CONTRIBUTIONS TO THE GLACIOLOGY OF NORTH EAST GREENLAND 1948–49 IN TYROLERDAL AND ON CLAVERING Ø

BY

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WITH 15 FIGURES IN THE TEXT

CONTENTS

Introduction.

The following account concerns two summer expeditions to N. E. Greenland, a Leeds University Expedition, in 1948, the first from this University, and a second expedition in 1949. The 1948 Expedition consisted of four members, W. R. B. Battle, leader, geographer and glaciologist; D. S. Brock (Cambridge), geographer and surveyor; J. W. Haines, geographer and glaciologist; G. P. Leedal, geologist. It had a two fold purpose. Firstly, to make a study of an ice cap glacier and corrie glaciers which had been recently separated from the ice sheet. It was hoped, using the technique initiated by Carol (1947), to reach the glacier bed by rope ladder in order to examine directly the mechanism of glacial erosion. Secondly, a geological survey of the area to the north and north west of Clavering Ø was planned. The Dansk Pearyland Ekspedition very kindly arranged transport to their southern base at Zackenberg, 74° N. on the mainland near Clavering Ø.

A base camp was made at the junction of Mellemdal and Tyrolerdal. The parties then divided; Haines and Battle established a high camp on the margin of the Pasterze glacier at the mouth of Ulændedal, Leedal and Brock started their geological reconnaissance in Svejstrups Dal and northwards.

A small Cambridge Expedition to East Greenland was planned for the summer of 1949, it was to consist of four men with the writer in charge of the glaciological work. However, owing to lack of space on the Godthaab, the Dansk Pearyland Ekspedition could at the last minute only take one, but could offer the assistance of some of their party from time to time. As the writer had to work alone for a part of the time it was not feasible to revisit the Pasterze glacier. Instead it was planned to concentrate on the corrie and subglacial work on Clavering Ø, and particularly on the Frejagletscher where Ahlmann (1939) had worked, and on the Skillegletscher visited by Flint and Washburn (1949) on the Louise Boyd Expedition in 1937. As an addition to the 1948 programme a series of flow measurements were planned, some on a micro-scale near thrust planes, to study the possible influence of these planes on glacier movement.

The author is most grateful for the help obtained from the Danes in both 1948 and 1949; firstly to the Grønlandsdepartementet which gave permission to work there and on whose ships the expedition travelled, and secondly to the Dansk Pearyland Ekspedition which facilitated every movement. In fact without the help of the Danes, especially Eigil Knuth, Ebbe Munck and Poul Winther, the expedition would not have been possible and their kindness and hospitality will always be remembered. The indispensable help of the staff of the Scott Polar Research Institute, who were responsible for putting the expedition in touch with the Dansk Pearyland Ekspedition is freely acknowledged.

In 1948 financial support was given by the University of Leeds, the Royal Geographical Society, which also lent instruments and helped in many other ways, and by Trinty College, Cambridge. The leader was granted the "Watkin Award" of the Scott Polar Research Institute in 1948. The advice of Mr. G. Seligman and Mr. W. V. Lewis on glaciological matters, together with the helpful co-operation of Professor A. V. Williamson at all times were very much appreciated. In 1949 further support was given by the Royal Geographical Society. The help of both Mr. J. Buhl and Professor M. Westergaard in that year was most valuable. The writer is most grateful to all those who accompanied him for their tireless energy and good cheer, which made the work possible.

To avoid a rather tiresome chronological sequence incorporating results from two different localities during two seasons a sequence from corrie glacier—through surface features—to subglacial observations has been adopted in the following account.

Previous Work.

The first scientific expedition which devoted any time to the glaciology of the region around Clavering Ø and the Tyrolerfjord area was the 1870 Koldewey Expedition (1873—74). Payer as expedition surveyor and cartographer mapped the extent of the glaciers in Tyrolerdal.

The work of Poser (1930) was mainly confined to the geology and geomorphology of the area farther to the south and west.

The Louise Boyd Expedition 1937 was the first glaciological expedition to visit the area since Koldewey. Unfortunately the war delayed the publication of their results until after the 1949 visit. During this expedition Flint and Washburn studied the glacial geology of lower Tyrolerdal, and also the Skillegletscher and lower valley on Clavering Ø.

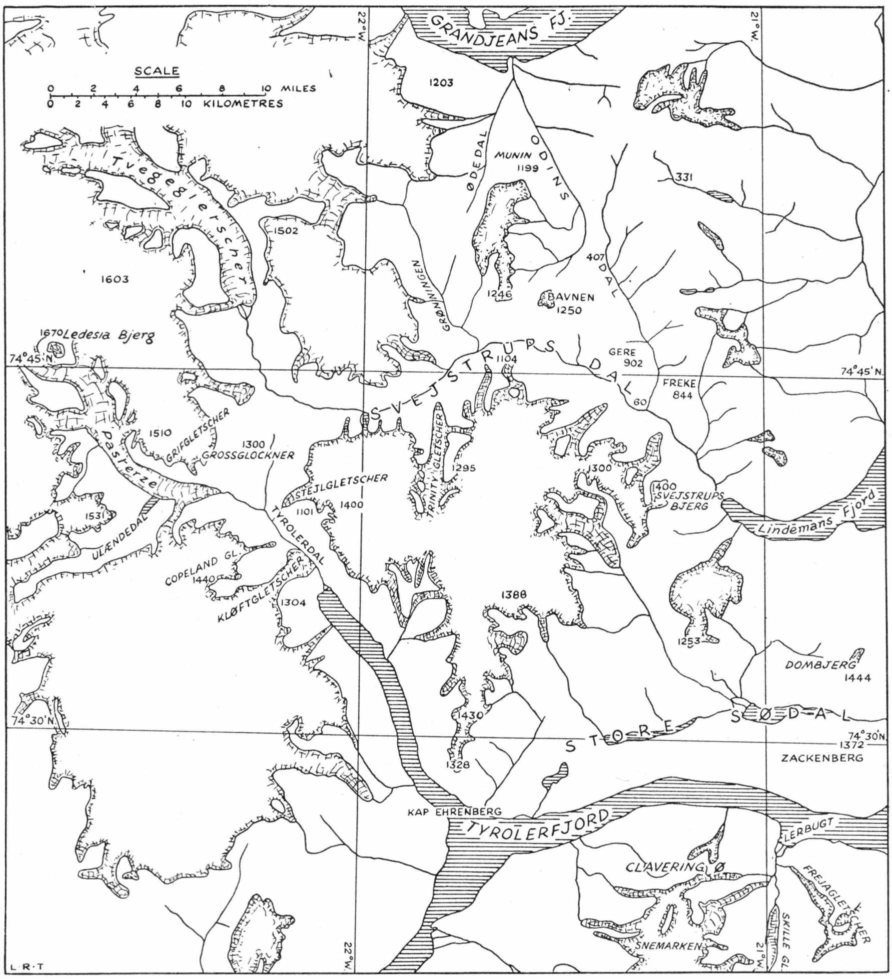


Fig. 1.

Mittelholzer (1941), during geological work with the 1938—39 Danish Expedition, had sledged down the Pasterze glacier and had noted the discrepancies between the extent of some of the tributaries and the existing map.

Ahlmann (1941) was the first glaciologist to initiate any detailed observations on one glacier in the area. In the summer of 1939 he worked on the Frejagletscher, Clavering Ø and during the winter his work was continued by Rosdahl. These investigations concerned the regime of the glacier.

Corrie Formation.

