there may be an agreement here. Dr P. THORSLUND has kindly told me that the circumstances found at Marby are repeated at a more westerly point in the section, at Mattmar NW. of lake Storsjön (letter, May 25th, 1945).

As regards boulder transports, HÖGBOM has given us a material of permanent value. I will do no more than mention his findings in moraines on Östberget on Frösön (14) and elsewhere, of garnet-bearing hornblende-schists from Medstugan (HÖGBOM, 1885, pp. 10, 20, 29; 1893, p. 31), as also the find of a boulder of micaceous quartzite, belonging to the Röros schists, as far down as Städjan (1894, p. 74). This means a transport far eastwards from the immediate vicinity of the water divide. Röros is situated in Norway, and Städjan is the SE-most Swedish fjell on the map fig. 34. On Röros schists see HÖGBOM 1910 p. 18 and 1913 pp. 64—66.

For HÖGBOM this find was an 'anomaly', because he had not yet taken into account the possibility of an ice movement 'conflicting with the direction of the glacial striae'. But later on (1894, p. 74; 1906, p. 119) he advanced these boulder transports as proof for the fact that the ice divide 'must some time have lain as far west as in the neighbourhood of the water divide'. FRÖDIN (1925, p. 18) refers these boulder transports from the W to an early period of the last glaciation. He could add new finds of his own (1925, p. 156).

Dr KARL WEDHOLM has told me that he, at Torvalla near Brunflo, found a boulder of the conglomerate from Offerdal, and that this find was verified by Professor A. G. HÖGBOM as well as by Dr BERTIL HÖGBOM. Dr R. SANDEGREN found at Hammarforsen in Ragunda some boulders of the Offerdal conglomerate (oral communication 1947).

Concerning the scratches of the easterly direction G. FRÖDIN (1914 a and c) was able in N. Jemtland to distinguish three groups of successive age. The oldest ones are those from the ESE., the middle group comprises those from the ENE., and the youngest ones are those from the NNE and N. In this counter-clockwise turning (which I had the opportunity to confirm on Åreskutan in 1944) FRÖDIN sees an expression of the growing influence of the ice development in S. Lappland (1914 a, p. 147, 1925, pp. 209—11). The agreement with the turning *b*—*c*—*d* in the northern section is obvious.

Our present knowledge (since 1925) of the Central Scandinavian ice divide during the last glaciation may thus be summarized as follows — if, that is to say, we follow HÖGBOM 1920 and FRÖDIN 1914 for the stretch S. of Storsjön, and not FRÖDIN's opinion of 1925, but his admission: Earliest on, the ice divide lay far to the W., near the water divide; later on, however, it assumed an easterly, wholly extramontane position. During a final phase it thence advanced some way in towards the mountain range again, with the exception of the short portion bounding Storsjön in the east. — According to later striae-observations on Frösön by ASKLUND (1936, p. 4), the last ice divide was supposed to have a more westerly position also at Storsjön, but this is contested by THORSLUND (1939, p. 12).

Thus, to our knowledge, the history of the ice divide in Jämtland contains nothing to conflict with the conditions in the Arjepluog section, although the Jemtland section has nothing corresponding to Svartisen's mountain group in the W. This southerly section is, in point of fact, very like the Northern Patagonian one through Nahuel Huapi. It is, however, even more like a Central Patagonian one, where the finger lake lies partly out on the foreland as a true 'Piedmont' lake.

b. Ice Surfaces and Local Glaciation. Discoveries of fossilized Arctic plants led ENQUIST (1918, pp. 82, 90) to think that the western ice margin was, already during the Ra period, situated on the Bothnian watershed. He was therefore also at liberty to refer the stage of intensified local glaciation to this time (1918, p. 84 et seq.). HOLTEDAHL (1928) considers the island Tautra in the Trondheim fjord to represent the Ra time. He is backed up (1942) by UNDÅS. If this is correct, then the intensified local glaciation can hardly belong to the Ra time, for an ice surface lower than the local cirque moraines (x on fig. 5) would be too flat if it were at the same time to have its margin in Tautra. The more probable form of the ice surface with its margin in Tautra is shown by line IV. On the basis of pollen material, MANNERFELT (1940, p. 36, cf. 1945 p. 204) has also found that the pertinent moraines in the mountain Fongen (1) are of late glacial origin (*sensu* DE GEER); he could not, however, fix a more exact time for them. He mentions tentatively the time for ØYEN's *Portlandia* level. According to ØYEN this denotes a considerable climatic deterioration; this is contested by HOLTEDAHL, however, (1924; 1925, p. 166).

There are also large cirques which have no local moraines, but which in several cases show distinct deposits of the inland ice. There is no difference in size or development between the cirques with and without local moraines. All of them came into being before the maximum spread of the inland ice.

Unlike the state of affairs in our more northerly section, the Swedish maps here are fairly new; the Norwegian ones, on the other hand, are very old. The Swedish maps allow of extensive morphological studies; this is particularly advantageous, since the glaciation limit is registered by means of glaciers only on the Swedish side. This limit has been drawn through

Storsylen (3) and Helagsfjället (5), in accordance with ENQUIST (1910; 1918) and AHLMANN (1934, p. 322). It rises normally eastwards, and may be supposed to do so throughout the entire range (cf. LJUNGNER, 1944). The firn limit lies in Helagsfjället about 300 m lower than the glaciation limit (ENQUIST, 1910, p. 15).

As all mountains with cirques must at one time have stuck up above the glaciation limit, we get a number of minimum measurements for the former depression of this limit, before the local glaciation was rendered impossible by the total glaciation. I have included in the section a number of larger cirques according to the map. Some of them have been the subject of investigations and been mentioned in the literature in another connection, *e. g.* the cirques in mountains 3 and 5 by ENQUIST (1910) and MANNERFELT (1945), in 4 by ERIKSSON (1914, p. 26) and ENQUIST (1918, p. 86; moraine-free), in 9 by ERIKSSON (1914, p. 44), in 10 by ERIKSSON (1914, pp. 127, 135). In 12 we have to notice not only the cirque to the east of Lillfjället (MANNERFELT 1945, Pl. 1) with ablation moraine but also the imposing "Skar" named Dörrsjöarne with a bottom at about 800 m (MANNERFELT 1945, plate IV) showing great eskers.

In mountain 9 the depression is 400 m, in 10 it is 500 m, and in 12 doubtless considerably more, perhaps exceeding 800 m. As, however, the cirques in these mountains are deep, and as the present position of the firn limit is altogether too high to fill the cirques in Helagsfjället or Sylarne with snow, the figures quoted must be augmented by a couple of hundred metres.

This indicates that less deep concavities in certain lower mountains are also glacial cirques and should, after a control in the field, be able to supply directly usable values, *e. g.* Dunsjöfjället (between 8 and 9 in the section) and Slaiva (at 7 in the section), which would give 600 and 770 m respectively.

As the section shows, several of the eastern cirque bottoms fall below line x, which itself is probably the lowest conceivable ice surface for the Ra stage if the ice margin lay at Tautra (16). The cirque in 10 has shore lines of an ice-dammed lake. The cirques were thus formed during a mountain stage.

There are no other records for the construction of ice surfaces from older phases in this section. The youngest stages of decay have been studied in detail, on the other hand, by HÖGBOM, G. ANDERSSON, ERIKSSON, G. FRÖDIN, and MANNERFELT.

c. Migrations of the Ice Divide at Lake Femund. In 1946 I had the opportunity to visit the region of the east of lake Femund, principally in its Swedish section. The result is to be seen in fig. 34, cf. LJUNGNER 1947.

At the beginning of the epoch registered on map B, the ice divide was situated far to the NW., outside the region. The distance might be difficult

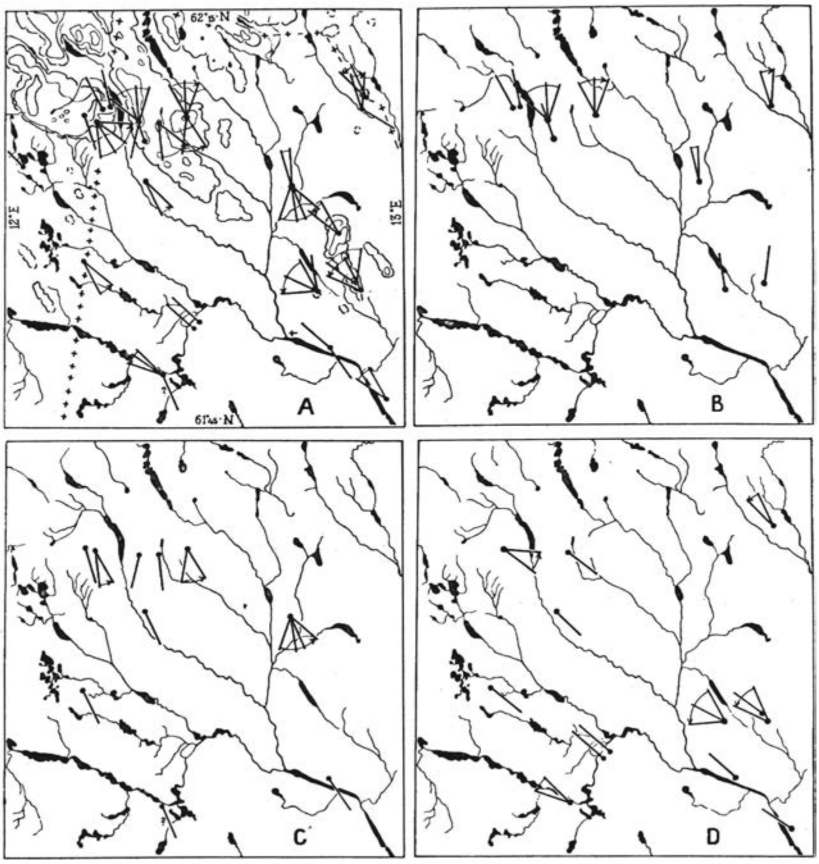


Fig. 34. Three epochs of glacial development in a district to the east of Lake Femund, in Dalarne and Herjedalen. Scale 1 : 1,000,000. Situation marked by a square in fig. 2 = F in fig. 35. The ice divide was in map B situated NW. of the area, in map C SE. of the area, and in map D it crossed the area diagonally. (The symbol nearest to letter C was based on stossides and striæ only.)
Map A gives all observations, also those which could not be dated. Map A has three contour lines. The lowest represents the forest limit, at 800—900 m, the next one the level of 1000 m, and the uppermost the level of 1200 m. The latter is surpassed by Storvetteshågna, the summit of which forms a good outcrop.

to establish as the whole district to the west of the map (the Norwegian sheets N. and S. Femund) is built up by rocks not having the capacity of preserving striae (HOLMSEN 1935, 1937); they belong to the sparagmites. After the direction of striae had turned clockwise from the NW. to the N. and NNE., the ice divide passed over the area and was for a time probably situated quite outside of it, to the S. or SE. The turning was now counter-clockwise and continued so. At the end of the glaciation the ice divide crossed the area, from its SW:ern to its NE:ern corner (cf HOLMSEN 1924, figs. 1 and 6). The last ice remnants which dammed great ice lakes in Norway had about the same situation, see HOLMSEN 1924 fig. 1.

The symbol nearest to letter C on fig. 34, localized to the dolerite quarry on the Vålå hills, was based on stosside inclinations and striae only. Thus I should wish to see my observations confirmed by the more decisive methods which I commonly use but seldom are applicable to this coarsegrained and often weathered dolerite.

Only in some southerly localities are faint signs visible of a very late clockwise turning of the striae, which outside the fjell region of Dalecarlia is pronounced (LJUNGNER 1947, cf LUNDQVIST 1941), corresponding to the late clockwise turning in map B, fig. 11. They are not marked on the map.

A very interesting fact is the clockwise turning on map B in fig. 34, which is the reflected image of the turning from *a* to *b* in the north (fig. 11, A). Consequently, the culmination must have developed between the two regions of observation and in this way followed the migrating ice divide down to the foreland.

D. The Piedmont Lakes.

a. Retrospective Survey. The fjord-like lakes ("finger lakes", "Piedmont lakes") lying along the eastern border of the Scandes were interpreted by SUESS (1888) as glacial rock-basins which had been excavated, as a result of the counter-incline, by ice flowing from the east. In his treatise on the fjords (1900 p. 182), we find that NORDENSKJÖLD — who had advance information of the results obtained by AHLENIUS — writes: "Zur Zeit ist es nicht möglich, die Bildung dieser Seen sicher zu erklären". Thanks to AHLENIUS (1900) it was ascertained what depths prevail in the Lapland lakes; soundings of up to 221 m were registered (Hornavan on our uppermost section). AHLENIUS discussed three possibilities: subsidence of the Silurian zone[1]; glacial erosion; and damming up by glacial deposits. The first hypothesis was rejected because the position occupied by the margin of the formation was not always appropriate; and faults were not known of. The second theory was discarded because the ice divide had lain above the lake-zone. But just because of this latter reason, it was considered that the remnant of ice might well have protected the lakes from the accumulation which filled up the valleys elsewhere. The origin of the lakes should thus be sought in glacial damming up, which was also taken to be the prime factor by HÖGBOM. But HÖGBOM allows other factors as well. He concludes his elaborate discussion (1906, p. 250) with the following general verdict: "There are so many different factors which help to determine the type and formation of these lakes that no single factor can

[1] Along the eastern border of the Scandes, from the southern section to the N., there is a so-called Silurian zone. Resting upon the pre-Cambrian subdeposit are sedimentary rocks of Silurian age, but towards the N., mainly Cambrian and Eocambrian rocks (my paper 1943 b). These rocks are capped by overthrust metamorphic rocks. Only in the region of the southern section have the sedimentary rocks been laid bare to some extent by erosion. Otherwise, the narrow strip of the Silurian zone is limited on the W. by a dentate precipice, called "glint", caused by the sapping effect of the erosion — starting from the easily eroded slates below the hard overthrust masses. In the southern part of the eastern Scandine border there is no Silurian zone of this kind. The Silurian district in the thrust region of Oslo belongs to the foreland.

justifiably be regarded as solely determinant." TANNER ascribes (1907) Lake Kilpisjärvi mainly to stream erosion and dislocations.

