Some Observations on Steep Ramps

by

ANKER WEIDICK

Abstract

The following account deals with observations on steep ramps at 4 localities in West Greenland. Comparison is made with the well known and thoroughly investigated areas with steep ramps and ice cliffs in Thule. In all the localities described, development of steep ramps and ice cliffs seems to be influenced by a relatively smooth topography of the ice free foreland, and with a glacier ice facies corresponding to the uppermost part of the ablation zone (mean yearly air temperature at the localities is less than $\div 5°$ C). However, the form of the steep ramps seems to indicate that the most important agency in their formation must be wind erosion at the face of the ramp.

Introduction

The following paper is based on observations made in the field (fig. 1, localities 1, 2, 3 and 5) and examination of aerial photographs (fig. 1, locality 4). No detailed investigation has been made of the phenomena described, but the occurrence of the same interesting ice margin features in the different parts of Greenland is worthy of record.

My thanks are due to J. WATTERSON, B. Sc., who has checked the manuscript.

Definitions

The definitions given by L. NOBLES (1961, pp. 189–191) of the various ice margin forms are in principle followed here. Of the forms which are of interest for the present communication, NOBLES made distinction between the following:

1) ice cliffs, characterized by vertical or near vertical surfaces.
2) steep ramps with a slope of 20–45° and like the ice cliffs, 20–50 metres in height.
3) gentle ramps with slopes generally less than 5°.

NOBLES interpreted the steep ramps in the Thule area as a "transitional stage in the decay of an ice cliff to a gentle ramp" (NOBLES 1961, p. 190). In the following description no such genetic relationship is implied by use of the term "steep ramp", which is used to indicate a transitional morphological type, whether or not the present ice margin is stagnant or advancing. The term is therefore purely descriptive.

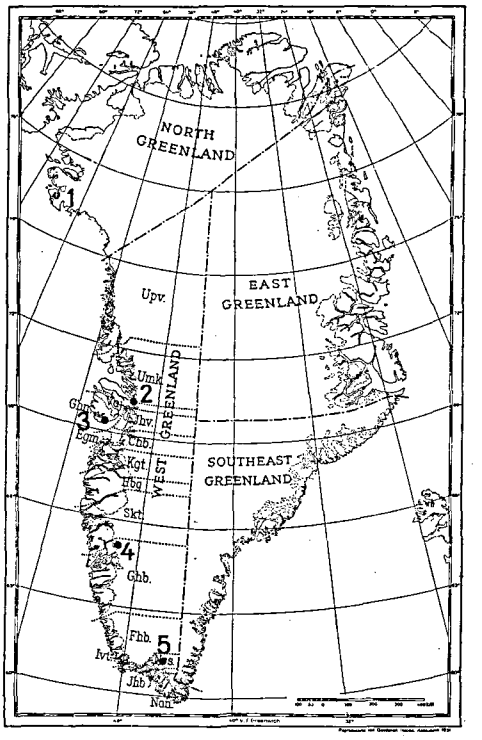

Fig. 1. Location map. Numbers refers to numbers of the localitites.

Earlier observations

Observations on steep ramps and ice cliffs in the broader sense defined above were first published by T. V. CHAMBERLIN (1895, pp. 565–584 and 669–681) and L. KOCH (1928, p. 226) from the Thule area, and by I. P. KOCH and A. WEGENER (1930, pp. 280–285) from Dronning Louise Land, East Greenland..

More detailed investigations of these features were later made in the Thule area by B. BISHOP (1937, pp. 33, 35–40), D. O. RAUSCH (1958, pp. 30–33), R. GOLDTWAITH (1961, pp. 107–115) and L. NOBLES (1961, pp. 189–191).

Interpretations

CHAMBERLIN considered the vertical walls of the glaciers to be a special high-arctic feature, and explained it as being due to radiation (CHAMBERLIN 1895, p. 566).

RAUSCH (1956, p. 33) explains the formation of the ice cliffs at Store Landgletscher, Thule, as being the result of the overriding of stagnant ice by active ice, the stagnant ice originating from an earlier thinning out of the glacier margin, which resulted in debris loaded ice.