Corries are now universally recognised by geomorphologists as being due to glacial erosion, the only disputable point being the exact emphasis one is to place on the various agents at work, such as freeze-thaw action and plucking. The latter was at one time considered to be a major factor but views then changed until quite recently Douglas Johnson (1941) suggested it might play a subsidiary part in corrie formation. The freeze-thaw hypothesis, developing from observations made by Lorange and Helland (1904) and more especially from the classic descent of Willard Johnson (1904) into a bergschrund, served to direct the attention of geomorphologists to the corrie head wall. The resulting bergschrund theory has been criticised by Bowman (1916), Odell (1937) and others on the grounds that in many regions, e. g. N.E.Greenland, the Andes and the Antarctic, corrie glaciers are found without any bergschrund. But G. Taylor (1914) has suggested the palimpest theory which may resolve the problem. From evidence in the Antarctic he believes that many corries may have formed during the advancing hemi-cycle of glaciation. Therefore, the absence of bergschrunds noted by the above writers in some corrie glaciers does not necessarily mean that bergschrunds were absent when the corries were formed. W. V. Lewis (1938) from a study of many bergschrunds, concluded that melt water from the upper névé descends the "schrund" and enables nivation processes to proceed at depth. Lewis (1947) suggests that meltwater may penetrate to the rock floor, in some cases many hundreds of feet lower than the bergschrund. He considers that the hydrostatic pressure of the water combined with melting of the channel walls will help to keep these tunnels open far below the depth at which the plastic collapse of the ice tunnel occurs.

In Greenland it was hoped to ascertain by direct observations, whether such freeze-thaw action is an effective agent of erosion. The most convenient corrie, Grifgletscher, for this investigation was situated high up on the north east slope of the Tyrolerdal and from its position and general appearance suggested that it had separated from the inlandice sheet less than fifty years previously. It lies 190 m above the trunk glacier, the Pasterze. The parent rock in this area is a highly metamorphosed complex composed of gneisses and schists, the latter predominating in the corrie. On weathering these schists are more friable than the gneisses.

The bergschrund was partly blocked by hard névé and even jumping on the narrow crack failed to enlarge it. However, a small opening was noticed and, by means of ice ledges leading to a number of small chambers a depth of 15 m was reached along the line of the crack. The roof over-

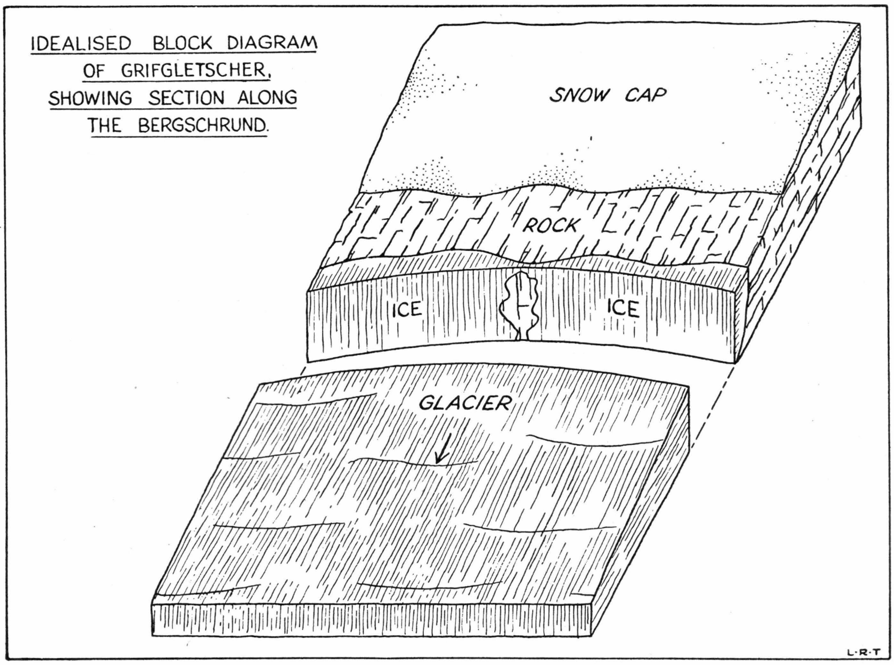


Fig. 2.

head let in no light and seemed to be formed of large blocks, some melt water was noticed running down the walls in streams. These were confined to the backwalls, which appeared to be formed of solid ice. The streams were small even on a warm August afternoon with an outside temperature of about 11° C. The final descent to the glacier bed was made at night, when melting was at a minimum.

The bottom of the bergschrund consisted of great blocks of crystalline snow fallen on top of one another, probably from the roof. It was difficult to pick a way over them. The final 15 m, descended by rope ladder, brought one between two seemingly solid walls of ice and it was at first feared that the rock wall would not be found. Walking over the blocks along the line of the bergschrund, with sides approximately 6 m apart one could see the roof 31 m above silhouetted in the glare of the miner's acetylene head lights. The rock wall was reached about 70 m further on. It projected as a rounded bulge from beneath a 5 cm casing of transparent ice. The huge blocks underfoot hid the base of the rock wall from view and it merged into the icecliffs above. The small portion of the wall visible was smooth, rounded, and nearly vertical and no sign of frost riving or even of meltwater was apparent.

A rough indication of the temperature difference between the inside and outside of the bergschrund (the thermometer having broken) could be detected by the effect on ones' clothes. On emerging from the bergschrund into the early morning air, the waterproofs and oilskins, which had been wet but causing no inconvenience to movement during the four hours inside, froze solid. The temperature outside was estimated from a knowledge of the temperature at the camp below and the height climbed 610 m, as -5° C. The difference between this and the temperature inside must have been about 5° C as there was some dripping from the icicles; making the inside temperature about 0° C.

L. H. McCabe (1939) in Spitsbergen, although he did not penetrate to the base, found that in many of the randclufts and bergschrunds he examined there was a sheet of ice apparently encasing the rock wall. This must be caused by melting and subsequent refreezing, and once iced over the sheet protects the rock from further erosion and more or less static conditions ensue. In the bergschrund in Grifgletscher this was certainly the case and a peculiar air of inactivity, of a suspension of all erosional forces, seemed to permeate the depths. Movement of any sort appeared quite inconceivable although, like McCabe, the glaciologists had expected that there would be some signs of it "Movement may be expected in summer rather than winter, yet no convincing evidence of any movement away from the backwall was found" (McCabe 1939 p. 464).

Of the corrie glaciers examined on Clavering Ø only one, the Misteltengletscher, had a bergschrund. Some of these were in and advanced state of decay: stagnant glaciers and glacierettes lying at the bottom of the 300 m or 450 m wall encircling them. The remainder wholly below the firn line in summer, flowed from headwall to snout by bergschrunds. Examples of the latter are the corries containing the Balmunggletscher and Hödgletscher, which were until recently both fed from the main Snemarken icefield. They are now cut off from this supply and it would appear that if present conditions continue they will steadily diminish in extent.

The Mistelten corrie is one of a succession of north facing corries overlooking the Skillegletscher, providing a first class example of a hanging valley. Geologically this central area, and especially the eastern sector, is closely connected to the Tyrolerfjord region and is an extension of the same metamorphic complex, gneisses and schists predominating. The walls of the corrie are approximately 366 m high and the glacier falls in a series of three fairly steep steps. The bergschrund lay a short distance above the firn line at 976 m. Entrance was facilitated by an open "schrund" 6—9 m wide and about 12 m deep. No headwall was visible, only a small ice cave under a projecting bulge of a snow bridge, in which some melting was taking place. Another corrie glacier, unnamed, 610 m above the snout of the Skillegletscher showed identical features but in a slightly more advanced stage of decay. Here again, although the ice tongue connecting the glacierette with the main snowfield looks as though it has but recently receded, the corrie walls are over 450 m high. In this case there was no definite bergschrund unless some tension crevasses and cracks found were a degenerate form of bergschrund. Correlating the observations on these two corrie glaciers and those on Grifgletscher the following points may be made:

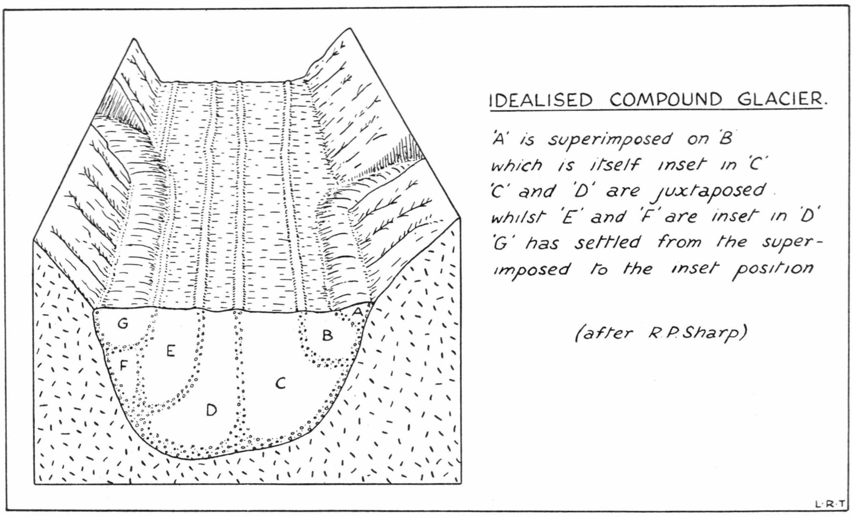
1. Although from a distance bergschrunds may not be visible, many close observations showed that in Arctic corrie glaciers they were present, at least when corries were full of ice. Thus, what on first sight, might have been taken for a small crack about 1 m deep on Grifgletscher proved to be a deep bergschrund.
2. There are many corries in N.E.Greenland with walls varying from 300 m to 600 m in height which now only contain glacierettes. These seldom have bergschrunds.
3. The cutting of corries 300 m deep requires a considerable period of time and judging from PAYER's map it is only seventy years since this whole area was ice covered. From the observations on Grifgletscher it seems that if a corrie is full of ice, erosion appears to be at a minimum. (BATTLE and LEWIS 1951).

One is therefore faced with the question, "when were these corries formed"? The evidence appears to favour different conditions from the present, in fact one must to some what warmer conditions for their formation. The 'advancing hemi-cycle' seems too vague a term for this, as it is now known there has been more than one climatic amelioration in the North Atlantic Coast region (AHLMANN 1947) since the end of Wurm III. However, until an assessment of the time required for head wall recession under generalised conditions has been made this term must suffice. Perhaps future research using pollen analysis methods will help to provide a first tentative dating for such corries. (MANNERFELT 1940). Our ultimate object as geomorphologists must be to provide a process and chronology for the various stages of corrie development.

Surface Features.

1. Ice Canyons.

Cryoconite holes and allied features were noted on the Pasterze glacier in 1948, but no further account of these will be attempted here. A recent comprehensive account of these features in N.America (the Yukon) has been published by SHARP (1947). An interesting feature



IDEALISED COMPOUND GLACIER.

'A' is superimposed on 'B' which is itself inset in 'C' 'C' and 'D' are juxtaposed whilst 'E' and 'F' are inset in 'D' 'G' has settled from the superimposed to the inset position

(after R.P. Sharp)

Fig. 3.

however, hitherto not noticed in Greenland were the ice canyons. These were first noticed on 'Nail Glacier', the lower western tributary to the main Pasterze glacier. The canyons were about 12 m to 15 m deep and were between 2 to 3 m wide at the bottom, they are not to be confused with the supra-glacial stream channels. Situated where the glaciers steepened, where in the Alps one would expect to find a maze of crevasses and a distorted jumble of seracs, these open canyons seemed weird and unreal. Sometimes the walls rose sheer for 12 m then gave way to domes of rounded ice, turrets and buttresses.

Their appearance suggested that the origin was at any rate partially due to intermittent erosion and melting by running water. As water absorbs more heat from the sun than does ice, it may be that the process of down melting is substituted for the normal attrition process common in stream erosion. That tension, as in serac falls, is a contributory factor is highly probable, because some of the canyons entered were associated with crevasses. It would seem that a combination of tensional forces and melt water action modified by ablation processes are the factors at work in the formation of these deeply incised canyons.

2. Glacier Junctions.

It is well known that tributary glaciers on entering a main trunk glacier frequently maintain their individuality and the junction between them is marked by two lateral moraines which unite to form a medial moraine. The junctions of temperate glaciers are usually considered to

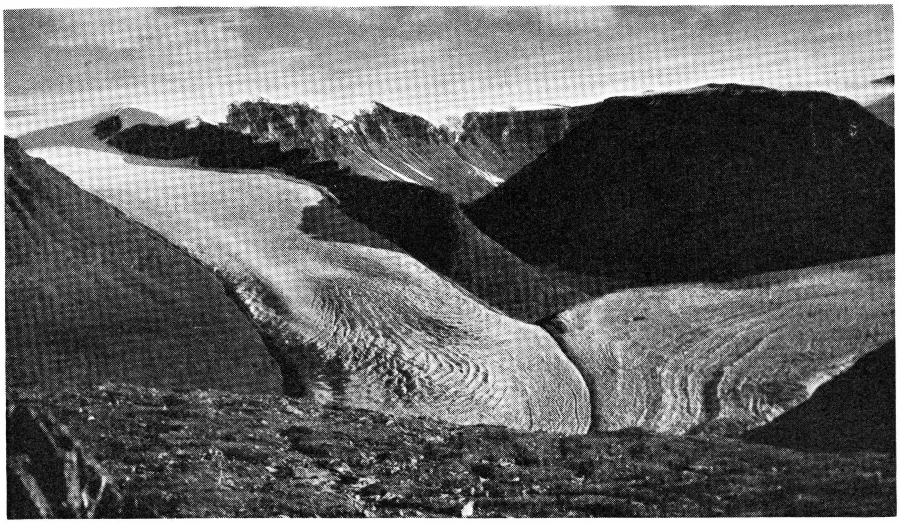


Fig. 4. The junction of the Pasterze and "Nail" glaciers from the Grossglockner. G. P. Leedal phot.

be juxtaposed but this does not apply to polar glaciers' nor to glaciers under high altitude conditions as in the Himalaya. These glaciers, influenced by a colder regime behave in a rather different manner overlapping at times so that surprising uncomformities of the surface may develop. SHARP (1948) basing his work on DEMOREST's theories of extrusion flow (1943), builds up an elaborate picture of three possible positions for a compound glacier, namely the juxtaposed, superimposed, and inset. ODELL (1937) suggested differential speeds and crystal structure as causes of discordancy, VISSER (1932) included volume, density and underlying relief as possible factors.

Some observations were made on two of the discordant junctions at hand, namely that between the Pasterze glacier and an upper western tributary, called 'Geologists Glacier' by the Leeds Expedition¹), and between the Pasterze and a lower tributary. It was noticed that the former junction was marked by a supra-glacial stream channel which had cut a bed 9 m deep; this flowed along the junction for 3.2 km before disappearing down a moulin. There was a discordance of 3 m between the trunk glacier, the Pasterze, and the tributary. The stream bed served to hide any deep unconformity and whether the glaciers merge beneath this could not be determined it is believed likely. Fig. 4 shows the discordant junction between the lowest western tributary on the right and the main trunk glacier, the Pasterze, on the left. The actual

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¹) The first man known to have sledged down the glacier was A. E. MITTELHOLZER, Swiss geologist with the 1938—39 Danish Expedition.