Thanks to the detailed investigations of SJÖGREN and J. FRÖDIN on the lakes strung along the courses of the rivers Torne and Lule (publ. in 1909 and 1914 respectively), it was ascertained that, in the main, these lakes are rock-basins, so that proper recognition could now be given to the part played by glacial erosion. Both writers seem to believe that the rock-basins were shaped beneath a mighty sheet of land-ice, independently of the position occupied by the ice divide. SJÖGREN sites the ice divide (right until the wasting stage was reached) above the western portion of the lake, making it culminate towards the Abisko fjells (18° 3/4 E), while FRÖDIN places it approximately over the centre of the stretch of lakes (19° E). At this point research came to a halt in Sweden, though further investigations were subsequently carried out in Norway, where preliminary soundings of a number of lakes had already been performed at an early date. AHLMANN (1919, p. 43) emphasized the fjord-like character of the lakes and went so far as to include several of the Swedish finger-lakes under the same heading. This similarity to the fjords (including the nature of the rock-basins) has also been stressed upon by KIÆR (1927) with reference to Tyrifjord, by HOLTEDAHL (1929, p. 142 ff) with reference to Mjösen, and by KALDEN and STRØM (1939) with regard to Fyresvand and a number of other lakes ("Fyresvand is a fjord-type lake and demonstrably a pure rock-basin").

A notable advance in our knowledge of the part played by glacial erosion in general in Scandinavia is chronicled in the lectures given in 1938 by AHLMANN and LAURELL in Amsterdam. These writers point out that the nature and effect of glacial erosion depend both on the terrain and on the phase of glaciation reached. The finger-lakes (whose origin is ascribed, in part, to a tectonic subsidence of the mountain chain) are already referred to here (p. 10) in connection with the initial phase of glaciation, when glacial erosion was at its strongest, owing to the previous period of weathering (regarding the fjord-like lakes occurring in the fjord-zone, on the westerly side, cf VOGT 1913, pp. 42, 46). It was then (claim AHLMANN and LAURELL) that the lakes received their first moulding, and their overdeepening, during the main phase, by the reorientation of the ice-current. Importance is also attached to this last factor by AHLMANN, LAURELL and MANNERFELT (1942); on p. 22 the fjord-like lakes of Norrland are referred to as products of the Ice Age as a whole.

When, in the course of lectures delivered during March and April 1943, I ventilated my own interpretation of the fjord-like lakes, describing them as the result of ice-tongue erosion during an early stage of glaciation (1943 a, pp. 199, 209), I believed this to be an entirely new hypothesis. It was not until a year later, when the chapter in question was finished, that my attention was drawn to TANNER's treatment of this issue in his book, Die Oberflächengestaltung Finnlands (1938, p. 454 ff), where the same interpretation is proposed. But TANNER adduces no reasons, either theoretical or empirical, for the vital assumption that the glacial period in question persisted long enough to produce an erosive effect of such magnitude.

b. The Lakes Interpreted as Old Glacial-Marginal Lakes. I would here attempt a purely geographical perspective. A cartographical exposure and scale of depths have been furnished by HÖGBOM (1913, pp. 139, 140, 149). In order to get the whole lake-zone on one and the same map, I have selected, as my working basis, a map by AHLMANN showing the limit of glaciation in Scandinavia, and on which the lakes are marked. On fig. 2 I have indicated the eastern limit of the Silurian and also drawn in the ice divide according to LUNDQVIST.

If we consider the limit of the Silurian as suggesting a possible explanation of how the lakes came into being, we note that the demarcation of this limit is partly appropriate in Southern Lapland and Jemtland, but not in Northern Lapland. In the Oslo region, certain lakes lie in the Silurian zone, and others lie between it and the axis of the mountain range; while to the SW. the chain of lakes continues without any Silurian accompaniment, just as, on the NE., the border of the Silurian continues without any accompanying lakes. A corresponding result is obtained in respect of the so-called "glint" (see III D a, note 1). The importance of the change in direction of the ice-current ought to be revealed in the relation of the chain of lakes to the most easterly site of the ice divide. This is not so widely known. But it is noteworthy that the chain of lakes nowhere stretches as far as the Gulf of Bothnia in Central Scandinavia, whereas in South Norway it extends far beyond what is generally agreed to have been the position of the ice divide even at the time when the ice had reached its maximum expansion.

The chain of lakes can only be geographically correlated with a single feature: the dominant chain of *fjells* stretching from Langfjellene in the south to Abisko in the north. Where the chain of *fjells* decreases in altitude, towards the north, the string of lakes sweeps in towards the *fjells* and disappears (cf the marginal formations in Tierra del fuego). Towards the *fjells* the limit of the chain of lakes is indefinite, and it is the outer margin that is noteworthy (cf Patagonia).

Since I have been able to show (for one section so far) that a westerly position of the ice divide, corresponding to the position of the ice divide in Patagonia (and one, moreover, which certainly also obtained in Jemtland) repeatedly recurred and sometimes persisted for lengthy periods, it follows that the chain of lakes, whose position exactly corresponds to that of its Patagonian counterpart, ought to be correlated with the same intramontane location of the ice divide. In other words it may be regarded as constituting the remnants of an old glacial marginal formation. When the lowlands were flooded, the resulting destruction was not limited to the arcs of the terminal moraines; the rock thresholds must likewise have been affected. I have ascertained that powerful disruption was still taking place in the threshold area of Storlaisan during a late glacial phase (1943 a, p. 206). And it is doubtful — especially as regards those portions of the lakes lying outside the glint — whether a basin-shape fashioned in ideal conditions could have been restored or undergone any significant enlargement as a result of deep erosion during the stage of maximum glaciation. No lakes of any size were formed in the parts of Norrland lying closer to the coast, where the terrane acquired powerful relief as a consequence of Tertiary elevations (AHLMANN and others, 1942 p. 20).

I admit that in suitable portions of the lake-zone other factors have helped to form the lakes or affected their later development. Thus we can claim with every assurance that the feebler resistance of the autochthonous sediment facilitated deep erosion in several Lapland lakes, just as the reduced height of the mountain ridge outside the glint meant a reduction in deep erosion. Tectonic as well as isostatic movements may have played their part. I have myself been able to demonstrate considerable Caledonian deformation of the subdeposit of primitive rock in the Silurian zone (1943 b)[1], but it is not until we get as far as Southern Lapland and Jemtland that the lakes fall within this zone to any marked extent. I have also had an opportunity, in the Laisan valley, to observe that a reversal of the ice-current increases the possibility of erosion (1943 a, esp. p. 204). My observations also tally with those of AHLENIUS when he points out that, at the final position of the ice divide, ice-remnants protected the basins from being filled up. The importance of marginal terraces for the damming up of marginal lakes is a fact well known to us from Norway (the lakes of Østland). But it seems incongruous that a chain of lakes pursuing a regular course should have been brought about by entirely different causes in various parts of the chain. There must be one factor common to all sections of the chain; and this must be the main factor.

c. Present Morphology of the Lakes. Some light is thrown on the origin of the lakes if we compare their present morphology and the way in which they were affected by deglaciation. In the South of Norway deglaciation was accompanied by intense ice-activity, taking the form of normal recession with very protracted halts — sometimes interspersed with advances. On its margin the ice assumed the form of tongues which were responsible alike for erosion and accumulation (HOLTEDAHL 1924, p. 78, cf 1925, 1934 p. 361 and KIÆR 1927). The process was the same as when the lakes came into being. In this way the old fjord-like lakes were renovated. And it is here that we find the greatest depths: in the Silurian region we have Mjösa 452 (the deepest part lies mainly in crystalline rocks) and Tyrifjord 295 m; while in the Pre-Cambrian basal ground we have Tinsjö 445, Fyresvand 369, and Bandakvand 289 m. By contrast, in the region where the more northerly lakes are situated, the ice wasted away as dead ice, and one of Norrland's larger lakes came to lie to the west of the last ice divide, namely Storsjön in Jemtland, which despite its width is only 80 m deep.

[1] I have recently shown, that the Lake Lockne in Jemtland, situated at the right end of the section fig. 5, occupies a tectonic depression (1948 a, p. 482).

E. Ice Balance in the Various Phases of the Last Ice Age.

1. The Evolution.

a. The Prime Glaciation developed first to a mountain glaciation reaching the mountain ice sheet stage (Chapter III B 1 d, e and 4 b). The ice sheet formed had probably a westerly orientation and was possibly identical with the sheet of the so-called "great ice age" in northern Norway. In fig. 35 its ice divide (1) is placed on the western slope. For the northern part of the Scandes it was the most important one. The ice divide then got a pronounced northerly culmination and migrated to the eastern border of the mountain range. The culmination remained within the Arctic circle. Considering the pronounced flow in the direction of the ice divide, this should possibly be looked upon rather as an appendage to a central ice nucleus culminating perhaps on the Finnish-Norwegian frontier (2 in fig. 35).

It is obvious that the ice masses, accumulated to maximum height on the Bothnian slope within the Arctic Circle, must find their principal outflow through the Baltic "valley" and form a Baltic ice stream. The oldest ice stream traced at the outlet of the Baltic sea (Skåne and Langeland) was in fact a Baltic stream (WENNBERG 1943). There may be identity, but the distance from the Arctic Circle is great for a true connection.

b. The Interval, which followed, imports a deglaciation of the foreland. The glaciation of the mountain range was reduced, but we do not know if the deglaciation here was complete. On bare outcrops in Krappesvare traces of the prime-scratches are to be seen in sparagmitic sandstones to about the same extent as the younger ones, and below a thin covering of earth the fine polish, if not substituted by a younger one, is also preserved. Shortly, there are no examples to show that the prime sculpture was spoiled by weathering during the interval. Consequently, if the earth cover was not greater during the interval than in postglacial times, there is no reason to believe that in the level of Krappesvare the ice-free time was of so long a duration as the postglacial time at the same level. At lower levels the ice-free time was shorter. If the covering was greater during the interval, or the climate of the latter did not comprehend so warm epochs as the postglacial time partly did, then the length of the interval may have been greater.

Based upon this estimation I am inclined to characterize the interval not as an interglacial but as an interstadial epoch. It not unlikely includes the intermorainic deposits of Jemtland and Lappland, in the region of the Piedmont lakes. According to the interpretation of KULLING (1945) they do not require the actual climatic conditions. If the arctic climate registered by the Danish and Continental peatbogs of the Herningen type (older than the last glaciation) can be parallellized with the prime-glaciation of the eastern foreland, then their upper layers containing a warmer flora would correspond

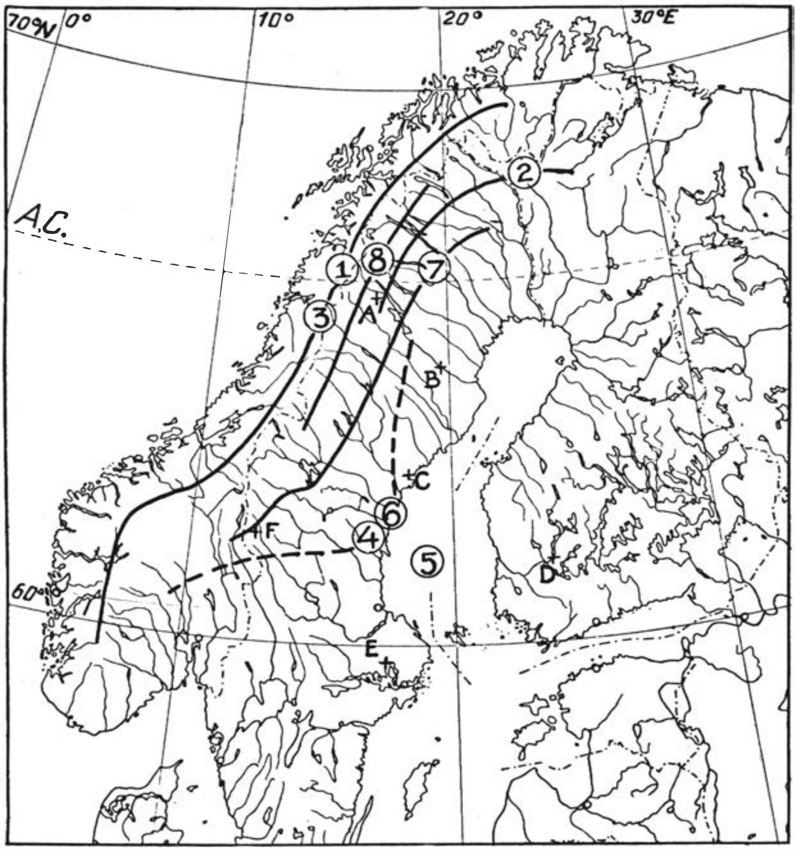


Fig. 35. Positions of the ice divide during the two glaciations of the last glacial age, cf fig. 2.
A = the centre of diagram A of fig. 11.
B = the centre of diagram B of fig. 11.
C = the highest shore line (295 m a. s.) in Fennoscandia.
D = Tammerfors (Tampere).
E = Locality of striæ observations S. of Upsala.
F = Idre, the church (cross) on fig. 34 A.

to our interstadial; the climate indicated seems, however, to have been warmer than necessary to explain the development in Scandinavia.[1]

c. The Posterior Glaciation began as the former one with a mountain glaciation. There was formed an ice sheet of westerly orientation. Its ice divide was on the western slope (3 in fig. 35). The further development, however, was directed to the S. The culmination grew up on the S. side

[1] According to S. A. ANDERSEN, Copenhagen (1946, and his lecture in Stockholm, Oct. 1946), the specimen of a warm temperate flora found in the upper layer of the Herningen peat-bogs should not originally belong to that horizon, but have been deposited there secondarily. He refers the horizon to an old Baltic interstadial epoch of the last glacial age. In such case the interstadial epoch found by me in the Northern Scandes would suite the upper layer at Herningen very well (cf LJUNGNER 1946 b).

of latitude 66°, probably in the central parts of the Scandes. The ice divide migrated to the foreland and the culmination developed to a central nucleus with almost radial outflow.

One reason to assume a pronounced central nucleus is the rather circular form of the ice border, as far as it is known. Another reason was supplied by my investigations along the S. side of the Skellefte River (fig. 11): the oldest flow of the posterior foreland glaciation was on the mountain slope not from the ESE. but from the SSE. and on the lower foreland not from the WNW. but from the SW. (S. 40° W.) was seen, but the most southerly direction of that region had probably not yet been observed.

For the position of the culmination at the maximum extension of the ice sheet the point of the highest shore line (295 m, Högsvedberget, C in fig. 35) is of great interest. As, however, the ice nucleus at the time of regression was migrating towards the N. (see below), the isostatic emergence was in the N. delayed, in the S. accelerated. Consequently, a greater part of the total rate of submergence was registered by shore-lines in the N. than in the S., and the maximum load may have lain more to the S.

The oldest scratches found by HELLAAKOSKI (1943) at Tammerfors are from the W. Provided that they belong to the last glacial age, the only epoch really conceivable for their engraving must be the stage in question. In Upland (60° S on the Baltic coast) only accidental observations have hitherto been made, but an old sculpture repeatedly found by me to the S. of Upsala is from the N. 10°—20°—30° E. and was effectuated by a very plastic ice. The flow from NNE. was plastic enough to polish and scratch leesides of 35° of inclination in the direction of the striae. That ice had a considerable thickness, much greater than the ice which brought about the predominant sculpture of the region (from NNW.). This sculpture is evidently younger, although probably prepared in old stages of advance. The sculpture from NNE., therefore, may very well be connected with the same stage of maximum extension.

The bearings of the oldest striae mentioned at Tammerfors and in Upland intersect in the Bothnian Sea, at lat. 61° 1/2 N. and long. 19° E. (5 in fig. 35). Here the culminating point is placed by way of experiment.

If there existed an ice ridge marking an ice divide at this very advanced stage, it must have been very slight, as the rôle of the origin of the outflow had been mainly taken over by the central culmination. But there must have been transitional stages, when the ice divide showed a more linear extension (4 and 6) and an ice ridge with an axial dip towards the N. and the W. With such a stage I have combined the oldest position now recognizable of the ice divide in the locality of the Skellefte River (fig. 11).

The dome shape of the ice body at this stage of maximum ice accumulation was of great importance for the ice-covering of the mountain range. From the centre in 5 (fig. 35) the distance was great to the part of the

Scandes lying within the Arctic Circle. Also the southern part of the Scandes lay more distant than did the central part. Consequently, it is possible that the ice sheet covered all summits of the central Scandes right out to the coast and contemporaneously left the highest and most distal parts of the N. and S. Scandes ice free. That such a spherical outline existed also on the Norwegian coast seems evident from the fact that the terminal moraines at Stad (about 62° latitude) when continuing their course towards the N do not follow the concavity of the central part of the coast but run out in the sea (UNDÅS 1942, known from a review) — the reflected image of the circumstances seen on the Arctic Circle, where the boundary between the forms of local and ice-sheet glaciation with a NE. trend cuts into the coast. The isobates of the upheaval of the land show the same course (HOLMSEN 1924, fig. 2, or any handbook).

The low ice surface supposed above for the time of the *b*-flow in the N. Scandes (fig. 4) thus seems natural. Especially so high latitudes as 70° must have had great possibilities to escape total glaciation. The formation of cirques, so characteristic for the western slope of the Scandes within the Arctic Circle, could go on partly undisturbed also at the time of the maximum extension of the ice sheet (see AHLMANN 1919, p. 228, and others). The same opportunity was given for the development of nunataks, which, according to NORDHAGEN (1933, cf AHLMANN 1919, p. 212), characterize also the coast of S. Norway (in Möre, at lat. 62° 1/2). The topographic maps are here old and but little detailed. (Jotunheimen was completely covered by the inland ice according to AHLMANN 1940, p. 99.)

The dome shape of the ice cap at the time of maximum extension on the continent seems to be the only manner to explain the bicentricity in the distribution of plants in the Scandes. There are plenty of plants inhabiting the N. and S. parts of the Scandes but lacking in the central part. In the last decades there have also been made finds which seem to indicate that, at the highest latitudes of Scandinavia, man survived the last glaciation.

In the time of regression the culmination passed to 7 (fig. 35) as described in Chapter III B 1 c. The course of the ice divide in the North seems to have been about the same as for 7, but then the ice divide migrated to the mountain range again and during that migration the culmination lost its importance. Number 8 in the figure indicates the divide — as also numbers 1 and 3 — and not a culmination.

As regards the migration of the culmination (ice nucleus) to the north, clearly manifested in both sections and on the Lapland foreland, the position of the last ice divide can hardly be synchronous in the southern and the northern sections. The position of the last ice divide in front of Storsjön (the southern section) has therefore not been combined with position 8 but with 7.

This migration of the ice nucleus towards the N. shows that the level and the extension of the ice sheet in the northern part of Scandinavia must have diminished relatively slowly. Between the stage of maximum extension and the Ra stage there must have been only a small difference. In a late stage there may have occurred a small advance in the north, which in the south was registered by an increased local glaciation. An important consequence is that the isostatic movements must have got into an uneven phase.

2. The Ice Balance from a Mechanical Point of View.

The movement of the ice up the eastern slope of the mountain range was explained by HÖGBOM (1885, p. 37) by the resistance to outflow towards the SE. of the slow ice masses resting on a great land area. After an interesting discussion between LEPSIUS, HÖGBOM, BRÜCKNER and AMPFERER (reviewed by ENQUIST 1936, p. 36—39) HÖGBOM's theory was accepted, i. e. that the position of the ice divide must be located where the resistance to movement is from both sides equal, irrespective of the position of the water divide. Certainly, ENQUIST (1916, p. 36 f.) made the objection that HÖGBOM's theory does not take into account the importance of atmospheric conditions, but we must not mix up two quite different things. HÖGBOM's theory on the position of the ice divide says nothing regarding the causes of the changed extension of the ice cap. It only explains mechanically the position of the ice divide as a consequence of the ice cap's extension in relation to the orography at any moment of development. His important theory will henceforth be referred to as HÖGBOM's law. The ice divide changes position in consequence of changed conditions of accumulation or wastage, but the position of the divide is always determined by HÖGBOM's law.

During the foreland glaciations the Scandes effectuated a great resistance to the outflow towards the Atlantic. This resistance varied, however, with time and space, being very great when or where the ice sheet had a small thickness in relation to the height of the water divide, but small, when or where the ice surface reached a great altitude in relation to that of the water divide. Consequently, at the time of the maximum development of the last foreland glaciation the ice divide could retire a great distance from the water divide and mostly in the central part. The great bend of the ice divide (4 and 6), as drawn in fig. 35, is an expression of the fact that towards the distal parts of the Scandes the ice sheet was thinning out and the ice divide therefore much dependent on the resistance from the mountain range, whereas in the cross section of the central Scandes the thickness of the ice cap was sufficient to make it almost independent. The saddle in the central Scandes, which obviously was a cause of the corresponding bend of the later ice divide (7) around the Storsjön depression, may have played a small rôle at the maximum stage.

During the growing extension of the ice cap towards the E. and S. the resistance to outflow in those directions must have increased. That is the other factor of equal importance for the migration of the ice divide to the SE.

At the times of wastage the ice divide had to migrate towards the water divide. The clearly experienced migration of the divide from 7 to 8 at the Arctic Circle is a good illustration. The higher the mountain range and the thinner the ice sheet, the nearer came the ice divide to the water divide — save the dead ice masses. In front of the great saddle of the Storsjö-Trondheimfjord depression, on the contrary, the ice divide remained at a great distance from the water divide. The thickness of the ice sheet here may in part have been inherited from the former conditions. If so, also the bend of the ice divide is partly inherited.

At the beginning of a new glacial cycle a mountain glaciation developed mainly on the Atlantic slope. The resistance of the ice-masses to outflow must here have determined the position of the ice divide a little to the W. of the water divide. An increase in glaciation under the same conditions of accumulation must theoretically cause a migration of the ice divide to the W. as the ice front advances over the lower coast land (now greatly inundated by the sea) and the shelf. As, however, the conditions of accumulation from a W. to an E. predominance probably changed by transition, we must suppose also a migration of the ice divide from the W. slope to the E. one.

3. Meteorological Conditions.

a. Present Conditions of Importance for the Question. As a consequence of the mountain range and of the prevailing western winds there is in Scandinavia, as in Patagonia, a clear contrast between a maritime western side and a continental eastern side, although not so conspicuous as in Patagonia. An expression of that contrast is given by a chart demonstrating the yearly amplitudes of temperature, published by H. E. HAMBERG in 1907 (Pl. 15, cf for Norway MOHN 1921 Pl. 14 and for Sweden WALLÉN 1930, fig. 13 and ÅNGSTRÖM 1942). Whilst the amplitude on the eastern side of the Scandes generally is high (exceeding 28° C in central Lapland, 25° in the upper part of Dalarne, and 26° in SE Norway), diminishing in front of the greater depressions of the Scandes (at Torneträsk to 22° and in W. Jemtland to 19°), it is at the Norwegian coast only about 10° C. The axis of continentality lies near to the mountain range, which reveals the importance of Föhn winds (JOHANSSON 1913, cf 1914, p. 248).

Another expression for the contrast in question is the distribution of precipitation, which strongly favours the Atlantic side. Most interesting are the works of WALLÉN 1923, treating part of the mountain range, and AHLMANN 1925, treating the peninsula (cf for Norway JOHNSSON 1937).

As a consequence of the climatic contrast mentioned between eastern and western Scandinavia the glaciation limit shows a pronounced inclination towards the N. Atlantic, called the Scandic by DE GEER 1910. That inclination was treated above and in a special paper of mine (1944).

Scandinavian weather is ruled by the passing Atlantic cyclones. Certain tracks are preferred, most of which have the waters to the South of Greenland as a starting point. One (v. BEBBER No. I) passes off the Atlantic coast touching Scandinavia in its northernmost part. Another (No. IV) does not hit Norway but passes England, the North Sea, Denmark, the southernmost part of Sweden, and the Gulf of Finland.

The storms following the northern track are those which benefit Scandinavia with the warm and moist SW. winds but bring cold NE. winds to Greenland. The storms of the southern track bring precipitation from the SE. over south-eastern Scandinavia and Finland, and at their back side cold polar winds from NE. and N., placing the main part of Scandinavia in the situation of Greenland just mentioned. The first ones are often generated or reinforced in the Scandic part of the Gulf Stream, the second ones in its middle part (W. of Ireland, S. of Iceland), although the air masses brought in vary in origin. A changed frequency between the two cyclonic tracks must exercise a great influence upon the mean conditions of a year in Scandinavia (SANDSTRÖM 1917, p. 242, cf for U. S. A. WARD and BROOKS 1936, p. 126). According to SANDSTRÖM 1944 the cold winters 1939—42 were due to a raised temperature of the Gulf Stream in its middle part and diminished temperature in its Scandic part. Probably polar conditions also play a rôle.

The precipitation at different winds was treated for S. Norway by BJERKNES and SOLBERG (1920), for the southern part of Sweden by ÖSTMAN (1927) and for Finland by KORHONEN (1943). Unfortunately no research exists on the rain and snow-bringing winds along the Swedish side of the mountain range. The experience of the inhabitants in the north is that all snow-falls of any importance occur during easterly winds. An illustration of the precipitation during storms of the southern track is afforded by charts of NYBERG (1945, p. 107), VAN MIEGHEM (1936, p. 99), and ÅNGSTRÖM (1926, p. 106, 107). According to KORHONEN (1943) the rain shadow of the Scandes includes also Finland, the snow being brought by south-easterly winds.

b. Mountain Glaciations and Atlantic Ice Sheets. A parallel sinking of the recent glaciation limit would result in mountain glaciation of a westerly orientation. It is, therefore, only natural that any new glacial cycle originated as such a mountain glaciation. The conditions required are just the present ones save a lower temperature.

The consequence of the first mountain glaciation must have been a sharpened contrast between the maritime western and the continental eastern sides of the Scandes and of Scandinavia. The investigations carried out in Norway by AHLMANN have demonstrated the enormous importance of a glaciated surface for the condensation of water vapor. In AHLMANN's map of precipitation the areas of the plateau glaciers excel all others. Consequently, an ice cap mainly covering, let us say, the upper half of the western slope and the uppermost part of the eastern one (contemporaneously augmenting the height of the range filling out its passes) must be of supreme importance. In such conditions the mountain range would have left uncondensated a much smaller part of the water vapor of the passing western air masses than they nowadays retain. The *Föhn* action on the eastern side must be greater, which was of twofold importane. Not only was the supply of warm air greater. The insolation, too, was highly favoured by the augmented clearness of the sky, and that was the most important consequence. As the amplitude increased, the sinking of the mean temperature had but small consequence for the summer temperature of the eastern foreland. On the western slope not only the opportunities for insolation were reduced by the increased maritimity, but also the area able to utilize the insolation for heating.