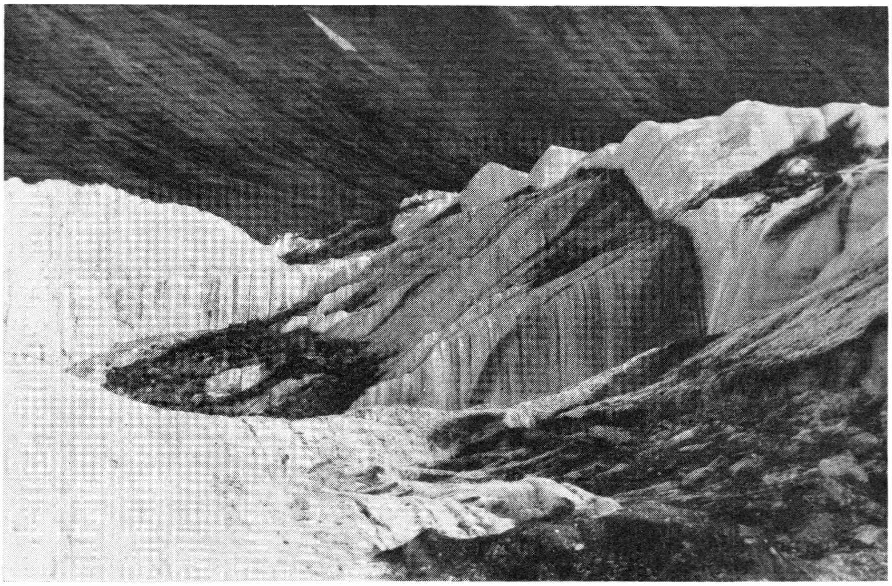

Fig. 5. Discordant junction of lower tributary and the Pasterze glacier showing junction at dirt band.

line of junction is marked by a nearly vertical dirt band which stretches downward for more than 15 m and distinguishes the Pasterze, with vertical banded strata, from the tributary which has a white non-banded appearance. In places there was a difference in level between the two glaciers of between land 2 m.

When a line of stones was placed across the two glaciers no differential movement showed itself over a period of ten days. Also the dirt band, shown on Fig. 5, which formed the junction between the two glaciers, did not show any obvious signs of the shearing which might be expected if differential movement occurred. Although from a height the glaciers appear juxtaposed they probably adopt an inset position.

In view of the doubt now thrown on the extrusion flow hypothesis, PERUTZ (1950), one must re-examine the conclusions arrived at by SHARP. It can be argued that any inset or superimposed position of two valley glaciers will lead to juxtaposition in the long run. If as he suggests, accordant valley glaciers take up a juxtaposed position owing to final re-adjustment, cannot discordant valley glaciers also do this? Even if extrusion flow did occur this would tend to limit to depths of 60 m any possibilities of inset and superposed glaciers. Below this the supposed plastic nature of ice would preclude such boundaries.

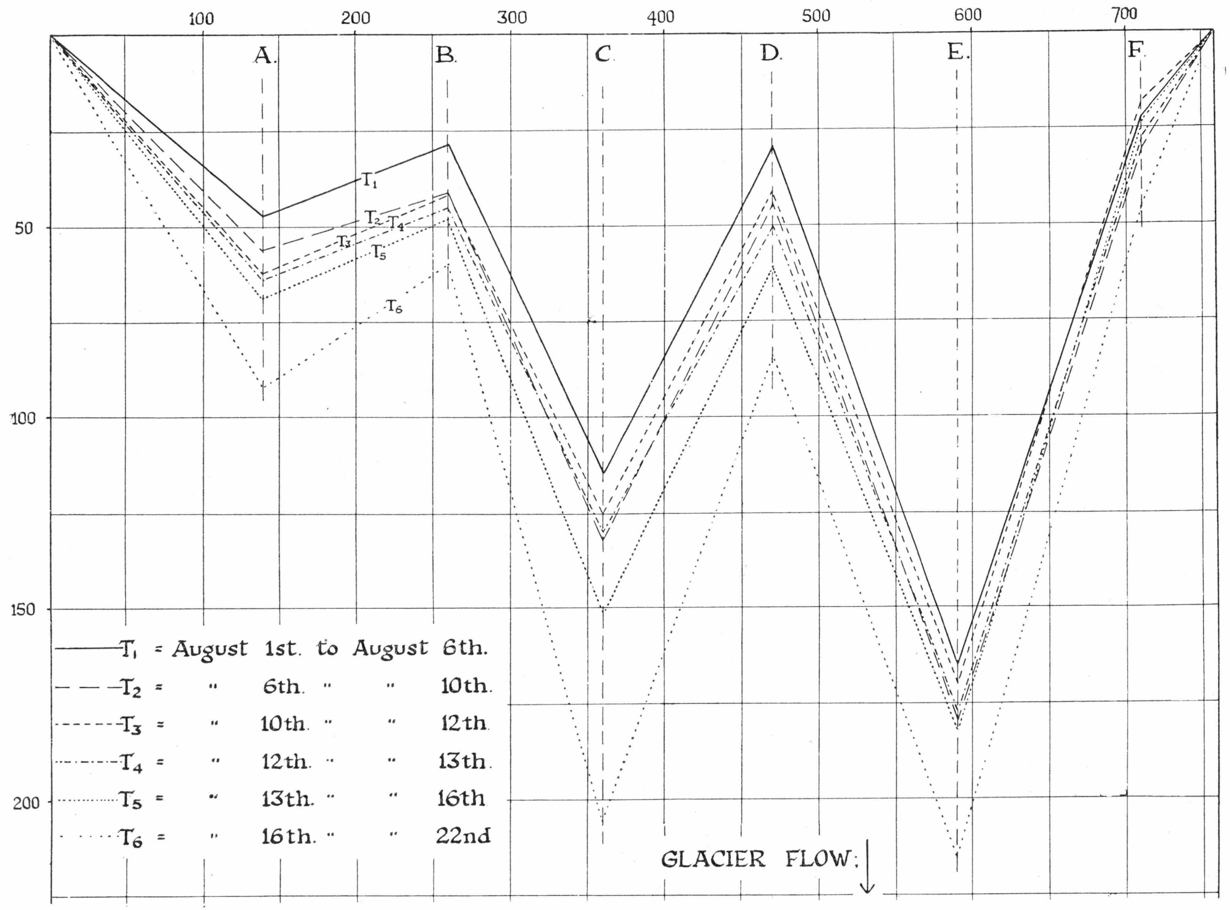

Fig. 6. Station 1. Movement in centimetres during the periods indicated. Abscisse show distance across glacier in metres.

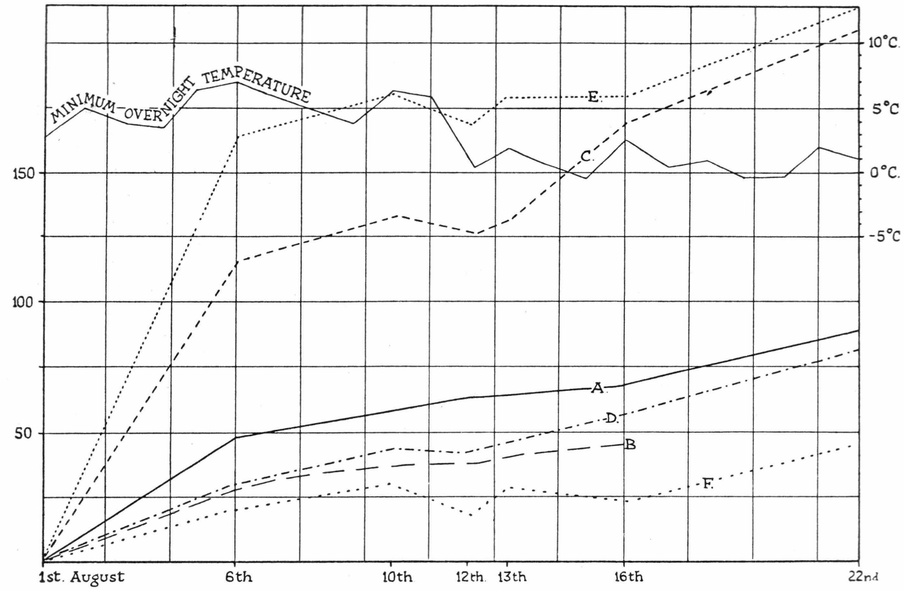

Fig. 7. Station 1. Showing distance moved in centimetres plotted against time in days.

Glacier Movement.

Observations on the velocity of flow were made in 1949 on the Frejagletscher, Clavering Ø. Goldthwait and Washburn (1937) working on glacier movement over short periods in Alaska in 1935 had found that glaciers do not flow at constant speeds. They suggested that there appeared to be a causal relationship between movement and relative humidity as shown by fair and rainy weather. Increased speeds were also noted during periods of maximum sunshine. Their measurements were over periods varying from a quarter hour to an hour. However, Carlson in his work in West Greenland (1939) had not been able to find any relationship between the weather and the variation of glacier movement. It was hoped that observations on the Frejagletscher would throw more light on this problem.

Two stations were set up on the Freja: Station 1 at 518 m, 2.4 km from the snout and Station 2 at a height of 396 m, 1.2 km from the snout. Stakes buried in the ice to a depth of a metre were placed in line across the glacier at these two points. A Wild theodolite set up on solid rock at one side of the glacier was used to measure the angular distance these stakes moved from an easily recognisable point on the ridge above. Over short periods of thirty six hours the stakes were quite rigid and sights were always taken at the junction of pole and ice. For long periods

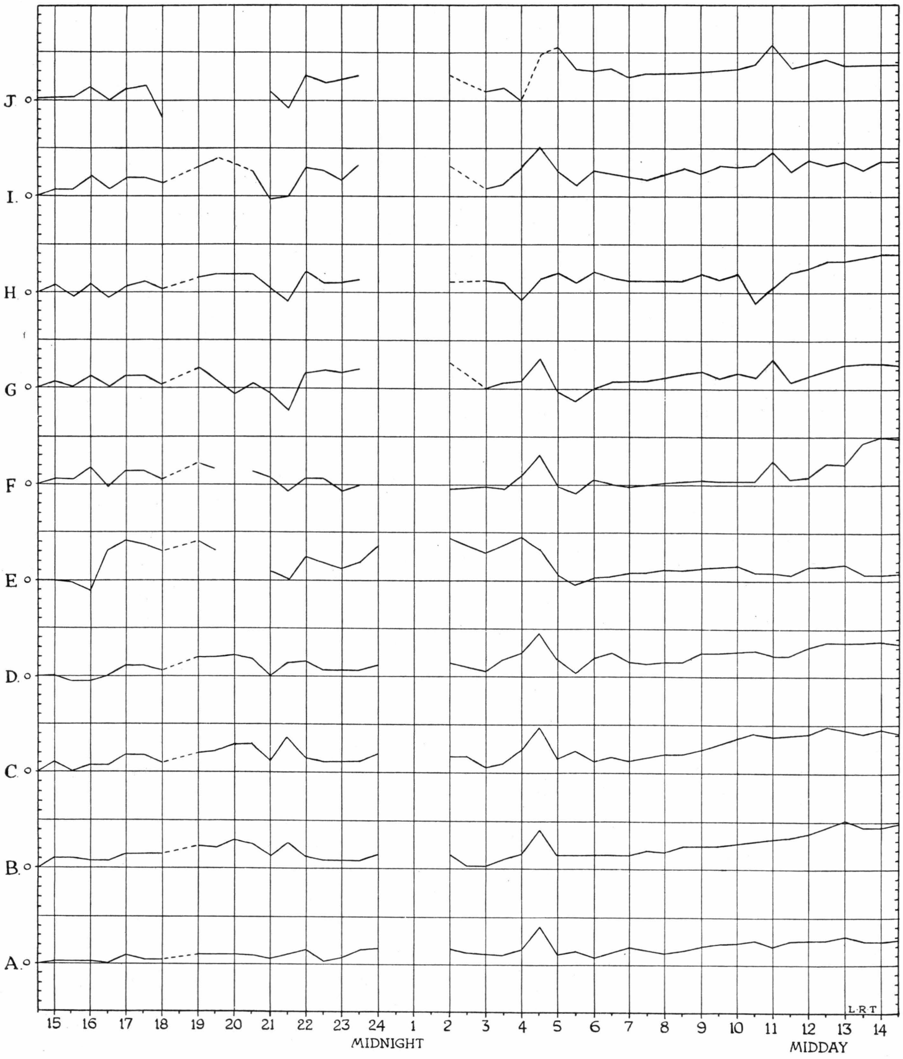

Fig. 8. Station 2. Showing movement over 24 hours of each stake against time in hours. One small marginal division = 1 cm.

the posts were removed and a stone placed over the hole, which was then deepened before the next set of observations.

Reading at Station 1 taken at irregular intervals over a three week period show that the maximum velocity was not in the centre of the glacier. Instead, there were two zones of maximum speed, the fastest about four fifths the way across, the other about half way across. In between these two was a zone of ice moving much more slowly, at speed less than half the maximum (Fig. 6). The slower zone of ice may be caused by a rock ridge thinly covered with ice which extends up the centre of the glacier, although no indication of this was visible.

The variations of glacier speeds over the three weeks are shown on (Fig. 7) where the distance travelled by each stake is plotted against time. The most noticeable feature of this diagram is the rapid drop in surface velocity from the 1st to the 10th August. If allowance is made for a time lag there may be a causal relationship between this drop in velocity and the drop in average daily air temperature, and indication of these being the night minima recorded on the same graph. This rapid falling off in temperature was noticed about the same time both in 1948 and in 1949. The evidence appears to confirm the conclusions of GOLDTHWAIT and FINSTERWALDER (1937) but further evidence must be sought before any definite correlation can be made.

The observations at Station 1 made every half hour continuously over a period of twenty four hours are not included, as bad weather in the early morning prevented a full set being obtained. However, observations at Station 2 over a twenty four hour period were completed and they are presented in (Fig. 8). The position of these stakes, showing glacier movement in relation to the whole glacier is seen from (Fig. 9). Their situation was such that they crossed as many thrust planes as possible for the glaciologists wished to examine thrust planes in relation to short period movements. These observations were on a micro scale, the stakes A to J, which were only 50 cm long, being a metre apart. The dotted line and breaks in the graph indicate times at which visibility was at a minimum and accurate observations were not feasible.

The jerky movement has a greater amplitude than that recorded by GOLDTHWAIT in Alaska, varying from 1 to 2 cm per hour in contrast to between 0 and 5 mm per half hour in Alaska. Although, the stakes on the Frejagletscher would probably not give as accurate results as the special marker used in Alaska, it is felt that the estimated margin of error of 50 mm was not sufficient to nullify the erratic motion observed. As there were no crevasses present between the theodolite and the stakes the irregular movement cannot be attributed to this; the South Crillon Glacier on which GOLDTHWAIT worked was highly crevassed.

The Frejagletscher moved faster by day than by night, a difference of between one 1 and 2 cm being recorded. The most noticeable features of the movement are the sudden forward surges of the glacier at 4.00 to 5.00 hr, and the equally sudden drop in velocity about 21.00 hr. The gradual increase of speed during the day appears to start about 6.00 hr. At present there is insufficient evidence to explain this jerky movement, although it may have some connection with an irregular movement noted on fast moving glaciers by FINSTERWALDER (1950) and called by him Block-Schollen movement BATTLE (1951). However,