In view of the circumstances treated, there are all reasons to assume that the inclination of the glaciation limit (snow limit) towards the Atlantic increased, the more the mountain glaciation developed. As a consequence the ice divide developed on the western slope and had — at least for a time — to move to the west.

Also at that very advanced stage of mountain glaciation, when almost the whole section of the mountain range was covered by an ice sheet — the Atlantic ice sheet stage — the ice divide had a westerly position, probably still to the west of the water divide, as the Svartisen plateau could be overridden at that time (see Chapter III B 4).

c. Atlantic and Continental Glaciations. Considering the great lowering of the glaciation limit (snow limit) during the stages of mountain glaciation — as demonstrated by the low eastern cirques (Chapter III B 2 c and III C b) — it seems very questionable whether the ice would ever have forced the eastern foreland, if the prevailing wind had not shifted.

The theory explaining the continental ice sheet as a leeside formation by drifting snow has been treated in Chapter II B b.

To explain the eastern foreland glaciation it seems necessary to assume a change in the regimen of winds. At least the easterly winds must have been common, and so the strong climatic contrast between the eastern and western sides of the Scandes levelled before an ice cap on the eastern foreland could come into existence.

In fact, there are under the present conditions two tendencies which, provided a weakening of the Gulf Stream in the Scandic, would develop to great force and act together in shaping the prevailing easterly winds over Scandinavia. The one is the recently mentioned cyclones of the southern track (IV). The other is the Arctic anticyclone which — as WUNDT has pointed out (1944) — would show an increased force and a greater sphere of action. Both would bring cold air. The first would mainly bring the precipitation (from the SE). The position of the ice nucleus stands in good relation to the feeding of the ice from that side. The second would help to check the tendencies of the storms to take the northern track. I will further develop this idea, §§ **d** and **e.**

d. The Gulf Stream and the Arctic Anticyclone. The Antarctic forms an ideal pole. In the immediate surroundings of the astronomic pole we find the ice centre, and the cold centre, and the centre of the great polar anticyclone which brings easterly winds.

The Arctic is built otherwise. A central sea is surrounded by continents, united by submarine thresholds. If these thresholds were effective throughout, the Arctic sea would probably be covered by ice so completely that its nature of water would loose its climatical importance. The Arctic would form a more solid cold district and generate a polar anticyclone of great power. As a starting point for a glacial age these conditions must have been very favorable.

One of the inlets to the Arctic sea is, however, deep enough to permit of an important communication with tropical waters. The superficial part of that communication is the Gulf Stream, which holds a great part of the Arctic sea ice free, splitting up the Arctic into scattered land and sea ices and impeding the formation of a firm polar anticyclone.

e. The Gulf Stream and the Cyclonal SE. Winds. The Antarctic is surrounded by a zone of low barometric pressure. The polar side of this trough is characterized by the same easterly winds as is the high pressure area of the polar calotte. These easterly winds are explained by MEINARDUS (1938) as the back side of the depressions moving eastwards. They are considered by him to glide up over the anticyclonal air masses and bring the main moisture for the feeding of the polar ice.

In the northern hemisphere no circumpolar sea exists. But the track of depression is a reality. The depression touching the European Continent generates in the Atlantic part of the Gulf Stream. That part (track IV) which is of special interest for Scandinavia was already mentioned as depressions moving over the Baltic and bringing precipitation from the SE. and cold winds from the NE. and N. For the creation and feeding of a continental ice sheet in Scandinavia they would be important, as at more advanced stages also the lows of track V b.

At present the cyclones traversing the Scandic or generated there (track I) move towards the Arctic bringing S and SW winds over Scandinavia, but if this fabrique of cyclones could be eliminated and the northern track closed, the southern storm track (IV) would have predominant influence upon the evolution in Scandinavia — in concurrence with the polar anticyclone.

f. The Elimination of the Gulf Stream in the Scandic and in the Arctic. The liberation of the forces apt to give prevailing easterly winds in Scandinavia requires, as we have seen, the elimination of that part of the Gulf Stream which now enters the Scandic and continues its course into the Arctic Sea.

An effective way of checking the Gulf Stream in the Scandic and Arctic must be the closing of its inlet into the Scandic. The critical pass is between the Hebrides and the Faroes, were the depth is less than 600 metres (fig. 36). Several authors have pointed out the importance of this inlet for questions pertaining to the Ice Age, from ENQUIST 1914 to WUNDT 1944. Of especial interest was a paper by AHLMANN and HELLAND-HANSEN 1918. In fact, there are geomorphological features which could not be explained unless a considerable part of the shelf around the Scandic had been laid bare, as submarine channels and fjords, submarine glacial cirques and the submarine part of the Strandflat. The submarine cirques in particular, claim a connection with a glacial age, as the lowest ones now visible, as stated above, require a glacial limit 800 to 900 metres lower than now (referring to the heights of the peaks).

If epeirogenetic or tectonic upheavals of coast and thresholds were the cause of glacial development in Scandinavia, then it must seem difficult to explain the coincidence of these events with the common causes of glaciation. Now, it is possible to assume that the higher position of the land masses was normal for Tertiary and Quaternary Ages, and that therefore the lacking amount of upheaval, necessary to close the inlet of the Gulf Stream, could be substituted by an eustatic change of level. We need, however, the elimination of the Gulf Stream before the continental ice sheet had come into existence. Only in the event of the other great ice sheets of the world having developed earlier can we count with a sufficiant rate of vertical movement. As we know but little about the order in which the ice sheets were built up, we can only speak of a possibility.

In this paper it has been established that the glaciations of the last glacial age were initiated by a mountain glaciation of westerly orientation which was so heavy that the glaciation limit was lowered some hundred metres below the present sea level and the shelf probably was invaded by an Atlantic ice sheet before the continental ice sheet was formed. This result seems to open a new way to explain the elimination of the Gulf Stream in the Scandic.

When the ice sheet of the Scandes had extended so far to the west upon the shelf that it calved in the open sea, the Gulf Stream passing immediately along the shelf edge must have been charged with icebergs.

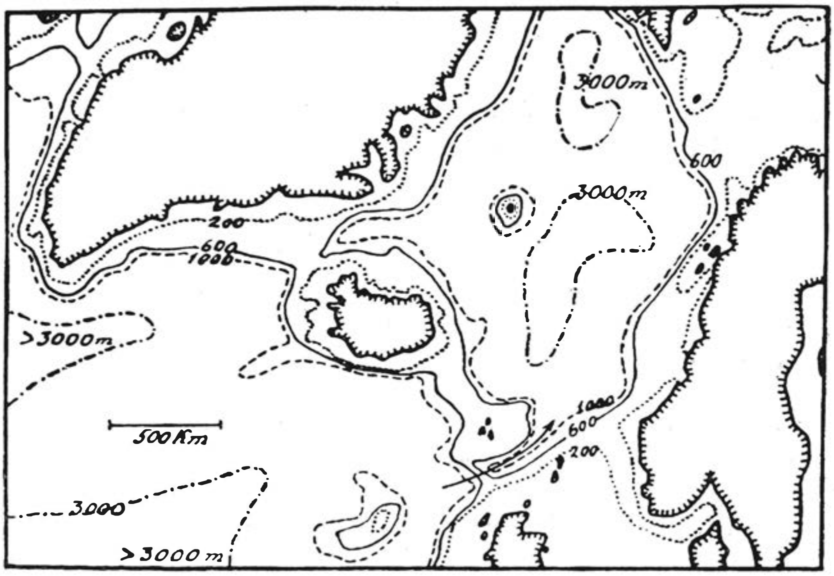


Fig. 36. Depths of the Scandic, from WUNDT 1944.

Then must have occurred here what now occurs in the Arctic: the Gulf Stream is cooled and forced to sink. According to O. PETTERSSON and SANDSTRÖM this cooling is the propelling force of the Gulf Stream (latest treated by SANDSTRÖM in 1944). On the northwestern slope of the Scottish Highlands there must also have existed an ice, and as the Gulf Stream here passes immediately in front of the coast, it probably received icebergs here too, which finally may have been sufficient to check its further way into the Scandic, or essentially weaken its force. For the western branch of the Gulf Stream the production of icebergs on Iceland must have been of importance.

With this hypothesis there is also a possibility to explain the almost sudden shift of the prevailing winds at a certain stage of development.

The growing ice fields around the coast of the Scandic may have increased the thermic contrasts and deepened the trough of low pressure and so intensified the action of cyclones moving up the Scandic towards the Arctic. This storm track was probably also more frequented. Snow precipitation increased. An increased supply of icebergs from the normal sources brought about no change in these conditions, as they pass along the Greenland coast. They have only made the trough narrower.

When the Norwegian and the Scottish coasts, however, begin to produce icebergs along their broad fronts, then the very artery of the Gulf Stream is attacked, and as the Gulf Stream has no possibility to escape these dangerous coasts, it will soon cease.

The shortening of the distance between the cold and warm poles of

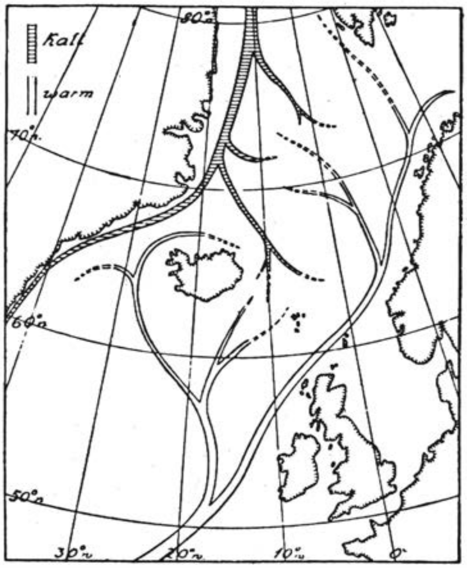


Fig. 37. Sea-currents of the Scandic according to MEINARDUS, from WUNDT 1944.

the Gulf Stream must have increased its energy, and this was in favour of the southern storm tracks.

g. The Continental Ice Sheet. When the predominance of easterly winds was established as a consequence of the subduing of the Scandic part of the Gulf Stream, the possibilities existed for the great ice sheet of the Baltic and its environs. It developed successively from the mountain ice sheet that generated Piedmont glaciers. During this epoch the glaciation of the northern coast of Scandinavia diminished as a consequence of reduced precipitation, and there a local glaciation developed of supreme importance for the present morphology.

We may expect a greater activity and erosion effect in the S. caused by the speedy renewal of the ice dome in its southern half which was due to the greater nourishment there. A fact suggesting a greater erosion in southern than in northern Sweden during the continental glaciation is the unequal distribution of the interglacial (or interstadial) deposits. Almost all known occurrences are found in the northern part of the country in spite of the circumstance that cuttings in the mantle rock are more common in the southern part.

A continued "hällanalys" will elucidate this question.

h. The Glacial Anticyclone of the North European ice sheet must have been of some importance for the climate of the surroundings. On the continent it may be impossible to distinguish between this anticyclone and the Polar one. But on the northern side of the great ice sheet, in the northernmost part of Norway, which, according to my interpretations above, was not reached by the last ice sheet, there is observed a loess cover

(NORDHAGEN 1941), and that must be connected with the periglacial climate of the last glaciation and its glacial anticyclone.

The loess is — if confirmed — an evidence of the dry and insolation-favouring sinking air masses from the high pressure area of the ice sheet. As the insolation had small effect upon the reflecting ice surface itself but an immense effect upon the immediately surrounding ground (if supramarine), ablation must have been concentrated to the ice front. The surface gradient found at the wastage period in the mountains — which corresponded to the surface ablation caused mainly by convection — was probably much surpassed at the time of the glacial anticyclone.

As, however, the glacial anticyclone could not build up the ice body, it would hardly have been able to take over the tasks of the building forces in the continued life of the ice. Furthermore, its independence was limited by the great Arctic anticyclone.

i. The Stages of Wastage have so many students that I may be brief. I will lay stress upon the conditions so distinct from those prevalent at the time of advance. Now there existed a great ice centre with a clear tendency to high pressure and reflecting nearly all radiating energy. The snow line was much depressed, and in the mountains probably inclined to the east since the time of changing of the prevailing winds. As the importance of the glacial anticyclone was reduced, the ablation by convection increased in importance and the inclination of the ice surface diminished. In spite of the low snow line, therefore, parts of the ice sheet could be dead. But the importance of dead ices has perhaps been exaggerated. An evidence of the life of the ice at a relatively late stage seems to me to be the migration of the ice divide almost right up to the water divide at the Arctic Circle. That migration can hardly have been due only to an asymmetric ablation. The ice had a nutritive area, and the migration of the ice divide to the west may have been a consequence of the beginning influence of westerly winds.

There is an important and interesting question concerning the last ice divide inside the Arctic Circle. On his map pl. 1, ENQUIST (1918) gathered a rich material of glacial striae, his own and the observations of others, from the mountains. The map gives the impression of a heavy mountain glaciation. In contraposition to an older view, which considered this sculpture to be brought about during a late local glaciation, ENQUIST (1918 pp. 110 ff) assumes it to have been carried out by the last dead masses left in the mountains at the time of the great ice-dammed lakes (p. 122), and denies the existence of a late glacial mountain glaciation (p. 78). Both interpretations are based on the common conception that the minute glacial sculpture, such as stoss sides and striae, dates only from the later epochs of the last glaciation.