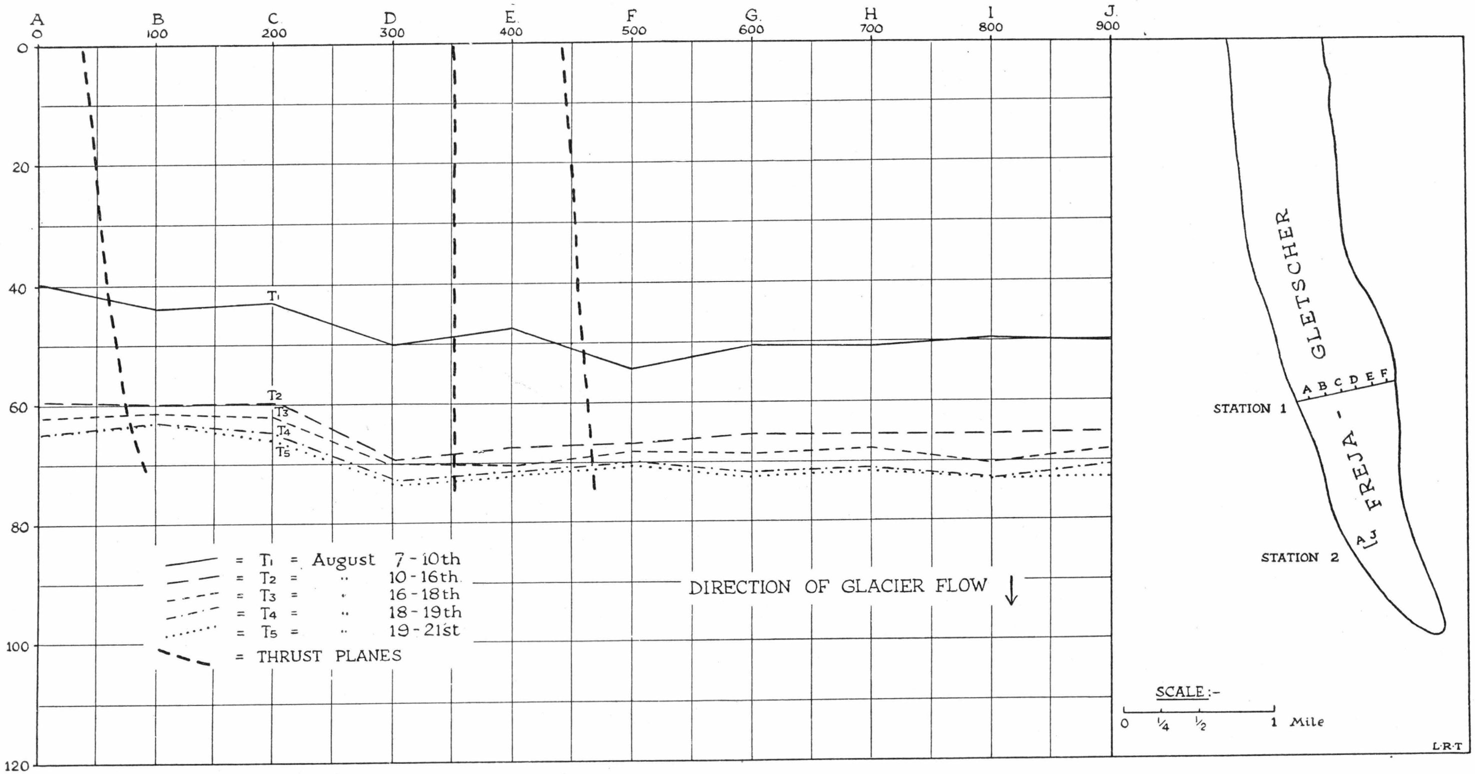

Fig. 9. Station 2. Distance moved in centimetres during the periods indicated. Abscissae show distance between each stake in centimetres. The sketch map gives the positions of Station 1 and 2.

the Greenland glaciers are ideally suited for such research as, especially on the west coast, the rate of flow is so high that the hourly movement is considerably greater than the probable error of theodolite observation. Thus the criticism of Mercanton (1941), that it is impossible to derive any reliable results from such hourly or half hourly observations because of the small margins of error, would not hold for the glaciers on which Carlson worked which have speeds of up to 80 cm an hour.

Fig. 7 shows the movement of the stakes at Station 2 over three weeks. The thrust planes are shown as dotted lines and it is clear that there is no visible correlation between these and the movement over the observed period. It is interesting to note that the general diminution in glacier speed noticed at Station 1 (Fig. 6) as the season advanced was visible also at Station 2. Thus from August 7th to 10th Stake C moved 43 cm but for a similar three day period from August 16th—19th it only moved 5 cm and from 19th—21st the movement was 1 cm. This decrease in speed was noticed a little earlier at the upper station, Station 1 and was probably transmitted gradually throughout the length of the glacier until noticed at Station 2.

Glacier Retreat.

Observations on the flow of glaciers are intimately related to phases of advance or retreat. The Pasterze glacier together with the Tvegegletscher in Svejstrups Dal confirm the general trend which prevails in the North Atlantic region so well studied by Ahlmann. Flint has given a detailed account of the retreat phases in the lower Tyrolerdal. The Pasterze glacier has retreated 9 km between 1870, when Payer first visited the area, and 1933, the date of the Danish air survey (Fig. 10). This may be related to a similiar retreat of the Ulændedal glacier, which was once a western tributary of the main stream.

It was Mittelholzer who, on a geological reconnaissance whilst a member of the 1938—39 Danish Expedition, first realised that there were serious errors on the maps of this area. He noticed a lake-filled valley, Ulændedal, instead of a glacier as marked on the map. Haines and the writer completed a reconnaissance of this valley, having approximately the same width and cross-section as Tyrolerdal. The lake, dammed against the Pasterze, was 4 km long and had been much more extensive at one time. A number of connected lakelets higher up the valley, and a very clear strand line 18 m above the present level provided ample evidence of this, as did the stranded bergs 12 m above the lake level. These latter, however, may only show a seasonal variation as it is not known if any water from the lake escapes into the Pasterze subglacial streams. If as is suspected none does escape, the presence of stranded bergs in July, at a time of maximum lake level, would imply that they are more than a season old. In fact, sheltered as they are from the low sun in the steep sided valley, these bergs may well be related to a former mild period, perhaps pre-1933. This is tentatively suggested on other grounds also, as a close study of the aerial photographs taken by the Danes in 1933 and photographs by the Leeds University Expedition in 1948 appeared to show little evidence for the retreat of the Pasterze over this period. Therefore it would appear improbable that the lake level in Ulændedal could markedly decrease between the years 1933 and 1948. The apparent lack of recent glacier recession in this area is strange as elsewhere glacier retreat noticeably increased within recent years.

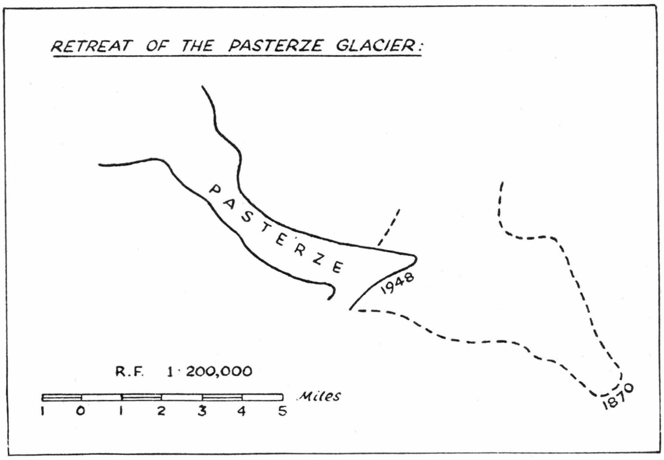

Fig. 10.

Tyrolerdal, up which the Pasterze glacier has retreated since 1870, shows many signs of inundation by ice, outwash sediments, a striations and glacier-worn valley sides are clearly visible. Features of the valley indicating different retreat stages are apparent just above the junction of the trunk valley with Mellemdal (Fig. 11). The 15 m flat topped kame terrace, so clearly marked for 366 m must indicate a long period of still-stand. The two terraces found below the kame terrace on the eastern side of the valley mark a period of down cutting of the valley train and their presence may indicate two colder periods during the retreat phase, when decreased rock load led to degradation.

During the geological investigations of the area lying between the Svejstrups Dal and the Grandjeans Fjord general observations were made on glacier retreat by Leedal and Brock. The following account is taken from Leedal's description.

The Svejstrups Dal, from it's source at the Tvegegletscher to it's mouth at Lindemans Fjord, is 56 km long and falls about 305 m in this distance. It has all the characteristics of a glaciated valley and in particular the polishing of the rock walls is very marked. On the south side of the valley the plateau is covered by a continuous ice-cap but on the north side the ice-cap is very fragmentary; most of the tributary glaciers therefore enter the Svejstrups Dal on the south side.

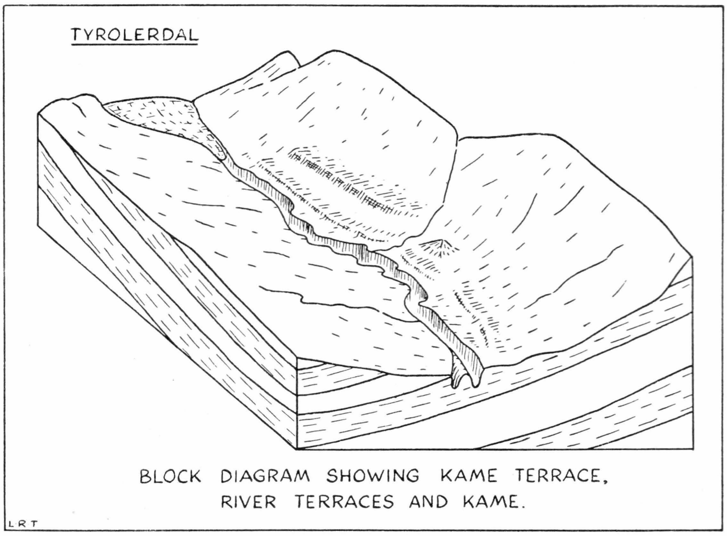

Fig. 11.

At the period of maximum advance of the glaciers, lakes were formed by the damming of the Svejstrups Dal river. The occurrence of shore-lines, overflow channels and lake silts is testimony to the former existence of these lakes. Trinity Gletscher once extended completely across the Svejstrups Dal and impinged on the north wall of the valley. This led to the damming of the river and the formation of a lake which can be picked out as a faint line on the south wall of the valley. Several shore-lines occur on the western moraine of Trinity Gletscher and also a well defined overflow channel. Lake silts and muds mark the former extent of the lake.

The glaciers of the Svejstrups Dal show by their moraines and by the nature of the adjacent valley walls that they were formally larger and more advanced than they are now. The recession from the old advance position varies from 5 km. Tvegegletscher to less than 1.3 km for the tributary glaciers.

Subglacial Observations.

The technique of subglacial observations was largely initiated by Carol although previous work had been carried out by Klebelsberg (1920) in caves excavated in the ice during the 1914—18 war in the Alps. The work in bergschrunds has been referred to in the section on corries and here observations made at depth in the middle and snout sections of a glacier will be described.

The glaciologists found that a descent of marginal crevasses between the rock walls and the main ice body was quite feasible. A number of these descents were made on the Pasterze and two tributary glaciers. In three or four places striations or score marks on the ice were noted as it pushed past bulges on the rock wall. They were identical in character with those photographed by Carol (1947) and were surprisingly symmetrical to be caused by irregular protuberances on what appeared to be a smooth rock wall. These regular incut score marks were observed on three occasions on two different glaciers. All were in similiar positions and none of the boulders or rock walls past which the ice was forced appeared sufficiently rough to cut the grooves. Crystal rubbings were made of ice which had been squeezed past the rock wall and of ice about 30 cm deeper; a cross section was visible at this point. Fig. 12. They illustrate the relationship between local pressure, probably involving extrusion, and crystal form. The rubbings taken 15 m below the surface show a junction between the grooved ice, which had extruded under local pressure and the ice which had not been subject to such intense pressure. The reduction in crystal size of the ice which had extruded past an obstacle may well be typical. Recent observations by Seligman (1950) in Switzerland point to a similiar diminution of crystals under stress, particularly near ice falls and at depth in the glacier. The results in Greenland would seem to substantiate his conclusions.

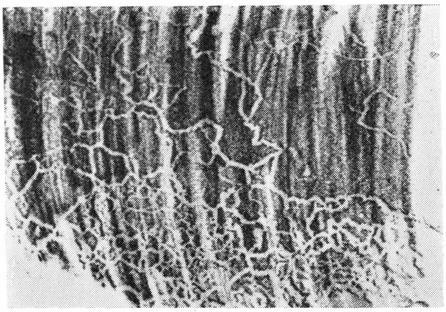

Fig. 12. Junction of small and large crystals coincident with grooved and non-grooved ice.

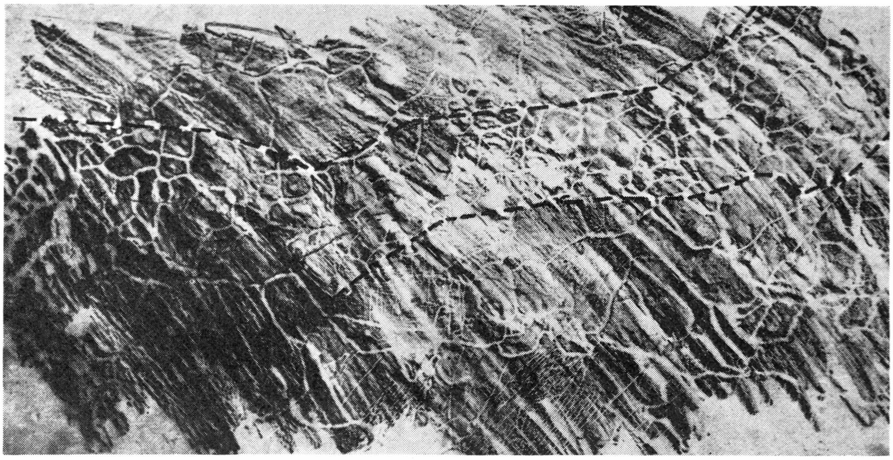

Fig. 13. Crystals at the snout of Frejagletscher. Band of smaller crystals is coincident with well defined dirt band.

An examination of the crystals at the tongue of the Frejagletscher in 1949 brought to light at least two interesting facts. Firstly, dirt bands in the ice sometimes affect crystal size. Figs. 13—14 shows rubbings taken at the snout on the underside of the glacier, across a very well defined dirt band. There was a very clear differentiation between the large crystals and a band of much smaller crystals which were coincident with the dirt band. The effect may perhaps be explained by the phenomena already mentioned, in the previous paragraph. The dirt bands may be located at shear planes along which overthrusting at the snout usually occurs Chamberlin (1928) and the excess pressure set up may be the prime cause of the band of smaller crystals.

It was also noticed that small crystals may be found at the tongues of glaciers although usually one expects to find the largest there. Fig. 15 shows the small crystals at the snout of the Frejagletscher. This was noticed again when the subglacial tunnel of the Skille Glacier was examined. Rubbings were taken at the snout, at 200 m and at 300 m inside the glacier and the crystals appeared to become larger not smaller as one went under the glacier.

Two other results of the enormous pressures at work were noted in the ice caves of the Pasterze glacier. In places the ice had been twisted back on itself in an overlapping fold and one could see this being warped even further during the period in which the observations were made The nearest analogy the writer can think of to illustrate the condition is twisted plasticine—the ice taking on an opaque form during the process. Elsewhere shearing appeared to be taking place with tearing along the shear plane which might be likened to the splitting of wood

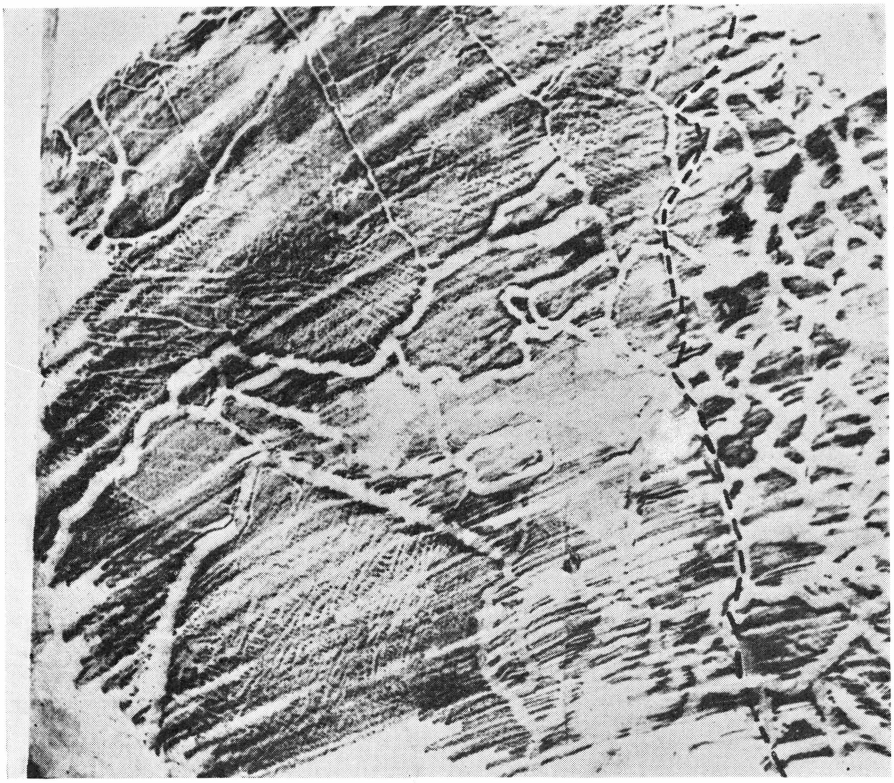

Fig. 14. Band of smaller crystals along dirt band, snout of Frejagletscher.