In view of recent experiences from the mountains the present writer would like to say: If the actual glacial minute forms (including "einen ungeheueren, von Westen abgeschliffenen Rundfelsen", ENQUIST pp. 118, 119) were brought about by the last ice masses of the mountains, these were probably nourished. If, on the other hand, the ice masses were dead, and the ice divide located to the east of the ice-dammed lakes, the mountains would have formed *nunataks* as recently described by MANNERFELT, and not centres of outflow.

Keeping to the old material, we can eliminate the contradiction if we assume that the influence of the westerly winds had forced the ice ridge to migrate right up among the highest mountains, leaving a great ice mass upon the foreland uncontrolled. Indeed, for the last weak scratches from the north on the lower foreland on the Skellefte River (fig. 11 B), I could give no other explanation than a growing influence from a foreland ice mass, the more the pressure from the westward-migrating ice divide diminished (§ III B I c). I can add that on a rock specimen of quarzite, handed me by Dr GÖSTA LUNDQVIST from the mountain Kebnats situated at a distance of 25 km *to the NW.* of the ice dam of the ice-dammed lake Lule (J. FRÖDIN 1914), I observed not only 1. the traces (crescentic gouges) of an old mountain glaciation (from NNW. or NW.) and 2. the (younger) polish of the continental ice sheet (from S. 35° E.), but also the striae from westerly directions *younger* than the last named ones, namely 3. a few undistinct striae from N. 55° W. (not sure) and 4. a slight polish from S. 55° W. (i. e. from Sarektjåkko). Three of these observations, 2., 3., and 4., were afterwards confirmed by Dr LUNDQVIST in his field diary from the same region.[1] Furthermore, in Torne Träsk, on the small Islands in front of Abisko (visited in 1938), part of the striae from SW. seemed to me to be younger than the striae from the foreland, cf. LUNDQVIST (1943 fig. 1) and ENQUIST (1918 p. 122).

Thus it will seem that ENQUIST's view needs but little correction. Part of the sculpture of his map may date from a late part of the inland ice which had its ice divide in the mountains and finally wasted down without being succeeded by local glaciation. The damming of the lakes was effectuated by the ice remnants left upon the foreland. I will here remind of G. FRÖDIN's studies in N. Jemtland. FRÖDIN considers the ice divide on the foreland to have existed partly contemporaneously with the young ice divide in the mountains (1914 a, 1925 p. 209). In Lapland, outside the Arctic Circle, no corresponding conditions are known. Inside the Arctic Circle, as in part of Jemtland and Dalarne, too, there must thus, from this point of view, in a late stage have existed two ice divides, one of which with the aid of

[1] In a recent publication (1947, distributed in 1948) LUNDQVIST refers to this decision. — A young movement corresponding to 3 was also found by HAMBERG still more to the NW. (Stora Sjöfallet, see A. HAMBERG 1909, p. 416, and 1910, pl. 2; cf. GAVELIN 1909 a, 1909 b, p. 10 footnote and p. 85). GAVELIN had formerly found that a late ice nucleus at Sulitelma was younger than that of the Sarek group (GAVELIN 1906). But he does not mention corresponding striae.

a great precipitation rapidly adjusted itself to new climatic conditions, and another due to conditions long past.

k. A North-South Balance. An ice divide must, as far as it is dependent on a mountain range, be marked by a ridge fairly parallel to that range. The position of the ice divide in Scandinavia, as in Patagonia, is an expression of the east-west balance of the ice cap. We have, however, seen also a migration of the culmination of the ice divide back and forth between the N. and the S., which requires an explanation.

In the migration of the culmination I have mainly seen the influence of temperature. As the atmosphere's capacity of water transport increases with increasing temperature, precipitation is generally greater at low latitudes (other conditions being alike). As, however, the precipitation must fall in a solid form to be able to feed a glacier, the most favorable conditions will be found in a zone where the air temperature at the time of the most important snow falls of the year is slightly below 0° C at the level where condensation occurs. Consequently, the heaviest glaciation should be expected not in the central parts of the polar calotte but nearer its margin; Greenland seems to be an example. N. Greenland has a small precipitation and only a moderate glaciation.

The last glaciation was characterized by a pronounced southerly development of glaciation already in mountain stages, as far as can be deduced from the studies on the Arctic Circle. The position of the culmination at the maximum extension of the ice sheet was a very southerly one, but from here the culmination migrated towards the N. at least 5 degrees of latitude, ending within the Arctic Circle. That corresponds to a very plausible change of temperature during that glacial cycle.

l. The Prime Glaciation compared with the Posterior One. During the prime glaciation the culmination remained within the Arctic Circle in the Atlantic ice sheet stages as well as the continental ones. That probably indicates that the lowering of the temperature during that glaciation did not reach the same rate as during the posterior one. Such a circumstance must, however, also have had an indirect effect. A smaller glaciation around the southern and south-western parts of the Scandic was not able to annihilate the Gulf Stream at so southerly a point of its path as could the heavy glaciation of the Atlantic stage of the posterior glaciation, when perhaps even the Scottish glaciation may have been sufficient to bring about an essential weakening and sometimes subduing, causing it to sink owing to the cooling effect of icebergs. The northern storm track then retained some importance in relation to the southern one, the consolidation of the Arctic calotte was only half, and therefore the continental phase of that cycle was less pronounced.

A great precipitation on the northern coast of Scandinavia was secured, as the effect of thermic contrast remained and the temperature was not very low as compared with the continental stage of the posterior foreland glaciation. It is possible that the top level of the Atlantic ice sheet was not much reduced when the eastern foreland was invaded. In such a case the direction of flow parallel to the eastern border observed on the Arctic Circle is well compatible with a very high level of the top surface of the continental part of the ice sheet, too, and therefore the Baltic stream may have been of great power (cf. LJUNGNER 1946 pp. 85, 86).

m. "The Great Ice Age". If the prime glaciation was characterized by a but moderate lowering of temperature and consequently a but little pronounced continental stage as compared with the posterior glaciation as "normal", we find, on the other hand, in the glaciation of the last but one glacial age — the Saale-Riss glaciation, in Sweden called the "great" one — — an example of an exceptional continental development. At the time of the maximum extension of the corresponding continental ice sheet the temperature along the north Scandinavian coasts must have then been exceedingly low and the precipitation consequently small.

From this point of view it is clear that what in northern Norway is called "the great ice age" cannot have been synchronous with the maximum extension of the great ice sheet upon the continent. Even that continental ice sheet must have been preceded or initiated by an Atlantic ice sheet of the same glaciation. But that Atlantic ice sheet must in later stages have been of the type of the Atlantic ice sheet of the posterior glaciation, i. e. with a very southerly centre of gravity. All these Atlantic ice sheets — that of the Saale-Riss glacial age and those of the last glacial age — must have had an influence upon the geology and geomorphology of northern Norway. As the first one, however, is very remote and in thickness and extension was probably surpassed by the prime Atlantic ice sheet of the last glacial age, and also the posterior one reached a considerable development, it seems likely that the now recognizable traces of an ice sheet (more recent than those of the last continental ice sheet) in those tracts belong to the Atlantic ice sheets of the last glacial age. — On the other hand, a good deal of the work of local glaciation may have been carried out in Northern Norway during the time of the great continental ice sheet of the "great ice age" (cf. AHLMANN 1919, p. 226).

IV. Patagonia and Scandinavia. Concluding Remarks.

The Scandes as vell as the southern Andes were in Quaternary time repeatedly the site of considerable ice caps with an ice divide on the western slope. During these glaciations there were formed lakes on the eastern margin and fjords on the western one.

It is possible that a great mountain glaciation has existed several times in Scandinavia without further development. Sometimes it happened, however — in the last glacial age twice — that the ice cap invaded the eastern foreland, and that a great ice nucleus grew up, the centre of an ice sheet of great extension. As the ice caps with a westerly centre of gravity in the Scandes, as in the Andes, must be in relation to the maritime climate now reigning on the western slope as a consequence of the prevailing westerlies, I have interpreted the great ice caps on the Scandinavian foreland as a consequence of prevailing easterly winds. Now why did the latter development not take place in Patagonia?

The prevailing easterly winds in Scandinavia were assumed to be the consequence mainly of a consolidation of the Arctic calotte, which normally is split up by the Gulf Stream, and its enlargement on adjacent continents. The circumpolar South Sea forbids such an enlargement of the Antarctic ice sheet. Furthermore, Patagonia lies at lower latitudes than Scandinavia.

Following the Andes from Patagonia almost to their northern end in northern North America, we will, however, again see a district dominated by the westerlies. That district reaches partly to the latitudes of Scandinavia, and is like Scandinavia connected with a great continental area to the east. At latitude 57°—60° N. we find in the Coast Range and the St. Elias Range a considerable mountain glaciation of a westerly orientation (CAPPS 1931, KERR 1933, 1934). Although it partly corresponds to the glaciations of the Scandes in the last ice age, it is modestly designated by KERR "alpine glaciation". KERR could trace old stages of heavier glaciations during the Quaternary Age, which he (1936) designated "intense alpine stages" and he supposed also "mountain ice sheet stages". I have already referred to these studies by KERR, as I found it convenient to use the terms coined by him. In those stages a drift from the Coast Range was spread to the east. At other times the same range was overridden from the east by the great inland ice of the Cordilleras. Such stages were called "continental ice sheet stages".

The east-west balance here developed seems to correspond well to that of the Scandes.

Literature.

B. G. I. = Bulletin of the Geological Institution of Upsala.
G. F. F. = Geologiska Föreningens i Stockholm Förhandlingar. Stockholm.
G. Ann. = Geografiska Annaler. Stockholm.
K. V. A. = Kungl. Svenska Vetenskapsakademien. Stockholm.
N. G. U. = Norges geologiske undersökelse. Oslo.
N. Geol. T. = Norsk geologisk tidskrift. Oslo.
N. Geogr. T. = Norsk geografisk tidskrift. Oslo.
S. G. U. = Sveriges geologiska undersökning. Stockholm.

AHLENIUS, KARL (1900): Beiträge zur Kenntnis der Seenkettenregion in Schwedisch-Lappland. B. G. I. Uppsala Vol. V.
AHLMANN, HANS W:SON (1919): Geomorphological Studies in Norway. G. Ann. I.
—— (1922): Glaciers in Jotunheim and their Physiography. G. Ann. 4.
—— (1924): Le niveau de glaciation comme fonction de l'accumulation d'humidité sous forme solide. G. Ann. 6.
—— (1925): Karta över den årliga nederbördens fördelning på den skandinaviska halvön. Medd. fr. Statens Meteorolog.-hydr. Anstalt Bd 3 nr 4. Stockholm. Résumé en français.
—— (1933: Scientific Results of the Swedish—Norwegian Arctic Expedition in the Summer 1931. V. Geomorphology. G. Ann. 15.
—— (1934): Present glaciation round the Norwegian Sea. G. Ann. 15.
—— (1935): Contribution to the physics of glaciers. The Geogr. Journal 86 pp. 97—113.
—— (1938): Über das Entstehen von Toteis. G. F. F. 60.
—— (1940): The Styggedal glacier in Jotunheim, Norway. G. Ann. 22.
—— (1943): Norge. Stockholm.
—— (1944 a): Nutidens Antarktis och istidens Skandinavien. G. F. F 66.
(1944 b): Sakkunnigutlåtande (Expert report) rörande tillsättande av professuren i geografi vid Upsala Universitet.
—— The glaciological works carried out under the leadership of H. W:SON AHLMANN up to 1943 are reviewed by C. TROLL, with complete list, se under TROLL
AHLMANN, H. W:SON, and HELLAND-HANSEN, B. (1918): Sambandet mellan kontinentala nivåförändringar, Norskhavets oceanografi och de pleistocena inlandsisarne omkring detta hav. G. F. F. 40.
AHLMANN, HANS W:SON, and LAURELL, ERIK (1938): Repräsentative Beispiele für die Tätigkeit der Glazialerosion in Schweden und Norwegen. Comptes rendus du Congr. int. de Géographie T. II. Amsterdam.
AHLMANN, HANS W:SON, LAURELL, ERIK, and MANNERFELT, CARL (1942): Det norrländska landskapet, särskilt dess topografiska och kvartärgeologiska utveckling. Ymer. Stockholm.
AHLMANN, HANS W:SON, und TRYSELIUS, O. (1929): Der Kårso-Gletscher in Schwedisch-Lappland. G. Ann. 11.
AIGNER, A. (1930): Das Karproblem und seine Bedeutung für die ostalpine Geomorphologie. Zeitschr. f. Geomorphologie V.
—— (1938): Geomorpholog. Beobachtungen aus dem Gebiete zwischen Salt- und Ranfjord im nördlichen Norwegen. Zeitschr. f. Geomorphologie 10.
ALT, E. (1932): Klimakunde von Mittel- und Südeuropa, in KÖPPEN-GEIGER, Handb. d. Klimatologie 3 M.
ANDERSEN, S. A. (1933): Det danske Landskabs Historie. København.
—— (1946): Det danske Lands Historie. Folkuniversitetet No. 457. København.
ÅNGSTRÖM, A. (1926): Praktisk meteorologi. Stockholm.
—— (1933): On the dependence of ablation on air temperature, radiation and wind. G. Ann. 15.
—— (1942): Norrlands klimat. Ymer.
ANTEVS, ERNST (1925): Quaternary Climates. On the pleistocene history of the great Basin. The Carnegie Inst. of Wash. Publ. Nr 352.
ASKLUND, BROR (1936): Frösöns submoräna avlagringar. S.G.U. Ser. C nr 402.
AUER, VÄINÖ (1941): Der Torf und die Torfschichten als historische Urkunden Feuerlands und Patagoniens. Geol. Rundschau 32.