sometimes seen in a fallen tree. A leaf of ice projected from one plane to the other.

Subglacial observations were carried out as a part of the programme again in 1949. Reconnaissances on the Frejagletscher revealed the lack of marginal crevasses and, although one transverse crevasse was descended to a depth of 28 m, work inside proved impracticable because of a vigorous englacial stream system. However, at a later date the much larger Skillegletscher, also on Clavering Ø, was examined, and one of the subglacial streams issuing from the snout through a large tunnel afforded a possible means of access.

The first entry was made with Professor WESTERGAARD and two other Danes. All the subglacial work was done at night when melting, and englacial streams were at a minimum and one hoped that low temperatures outside would prevent possible roof collapses. The tunnel was between 2 and 3 m high and for the most part 3.3 m wide. At night the water was nowhere deeper than 0.7 m. Not far from the entrance a dry side tunnel led away from the stream but after 50 m this rejoined

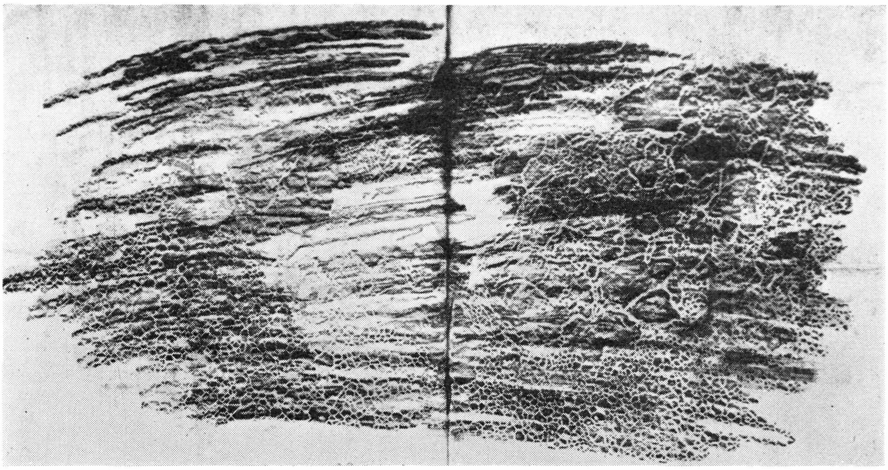

Fig. 15. A matrix of large and small crystals at the snout of Frejagletscher.

the main tunnel. In many places the walls of the tunnel consisted of large ice encrusted boulders: a frozen moraine. On the first visit the farthest point reached was about 120 m under the glacier.

It was only possible to make two subsequent visits up the subglacial stream bed. The writer hoped to compare the subsurface flow with that of the surface but practical difficulties precluded any such comparison. The second visit was made alone and therefore it was only possible to push forward a further 75 m. Boring tools and a resistance thermometer were taken and the temperature of the ice was found to be 0° C, 30 m below the surface. Warm air was always present although the ice never showed signs of melting. In one place a large water worn hole in the roof showed where a moulin at one time had discharged surface water into the subglacial stream.

After this second visit it was decided to follow the subglacial channel up as far as possible. If Demorest's ideas on extrusion flow were correct some obvious changes in the nature of the ice should be noticed where the thickness of ice exceded 60 m. The best way to check the depth was to map the inside taking aneroid readings, and then, following the same route on the surface, calculate the depth of ice at the farthest point of penetration.

Buhl and the writer penetrated 500 m up the subglacial stream bed, keeping an accurate check on distance with compass and metre tape. The tunnel was often as high as 6 m and in places the moraine sides gave way to solid ice walls. Crystal structures were recorded by rubbings at points throughout the traverse, although at times hoar frost made this difficult. However, a candle held close to the roof melted the surface sufficiently for the crystal boundaries to appear etched in candle black. The air temperatures inside were always above freezing, 2° C being recorded after a penetration of 300 m. The roof at this depth appeared to be flaking off because of pressure and there had been occasional roof falls leaving great ice blocks. The subglacial stream had previously been much larger, whether in early spring or some years ago was difficult to tell, but it was possible to leave it at times and follow and old dry bed. The tunnel ended at a roof and the subglacial stream thundered out of a crack in the ice 6 m above the stream bed. The power of the stream made it impossible to ascertain if in fact this was the end or whether a major roof fall had blocked up the passages and the subglacial bed continued beyond. The floor of the valley must be exceedingly flat as there was no increase in height over the 500 m distance.

The air temperature was 1.4 C, at 500 m cooler than the 2° C at 300 m. However, even with air temperatures above 0° C melting was not visible and the ice walls were dry and often covered with frost. The wall nearest the valley side had for much of the way consisted of frozen moraine debris with now and again a hole where a larger boulder had thawed out. This suggested the subglacial channel was close to one edge of the glacier.

After five hours had been spent inside the glacier the same compass traverse was followed over the surface of the glacier and the position of the furthest point checked. Although the traverse started at the side of the glacier tongue it soon appeared to veer towards the centre of the glacier. The terminus of the central moraine was reached after 200 m and it rapidly became apparent that the route under the glacier coincided with the line of this moraine. The height of the farthest point reached under the glacier was measured by aneroid on the surface and found to be 150 m. Subtracting this from the height at the same point under the glacier it was found that at this final point under the glacier the thickness of ice was 76 m.

This work raises interesting points in connection with the physical behaviour of glaciers. Whether one believes in extrusion flow or not, the observations prove that in Greenland, subglacial tunnels do exist deep within the glacier. A factor which may help to keep the tunnel open is the presence of warm air (2° C) found inside this Arctic glacier when outside temperatures were well below freezing. The warm air may be evidence of an equilibrium condition between the melting of the ice roof and its height, which prevents the tunnel closing. Alternatively the tunnel might have been formed there was a greater volume of water present. It is difficult to decide on the exact mode of formation of these subglacial streams especially when such large caverns occur within them.

From these observations it would seem that the three dimensional picture of a glacier first drawn by de Martonne is substantially correct and that the medial moraines are not purely surface phenomena. They can extend from the surface to the bed of a glacier and in some cases their direction appears to coincide with the subglacial streams. Surface streams which follow the moraines will be present from the very mode of formation at the margin of two converging glaciers. There is no reason to suppose that when these surface streams become englacial and subglacial, they will not likewise follow the same line, especially as radiation, and consequently downmelting, are concentrated at this point.

New Names.

The following new names have been authorised by the Danish authorities.

Ledesia Bjerg	Leeds Mountain
Svejstrups Bjerg	Svejstrups Mountain
Trinity Gletscher	Trinity Glacier (after Trinity College, Cambridge)
Stejlgletscher	Steep Glacier
Barriere Gletscher	Barrier Glacier
Grifgletscher	Gryphon glacier (The gryphon is the major part of Leeds University crest)
Ulændedal	Stony valley
Ødedal	Desolate valley
Grønningen	Green valley

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