AUER, VÄINÖ: The pleistocene and Post-Glacial Period in Fuegopatagonia. Without year. Received Nov. 1946.
BERGERON, T. (1943): Väderlek och klimat. In: AHLMANN, "Norge". Stockholm.
BERGSTEN, FOLKE (1936): Influence of the Gulf Stream on the Winter Temperature of Europe. G. Ann. 18.
BIRKELAND, B. J., and FØYN, N. J. (1932): Klima von NW-Europa, in KÖPPEN and GEIGER, Handbuch der Klimatologie 3 L. Berlin.
BJERKNES J., and SOLBERG, H. (1921): Meteorological conditions for the formation of rain. Geofys. publikationer II nr 3. Oslo.
BLACKWELDER, (1933): Pleistocene Glaciation in the Sierra Nevada and the Basin Ranges. Bull. Geol. Soc. Am. 42.
BLÜTHGEN, J. (1942): Tatsachen und Deutungen zur Geschichte des Skandik. Geologie d. Meere und Binnengewässer V. Berlin.
—— (1942): Die diluviale Vereisung des Barentsseeschelfes. Die Naturwissenschaften Bd 30.
BRAUN, G. (1929): Das Nordende des Kjölen. Forschungen und Fortschritte 4, p. 17.
—— (1930): Das Südende des Kjöl. Die Naturwissenschaften 18 p. 693.
—— (1935): Studien am Kjöl. G. Ann. 17.
BRØGGER, W. C. (1900): Om de senglaciale og postglaciale nivåforandringer i Kristianiafeltet. N. G. U. Nr 31.
BRYAN, K., and CADY, R. C. (1934): The pleistocene Climate of Bermuda. Am. J. Sc. 227.
BRÜGGEN, J. (1919): Zur Glazialgeologie der chilenischen Anden. Geol. Rundschau 20.
—— (1934): Grundzüge der Geologie und Lagerstättenkunde Chiles. Tübingen.
CADY, see BRYAN.
CAILLEUX, ANDRÉ (1942): Les actions éoliennes périglaciaires en Europe (Thèse). Paris. Mém. N. 46 de la Soc. géol. de France Nouv. Sér. T. XXI.
CALDENIUS, CARL C:ZON (1931): Från en treårig forskningsresa i Patagonien. Ymer. Stockholm.
—— (1932): Las glaciaciones cuaternarias en la Patagonia y Tierra del Fuego. G. Ann. 14.
CAPPS, St. R. (1931): Glaciation in Alaska. Geol. Surv. (Washington) Prof. Paper 170-A.
CARLZON-CALDENIUS (1909): Några iakttagelser angående isdelaren i Jämtland. G. F. F. Bd 31.
CHARLESWORTH, J. K. (1931): A tentative reconstruction of the successive margins of the Quaternary ice-sheets in the region of the North Sea. Proc. Roy. Irish Acad. vol. 60 sect. B.
COLLINI, BENGT (1943): Soil samples from the Nahuel Huapí region of northern Patagonia. (= Report 9 of the Ljungner Exp.) B. G. I. Bd XXX.
CONNOR, A. J. (1938): The climates of North Amerika: Canada, in Handbuch der Klimatologie 2 J.
COOPER, W. S. (1937): The problem of Glacier Bay, Alaska. Geogr. Review 27.
DE GEER, G. (1888): Om isdelarens läge under Skandinaviens bägge nedisningar. G. F. F. Bd 10.
DE MARTONNE, E. (1926): Traité de géographie Physique. 4me éd. II. Paris.
DUROCHER, J. (1846): Études sur les Phénomènes erratiques de la Scandinavie. Bull. Soc. Géol. de France, 2me sér. IV. Paris.
ENQUIST, FREDRIK (1910): Über die jetzigen und ehemaligen lokalen Gletscher in den Gebirgen von Jämtland und Härjedalen. S. G. U. Ser. Ca nr 5:V.

ENQUIST, FREDRIK (1914): Eine Theorie für die Ursache der Eiszeit und die geographischen Konsequenzen derselben. B. G. I. 13.
—— (1916): Der Einfluss des Windes auf die Verteilung der Gletscher. Diss. B. G. I. Vol. XIV.
—— (1918): Die Glaziale Entwickelungsgeschichte Nordwest-Skandinaviens. S. G. U. Ser. C. Nr 285.
—— Trädgränsundersökningar. Zusammenfassung: Baumgrenzuntersuchungen. Svenska Skogsvårdsföreningens tidskrift. Stockholm.
ERIKSSON, KJELL (1914): Landisens avsmältning i sydvästra Jämtland. S. G. U. Ser. C. Nr 251.
FLINT, R. F., and DORSEY, H. G. (1945): Glaciation of Siberia. Bull. geol. Soc. Am. 56 (received May 1946).
FOSLIE, S. (1941): Tysfjords geologi (English Summary). N. G. U. nr 149. Oslo.
FREBOLD, H. (1935): Geologie von Spitzbergen, der Bäreninsel, des König Karl- und Franz-Joseph-Landes. (Geologie der Erde.) Berlin.
FRÖDIN, G. (1913): Bidrag till västra Jämtlands senglaciala geologi. S. G. U. Ser. C. Nr 246.
—— (1914 a): Isavsmältningen inom nordvästra Jämtland. G. F. F. Bd 36.
—— (1914 b): Några glacialgeologiska frågor inom våra sydliga fjälltrakter. G. F. F. Bd 36.
—— (1914 c): Glacialgeologiska studier i nordvästra Jämtland. S. G. U. Ser. C. Nr 253.
—— (1915 a): Om den förmodade forna glaciären på Hammarfjället i Härjedalen. G. F. F. Bd 37.
—— (1915 b): Några bidrag till det avsmältande istäckets ytlutning. G. F. F. Bd 37.
—— (1916): Ett par nyare svenska mammutfynd. G. F. F. Bd 38.
—— (1925): Studien über die Eisscheide in Zentralskandinavien. B. G. I. Vol. XIX.
FRÖDIN, J. (1914): Geografiska studier i St. Luleälvs källområde. S. G. U. Ser. C. Nr 257.
—— (1916): Skogsgränserna i norra delen av Lule lappmark. Lunds Universitets Årsskrift N. F. Avd. 2. Bd. 13. Nr. 2.
GAVELIN, AXEL (1906): Några iakttagelser rörande istidens sista skede i trakten NW om Kvikkjokk. G. F. F. Bd 28.
—— (1909 a): Yttrande efter Hambergs föredrag. G. F. F. Bd 31.
—— (1909 b): Om trädgränsens nedgång i de svenska fjälltrakterna. Skogsvårdsföreningens tidskr. Bd 7.
—— (1910 a): Trädgränsförskjutningarna inom Kamajokks vattenområde. S. G. U. Ser. C. Nr 227.
—— (1910 b): De isdämda sjöarna i Lappland och nordligaste Jämtland. S. G. U. Ser. Ca. Nr 7.
—— (1910 c): Uber die Gletscher des Norra Storfjället und des Ammarfjället. S. G. U. Ser. Ca. Nr 5 :IV.
—— (1943): Yttrande efter Ljungners föredrag. G. F. F. Bd 65.
GEIJER, P. (1922): Block av sevebergarter vid Kiruna. G. F. F. Bd 44.
GRAHMANN, R. (1937): Form und Entwässerung des nordeuropäischen Inlandeises. Mitt. Ges. f. Erdkunde. Leipzig 1934—36.
GRANLUND, E., och LUNDQUIST, G. (1936): Några iakttagelser från en resa i Helgeland sommaren 1935. N. Geogr. T.
GRØNLIE, OLE T. (1908): Om de marine avleiringer i Dunderlandsdalen. Tromsö Museums Aarshefter 29 (1906). Tromsö.

GRØNLIE, OLE T. (1910): Kvartaergeologiske iagttakelser i Salten. Ibidem 31—32 (1908—1909). Tromsö.
—— (1911): Kvartaergeologiske iagttakelser i Korgen i Ranen. Ibidem 33 (1910).
—— (1927): The Folden Fiord. Tromsö Museums skrifter Vol. I. Part II.
—— (1931): Breer i Balsfjorden. N. Geol. T. 12.
—— (1940): On the traces of the ice Ages in Nordland, Troms and the South-Western Part of Finmark in northern Norway. N. Geol. T. Bd 20.
HAMBERG, AXEL (1896): Om Kvikkjokkfjällens glaciärer. G. F. F. Bd XVIII.
—— (1901): Geologiska och fysiskt-geografiska undersökningar i Sarekfjällen. Diss. Stockholm.
—— (1909): Inlandsisens afsmältning i fjälltrakten mellan Stora och Lilla Lule Älf. G. F. F. Bd XXXI.
—— (1910): Die Geomorphologie und Quartärgeologie des Sarekgebirges. G. F. F. Bd 32.
—— (1915): Lufttemperatur och skogsgränser i Sarektrakten. G. F. F. Bd 37.
—— (1922): Sarekfjällen. Svenska Turistföreningens resehandböcker XXVII. Stockholm.
—— (1926): Bau von Hütten im Sarekgebirge. Naturwiss. Untersuchungen des Sarekgebirges, geleitet von A. HAMBERG. Bd I. Abt. I. Lief. 1.
HAMBERG, H. E. (1907): Moyennes et extrèmes de la température de l'air en Suède 1856—1907. Appendice aux Observations Météorologiques Suédoises Vol. 49.
HEBER, G. (1941): Morener, terasser og strandlinjer ved bunnen av Altafjorden. Oslo.
HELLAAKOSKI, A. R. (1940—43): Uber die Bewegungsrichtungen des Inlandeises an der Küste von Pohjanmaa in der Umgebung von Tampere. Fennia 67 (1943).
HESSELBERG, TH. (1922): The meteorology of the British Antarctic Expedition 1910—13. G. Ann. 4.
HESSLAND, IVAR (1943): Marine Schalenablagerungen Nord-Bohusläns. Diss. B. G. I. Vol. XXXI.
HOBBS, W. H. (1926): The glacial Anticyclones: The poles of the Atmospheric Circulation, University of Michigan Studies, Sc. ser. vol. IV. New York.
HOEL, ADOLF (1910): Okstinderne. N. G. U. Nr 57, II.
HÖGBOM, A. (1923): Glacialgeologiska iakttagelser från Ångermanälvens käll-område. S. G. U. Ser. C. Nr 328.
—— (1937): Skelleftefältet. S. G. U. Ser. C. Nr 389.
—— (1939): Nutida malmletning. N. Geol. T. 18.
HÖGBOM, A. G. (1885): Glaciala och petrografiska iakttagelser i Jämtlands län. S. G. U. Ser. C. Nr 70.
—— (1885): Iakttagelser rörande Jämtlands glaciala geologi. Diss. Identic with preceding work.
—— (1893): Om interglaciala aflagringar i Jämtland. G. F. F. Bd 15.
—— (1894): Geologisk beskrifning öfver Jämtlands län. S. G. U. Ser. C. Nr 140. 1st edition. (1920) Id. 2nd edition. Ibid.
—— (1897): Några anmärkningar om de isdämda sjöarna i Jämtland. G. F. F. Bd 19. S. G. U. Ser. C. Nr 169.
—— (1906): Norrland. Naturbeskrivning.
—— (1910): Studies in the post-Silurian thrust region of Jämtland. G. F. F. Bd. 31.
—— (1910): Quartärgeologische Studien im mittleren Norrland. G. F. F. Bd. 31.
—— (1913): Fennoskandia. Handbuch der Regionalen Geologie. IV:3. Heidelberg.
HOLMSEN, G. (1916): Snegrensen i Norge. Festskrift til prof. A. Helland. Kristiania.
—— (1924): How the surface deposits of Norway were formed (Summary). N. G. U. Nr 123.

HOLMSEN, G. (1931): Rana, beskrivelse til det geologiske generalkart. N. G. U. Nr 136.
—— (1935): Nordre Femund. Description of the geological map. N.G.U. Nr 144.
—— (1937): Søndre Femund. Description of the geological map. N. G. U. Nr 148.
HOLTEDAHL, O. (1924): Studier over israndterassene syd for de store östlandske sjøer. With an english summary. Vidensk. Selsk. Skrifter Kristiania.
—— (1925): Om isens avsmeltning paa Ovre Romerike. Naturen. Bergen.
—— (1928): Om landisens bortsmeltning fra Strøket ved Trondheimsfjorden. N. Geogr. T. Bd 2.
—— (1929): On the geology and physiography of some antarctic and subantarctic Islands. Scient. results of the Norwegian Antarctic Expeditions 1927—28 and 28—29. Nr 3. Oslo.
—— (1929): Some remarkable features of the sub-marine relief on the north coast of the Varanger Peninsula, Northern Norway. Avhandlinger Norske Videnskaps-Akademi i Oslo. I. Mat.-Nat. Klasse 1929 no. 12.
—— (1934): Geology of parts of southern Norway 8. Quaternary geology. Proceed. Geologists Ass. Vol. 45. Part 3.
HÖRBYE, J. C. (1857): Observations sur les phénomènes d'erosion en Norvège. Christiania.
HYYPPÄ, E. (1933): Das Klima der Wälder der spätglazialen Zeit im Bereich der Karelischen Landenge. Acta Forestalia Fennica 39.
—— (1936): Uber die Spätquartäre Entwicklung Nordfinnlands mit Ergänzungen zur Kenntnis des spätglazialen Klimas. Bull. Commission géologique de Finlande no. 115.
JOHANSSON, OSCAR V. (1913); Uber die Entstehung und Wirkungen absteigender Luftströme. Acta Soc. Sc. Fenn. 44 no. 1.
—— (1914, 1915): Om vindförhållandena i Fennoskandia. Terra 1914, 1915. Helsingfors.
JOHNSSON, O. H. (1937): The Distribution of precipitation in Norway. G. Ann. 19.
KALDEN, KJELL, and STRØM, K. M. (1939): Bathography of Fyresvatn. N. Geogr. T.
KAUTSKY, F. (1940): Das Feuster von Gautojaure im Kirchspiel Arjeplog. G. F. F. 62.
KEINDL, J. (1936): Geomorpholog. Untersuchungen in Nord-Norwegen. Mitt. Geogr. Ges. Wien Bd 79.
KERR, FORREST A. (1933): Ice fields of Western Canada. Canad. geogr. Journal.
—— (1934): Glaciation in Northern British Columbia. Trans. Royal Soc. Canada. 3rd Ser. 28. Sect. 4. Ottawa.
—— (1936): Quaternary glaciation in the Coast Range. Journ. Geol. Vol. 44.
KJAER, J. (1927): Tyrifjord. N. Geogr. T. Bd 1. (1926).
KLUTE, FRITZ (1928): Die Bedeutung der Depression der Schneegrenze für eiszeitliche Probleme. Zeitschr. f. Gletscherkunde Bd 16.
—— (1930): Verschiebung der Klimagebiete der letzten Eiszeit. Petermanns Mitt. Ergänzungsheft 209.
—— (1937): Eiszeit und Klima. Frankfurter geogr. Hefte 11, 56.
KÖPPEN und WEGENER (1924—40): Die Klimate der geolog. Vorzeit. Berlin.
KORHONEN, V. V. (1942): Die Verteilung der Niederschläge, besonders der Schneefälle, auf die verschiedenen Windrichtungen in Finnland. Ann. Ac. Sc. Fennicæ, Ser. A I Nr 13. Helsinki.
—— (1943): Om regnens, särskilt snöfallens, fördelning på olika vindriktningar i Finland. Terra 1943 p. 118., Helsingfors.
KULLING, O. (1945): Om fynd av Mammut vid Pilgrimstad i Jämtland. Summary: On the find of mammoth at Pilgrimstad in Jämtland. S. G. U. Ser. C. Nr 473.

LARSSON, WALTER (1940): Petrology of interglacial Volcanics from the Andes of northern Patagonia. Diss. (= Report No. 7 of the Ljungner Exp.) B. G. I. Bd XXVIII.

LIDÉN, R. (1913): Geokronologiska studier över det finiglaciala skedet i Ångermanland. S. G. U. Ser. Ca. Nr 9.

LJUNGNER, ERIK (1930): Spaltentektonik und Morphologie der schwedischen Skagerrak-Küste III: 1. B. G. I. Vol. XXI.

—— (1931): Geologische Aufnahmen in der patagonischen Kordillera. B. G. I. Vol. XXIII.

—— (1933): Rapport från Patagonienexpeditionen. G. F. F. Bd 55.

—— (1935 a): Rapport 2 från Patagonienexpeditionen. G. F. F. Bd 57.

—— (1935 b): Hällskulpturen och den kvartära Skagerrakskalkens tillkomst, reprinted in Erinringar etc., see 1944 b.

—— (1939): A forest section through the Andes of northern Patagonia. Svensk botanisk tidskrift. Vol. 33. Stockholm.

—— (1943 a): Isdelarstudier vid polcirkeln. Zusammenfassung: Eisscheidenstudien am nördlichen Polarkreis. G. F. F. Bd 65.

—— (1943 b): Deformationen der Grundgebirgsoberfläche unter dem kaledonischen Gebirgsrand in Lappland. Geol. Rundschau Bd 34.

—— (1944 a): Massupphöjningens inflytande på höjdgränser i Skanderna och Alperna. Zusammenfassung: Einfluss der Massenerhebung auf die Höhengrenzen in den Skanden und den Alpen. Geographica Nr 15. Uppsala.

—— (1944 b): Erinringar angående sakkunnigutlåtandena rörande tillsättandet av den lediga professuren i geografi vid Upsala Universitet.

—— (1945): Den sista nordiska nedisningens förlopp. Zusammenfassung: Verlauf der letzten nordischen Vereisung. G. F. F. 67.

—— (1946 a): Ein Ostskandinavisches Vergletscherungsintervall. G. F. F. 68.

—— (1946 b) Yttrande efter S. A. Andersens föredrag. G. F. F. Bd 68.

—— (1947): Isdelarstudier i övre Dalarne. G. F. F. Bd 69.

—— (1948 a): The shape of the surface of the crystalline besement along the margin of the Caledonian mountain range in Sweden. B. G. I. XXXII.

—— (1948 b): The Kjøl and the Scandes. Svensk Geografisk Årsbok, Lund.

—— (—): Nahuel Huapi. Ein geographischer Querschnitt durch die Anden im nördlichen Patagonien. Upsala Univ. Årsskrift (in preparation).

LOEWE, F. (1933): Die Bedeutung des Schneefegens für den Massenhaushalt von Inlandeisen. Meteorolog. Zeitschr. (Braunschweig) p. 434.

—— (1935): Klima des Grönländischen Inlandeises. Handb. d. Klimatologie v. KÖPPEN u. GEIGER. Bd II K. III.

LUNDQVIST, G. (1941): En lokal glaciation i övre Dalarne. G. F. F. Bd 63.

—— (1942): Jordarterna och deras fördelning inom Norrland och Dalarne. Ymer.

—— (1943): Norrlands jordarter. S. G. U. Ser. C No 457.

—— (1947): Ice Movements and Boulder Trains in the Murjek-Ultevis Districts. Appendix to S. G. U. Ser. C, No 487 (ÖDMAN).

LÜTGENS, R. (1933): Schwedische Forschungen in Patagonien. Petermanns Mitteil. 79 203. Gotha.

MACHATSCHEK, F. (1944): Diluviale Hebung und eiszeitliche Schneegrenzedepression. Geol. Rundschau 34.

MANNERFELT, CARL (1940): Glacialmorfologiska studier i norska högfjäll. N. Geogr. T. Bd VIII.

—— (1945): Några glacialmorfologiska formelement. G. Ann.

MARSTRANDER, ROLF (1911 a): Svartisen, dens geologi. N. G. U. Nr 59: IV.
—— (1911 b): Svartisen, Strøgets morfologi og Braeerne. Archiv for mathematik og naturvidenskab. Bd XXXI. Nr 8.
MEINARDUS, W. (1937): Allgemeine Zirkulation und Niederschlagsverteilung in der Eiszeit. Frankfurter geogr. Hefte 11, Z. f. Meteorologie 1937.
—— (1926): Die hydrographischen Kurven Grönlands und der Antarctis und die Normalform der Inlandeisoberfläche. Pet. Mitt. 72.
—— (1932): Bemerkungen zur Form der Inlandeisoberfläche Grönlands. Z. f. Gletscherkunde 20.
—— (1938): Klimakunde der Antarctis. KÖPPEN-GEIGER, Handb. d. Klimatologie 4 U.
—— (1944): Zum Kanon der Erdbestrahlung. Geolog. Rundschau 34, H. 7—8.
MIEGHEM, J. van (1936): Prévision du temps. Institut Belge de Recherches Radioscientifiques. VI. Paris.
MILANKOVITCH, M. (1930): Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen. Handb. d. Klimatologie, hrsg, von KÖPPEN und GEIGER. München.
—— (1938): Astronomische Mittel zur Erforschung der erdgeschichtlichen Klimate. Handb. d. Geophysik 9.
—— (1941): Kanon der Erdbestrahlung und seine Anwendung auf das eiszeitliche Problem. Serb. Akad. Math. Nat. Sekt. 33. Belgrad.
MILTHERS, K. (1942): Ledeblokke og Landskabsformer i Danmark. Danmarks geolog. Undersøgelse, 2. Række No 69.
MOHN, H. (1921): Atlas de climat de Norvège, nouvelle éd. par GRAARUD et IRGENS. Kristiania. Geofysiske Publikationer II: 7 udgit av den Geofysiske Kommission.
NANSEN, FRIDTJOF (1904): The Norwegian North Polar Expedition 1893—96, Scientific Results IV.
—— (1922): The Strandflat and isostasy. Videnskapsselskapets Skrifter. I. Mat.-naturvet. kl. 1921. Nr 11. X-ania.
NATHORST, A. G. (1914): De gåtfulla glacierrefflorna på Beeren Eiland. G. F. F. Bd 36.
NISKANEN, E. (1943): On the deformation of the earth's crust under the weight of a glacial ice-load. Annales Acad. Sc. Fennicae ser. A. III. Geologica-Geographica 7.
NYBERG, ALF (1945): Synoptic-aerological investigation of weather conditions in Europe 17—24 april 1939. Statens meteorologisk-hydrografiska anstalt. Communications, Series of Papers no. 48. Stockholm.
NORDENSKJÖLD, OTTO (1900): Topographische Studien in Fjordgebieten. B. G. I. Vol. IV.
NORDHAGEN, ROLF (1933): De senkvartaere klimavekslinger i Nordeuropa. Oslo.
—— (1941): Staurene ved Ofjordnaeringen på Sørøya. N. Geogr. T. 8.
OKKO, V. (1941), Über das Verhältnis der Gesteinszusammensetzung der Moräne zum Felsgrund. Geol. Rundschau XXXII.
ÖSTMAN, C. J. (1927): Studier över nederbördens fördelning vid olika vindar i Svea- och Götaland. Medd. Stat. Meteorolog.-hydrogr. Anstalt 4:3.
—— (1933): Vinden i Sveriges högre luftlager. Medd. Stat. Meteorolog.-hydrogr. Anstalt 6:3.
OXAAL, JOHN (1914): Traenlandet. Et stykke av Strandflaten. Det norske geograf. selskabs aarbok. Bd XV.

OXAAL, JOHN (1919): Dunderlandsdalen. N. G. U. nr 86.
PETTERSSON, KARL (1882): Inlandsisens udstrømming. Tromsø museums aarsh.
—— (1885): Inlandsisens udstrømming. Tromsø museums aarshefter.
QUENSEL, P. D. (1910): On the influence of the Ice Age on the continental Watershed of Patagonia. B. G. I. Vol. IX.
RABOT, CH. (1882): Un été au-dessus du cercle polaire. Annuaire du Club alpin Français, p. 261.
REKSTAD, J. (1910): Geologiske iagttakelser fra ytre del av Saltenfjord. N. G. U. Nr 57, III.
—— (1913 a): Opdaemning i Bjellaadalen ved istidens slutning. N. G. U. Nr 61, III.
—— (1913 b): Fjeldstrøket mellem Saltdalen og Dunderlandsdalen. N. G. U. Nr 67.
—— (1917): Fjeldstrøket Fauske-Junkerdalen. N. G. U. Nr 81, IV.
RICHTER, KONRAD (1937): Die Eiszeit in Norddeutschland. Berlin. (Deutscher Boden IV).
SANDSTRÖM, J. W. (1913): Meteorologiska forskningsresor i de svenska fjälltrakterna. Ymer. Stockholm.
—— (1916): Meteorologische Studien im schwedischen Hochgebirge. Göteborgs Kungl. Vet. o. Vitterhets Samhälles handlingar, 4:e följden XVII:2.
—— (1932): Vinden. Svenska skogsvårdsföreningens tidskrift. Bd 30.
—— (1936): Den svenska vintern. Svenska Turistföreningens Årsskrift. Stockholm.
—— (1941): Warm winters and cold winters in Scandinavia. K. V. A. Arkiv f. Mat., Astron. och Fysik 28 A nr 1.
—— (1944 a): The Gulf Stream and the weather. K. V. A. Arkiv f. Mat., Astron. och Fysik 30 A nr 18.
—— (1944 b): Snow Studies. K. V. A. Arkiv f. Mat., Astron. och Fysik 31 A nr 20.
SHEPARD, FRANCIS P. (1938): Origin of the Great Lakes Basins. Journ. of Geol. Vol. 45.
SIMPSON, C. G. (1919): British antarctic expedition 1910—1913, vol. 1—3. Calcutta.
—— (1934): World climate during the Quaternary period. Quart. Journ. of R. Met. Soc. Bd 60. Nr 257.
SJÖGREN, O. (1909): Geografiska och glacialgeologiska studier vid Torne Träsk. S. G. U. Ser. C. Nr 219.
SMITH, HARRY (1920): Vegetationen och dess utvecklingshistoria i det centralsvenska högfjällsområdet. Diss. Norrländskt handbibliotek IX.
SOERGEL, W. (1937): Die Vereisungskurve. Berlin.
—— (1942): Die eiszeitliche Temperaturminderung in Mitteleuropa. Jahresber. und Mitt. d. Oberrheinischen geolog. Verein. 31.
STEFFEN, HANS (1919): Westpatagonien. Berlin.
STRØM, se KALDEN.
SUESS, E. (1888): Das Antlitz der Erde. II.
SVERDRUP, H. U. (1935): The Ablation on Isachsen's plateau etc. G. Ann. 17.
TANNER, V. (1907): Zur geolog. Geschichte des Kilpisjärvi-Sees in Lappland. Bull. Comm. Géol. Finl. 20. (1915).
—— (1915): Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning etc. Bull. Comm. Finl. Nr 38.
—— (1930): Studier över kvartärsystemet i Fennoskandias nordliga delar IV. Om nivåförändringarne etc. Bull. Comm. Finl. Nr 88.
—— (1938): Die Oberflächengestaltung Finnlands. Helsingfors.
TENGWALL, T. Å. (1920): Die Vegetation des Sarekgebietes I. Naturwiss. Unters. d. Sarekgebirges in Schwedisch-Lappland, geleitet von Dr. AXEL HAMBERG. Bd III Lief. 4.

THORSLUND, PER (1939): Kvartärgeologiska iakttagelser inom östra Storsjöområdet i Jämtland. S. G. U. Ser. C. Nr 429.

TROLL, C. (1943): Fünfundzwanzig Jahre nordisch-arktischer Gletscherforschung unter Leitung von H. W:SON AHLMANN. Geol. Rundschau 34.

TÖRNEBOHM, A. E. (1872): Några iakttagelser med afseende på flyttblocken i Jämtland. G. F. F. Bd 1.

UNDÅS, ISAK (1938): Kvartaerstudier i Vestfinnmark og Vesterålen. N. Geol. T. 18.

—— (1942): On the marin limit of the Ra-period. N. Geogr. T.

—— (1943): On the late-Quaternary history of Møre and Trøndelag. Kgl. Norske Videnskapsselskap (Trondheim) Skrifter 1942 nr 2.

VOGT, J. H. L. (1900): Søndre Helgeland. N. G. U. Nr 29.

—— (1913): Om to endemoraenetrin i det nordlige Norge etc. N. Geol. T. Bd 2.

WAGNER, ARTUR (1940): Klimaänderungen und Klimaschwankungen. Die Wissenschaft. Bd 92.

WALLÉN, AXEL (1923): L'eau tombée dans la haute montagne de la Suède. G. Ann.

—— (1930): Climate of Sweden. Statens meteor.-hydr. Anstalts Skrifter. Nr 279. Stockholm.

WARD, R. DE C., and BROOKS, C. F. (1936): The climates of North America. KÖPPEN-GEIGER, Handb. d. Klimatologie II J.

WEGENER, K., und HOLZAPFEL, R. (1933): Das Schneefegen. Wiss. Ergebn. der D. Grönlandsexpedition ALFRED WEGENER Bd I p. 172. Leipzig.

WEGENER, K. (1933): Richtigstellung (Contest to LOEWE). Meteorolog. Zeitschrift (Braunschweig) p. 436.

WENNBERG, G. (1943): Eisströme über Schonen während der letzten Eiszeit. Lunds Univ. Årsskrift N. F. Avd. 2, Bd 39, Nr 3.

WOLDSTEDT, PAUL (1929): Das Eiszeitalter. Stuttgart.

WUNDT, W. (1938): Das Reflexionsvermögen der Erde zur Eiszeit. Met. Z.

—— (1942): Luftdruckgürtel, Niederschläge und Vereisungszentren in Quartär. Met. Z.

—— (1944): Die Mitwirkung der Erdbahnelemente bei der Entstehung der Eiszeiten. Geolog. Rundschau 34, Heft 7/8.

Explanation of Plates.

Plate I.

Orographic map on a Scandine zone along the Arctic Circle (A. C.). Scale 1 : 1,000,000. The dash line from WNW. to ESE. is the line of reference of the profile fig. 4. *Symbols:*

1. Areas exceeding 1500 m above sea-level.
2. » » 1000 » » » »
3. Mountains of less height.
4. Glacier.
5. Church (A = Arjepluog, M = Mo).

Objects near to the line of reference and their heights in metres above sea-level:

1. The Svartisen plateau, western part, with Snetind 1599 m.
2. » » » eastern » » Istind 1577 m.
2. Skjelåtind 1640 m
3. Ørtefjell 1442 m
4. Bolna 1506 m
5. Nasafjell 1218 m
6. Kargasatåive 1219 m
7. Ferras 1609 m
8. Svaipa 1426 m
9. Tjäksa 1085 m
10. Kaissetjåkko 1064 m in Krappesvare.
11. Peljekaisse 1133 m
12. Nebsuort 914 (912) m
13. Galtispuoda 800 m
14. Lake Hornavan 425 m
15. » Storlaisan 424 m
16. Uddjaur 419 m
17. Rana fjord.
18. Holand's fjord.
19. Glom fjord.

Objects at some distance from the line of reference:

a. Lukttiderne 1344 m
b. Oxtindere 1912 m
c. Ørfjell 1764 m
d. Solvågtind 1561 m
e. Satertind in Sjurfjell 1624 m
f. Båtfjell 1514 m
g. Straitestjåkko 1610 m
h. Tausa 1710 m
i. Argaladeitjåkko 1626 m
j. N. Saulo 1775 m
k. N. Storfjellet 1764 m
l. Ammarfjell 1609 m
m. Dermatjåkko about 1540 m
n. Tjidtjak 1579 m
o. Kustarakaisse 1694 m
p. Staika 1799 m
q. Tarrekaisse 1850 m
r. Kaissatj 919 m
s. Kåbrek in Tjamort, about 1060 m
t. Prinskullen 742 m
u. Snjärak 877 m
v. Kassavara 990 m
w. Kaissetjåkko 1063 m
x. Lake Kujjaur (Godejaur) 686 m
y. » Tarraure 504 m
z. Saggat 303 m

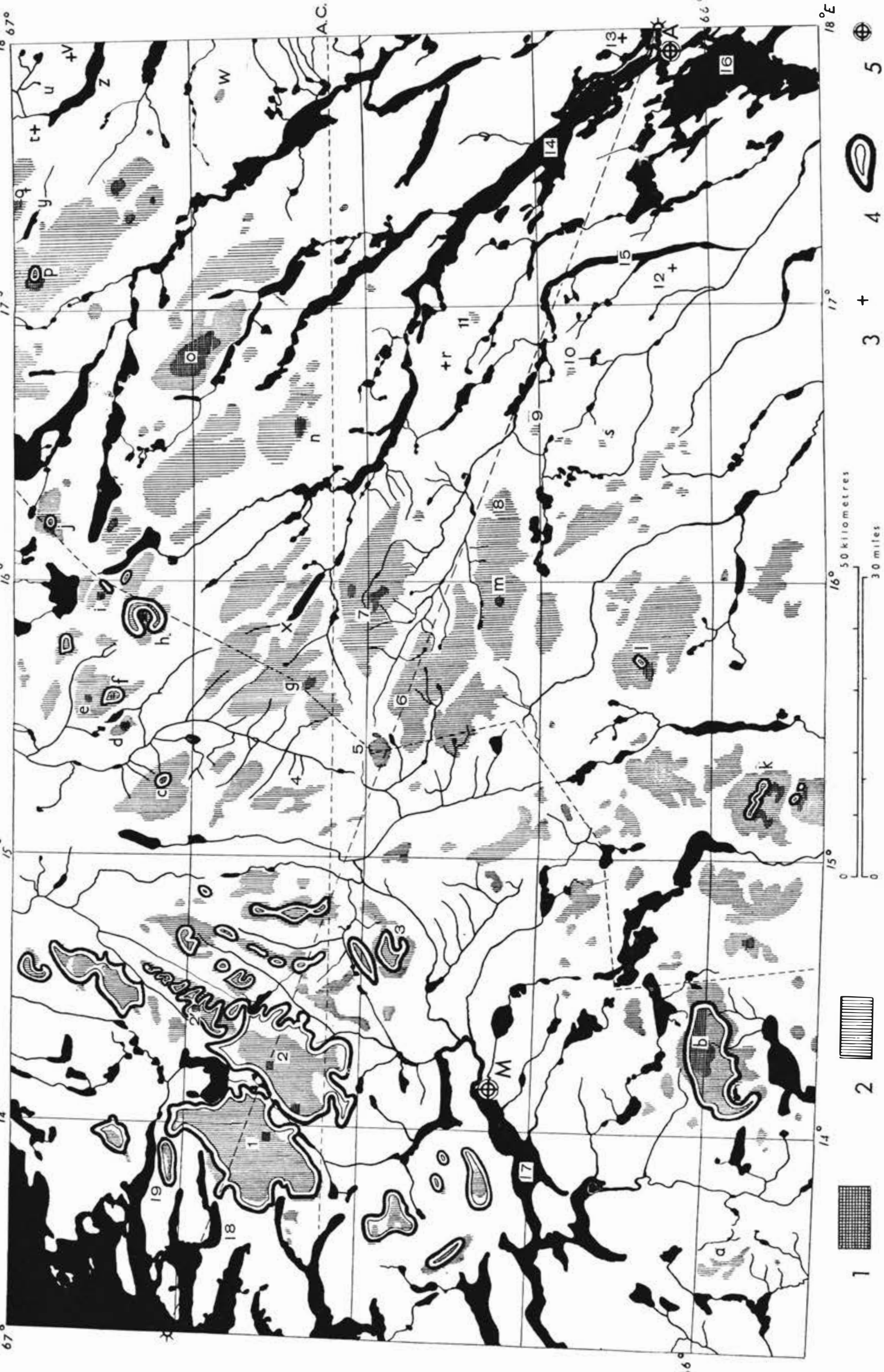
Plate II.

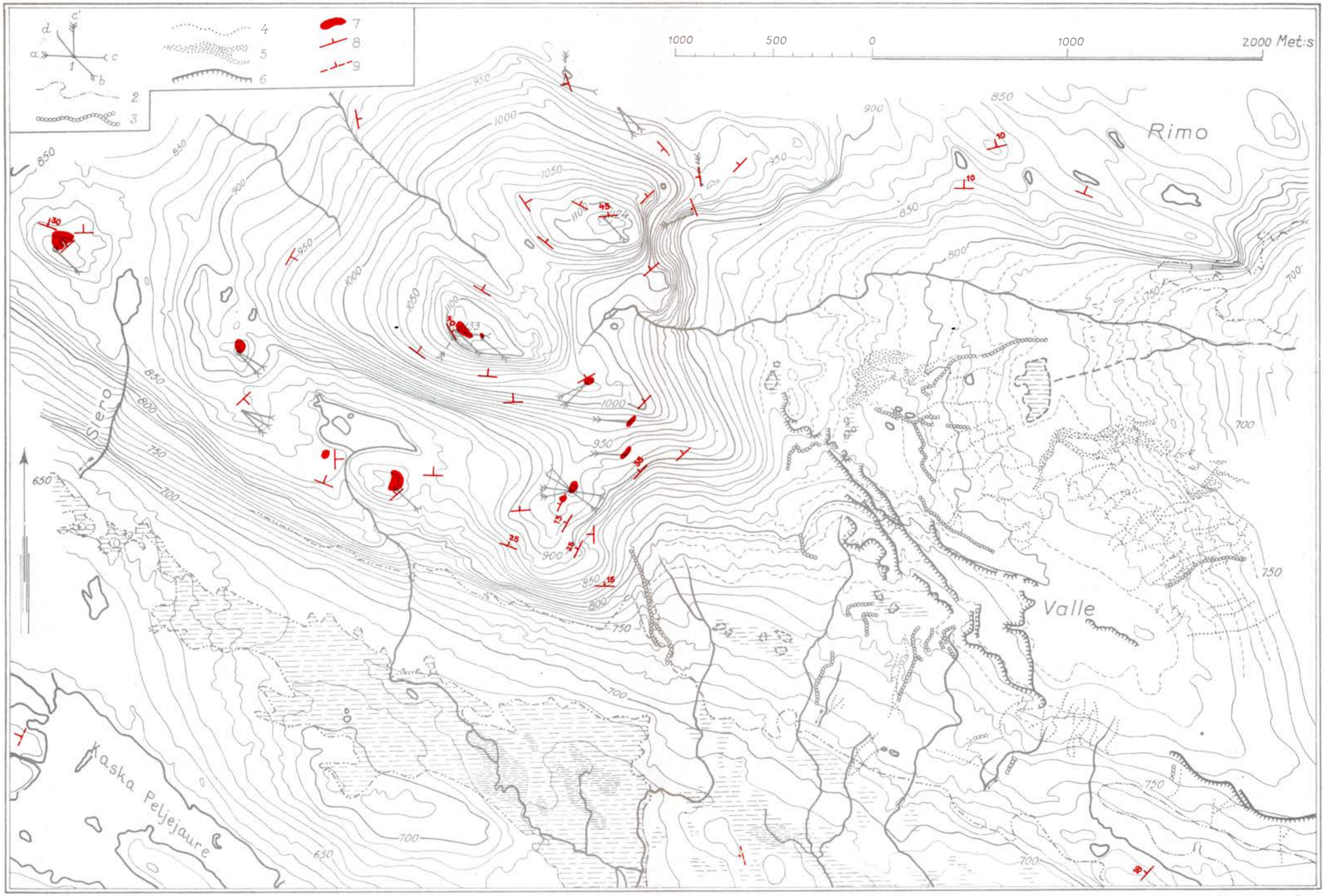
Map of Peljekaisse (pl. I: 11) based on the author's investigations in 1942—45 and airphotos from 1939, drawn by Nils Marklund by the aid of a stereometer. Scale 1 : 25 000.

1. Directions of glacial striae. The age of the northern ones are here undecided (may be *cd* or *c'*).
2. Forest limit. There are two bleak areas: the upper one, which is climatic, and a low one caused be fens.
3. Subglacially engorged esker.
4. and 5. Subglacial chute.
6. Lateral terrace, sometimes accompanied by a lateral drainage channel.
7. Doleritic sill in the *Seve* schists.
8. Strike and dip observations in the "Yraf komplex" (see KAUTSKY), which corresponds the *Seve* schists forming the *Seve* thrust nappe.
9. The same in the "Kaskajaure komplex" (see KAUTSKY), a lower thrust unity.

Corrigendum.

On fig. 10 (p. 30) in the second left hand quadrangle the numbering is given **b**, should be **b'**.


67°
66°
14°
15°
16°
17°
18°E
A.C.
M
A
50 kilometres
30 miles
1
2
3
4
5


1000
500
0
1000
2000 Met:s
Rimo
Valle
Siero
Kaska Peljejaure
850
900
950
1000
1050
1100
800
750
700
650