BISHOP (1957, p. 46) explains the formation of the same ice cliff and the adjoining steep ramp as being due to wind erosion, aided by extramarginal meltwater erosion.

GOLDTWAITH (1961, p. 114) from his study of the more northerly situated ice cliff at Nunatarssuaq, supposed that the formation of the ice cliffs was due to the movement of the upper ice along shear zones over lower stagnant ice.

All the above mentioned explanations have been used for ice cliffs proper as well as for steep ramps.

At the above mentioned nunataks and also in the areas described below, steep ramps seem to occur in the uppermost part of the ablation zone.

In the investigations described below the main purpose has been to determine whether or not uniform conditions exist at the different localities described. The conditions taken into account are those of morphological as well as of meteorological character.

Localities

Locality 1: The Thule area (see figs. 1 and 2).

With regard to this area, no comment will be made on the interpretations which have earlier been suggested by RAUSCH, GOLDTWAITH, BISHOP and SCHYTT (V. SCHYTT 1955, pp. 76 and 88). Attention will only be paid to those features which all ice cliffs and steep ramps seem to have in common, in this "classical" area.

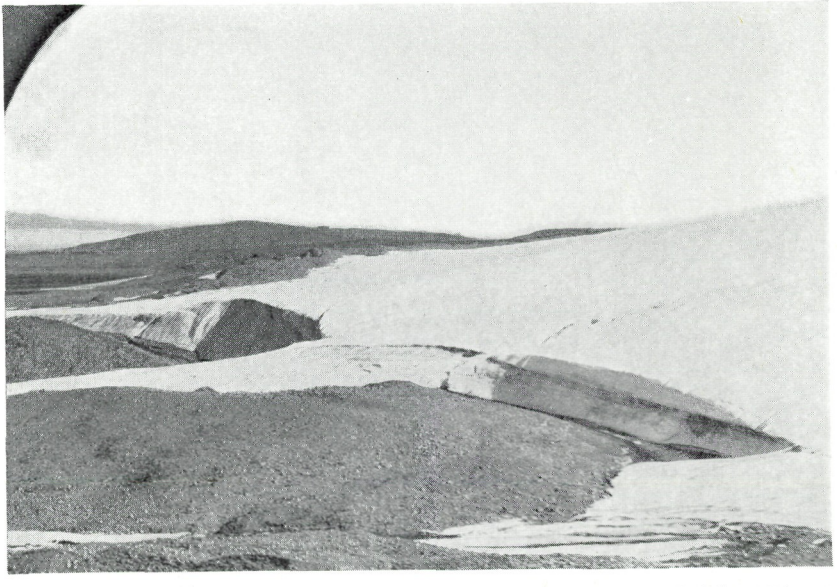

Fig. 2. Ice cliff near Thule. Store Landgletscher. phot. A. Weidick july 1959.

The essential characteristics seem to be morphological; a situation on the Inland ice margin proper and not at the front of a real glacier lobe. Furthermore, a connection with shear moraines is evident (moraines later called by WEERTMANN (1961, p. 965) "Thule-Baffin moraines"). The ice cliffs and steep ramps in the area are partly bordered by extramarginal melt water streams.

The ice cliffs and steep ramps mostly face toward northwest, with their bases situated at 200 (Thule area) and 640 (Nunatarssuaq area) metres a. s. l.

The essential meterorological data, given by M. DIAMOND (1958, pp. 4–5) and R. GOLDTWAITH (1961, p. 108) shows a mean annual temperature in the area of between ÷12° and ÷16° C. and a total yearly precipitation of about 0,5 m.

Futhermore, it must be concluded that most of the glacier ice forming the ice margin features described is at temperatures slightly higher than the mean air temperature for the year. This can be controlled by the measurements at Nuna ramp (elevation ca. 600 m. a. s. l.), which show that the temperature of the glacier ice is about ÷14°C (NOBLES 1960, pp. 6–7) and at the ice tunnel at Tuto (elev. ca. 500 m. a. s. l.), where temperatures down to ÷10° C have been measured (D. RAUSCH 1958, p. 16).

The area is characterized by strong local winds from the Inland ice, which in places sweep along the faces of the ice cliffs.

As mentioned above, the ice cliffs and the steep ramps in the area near Camp Tuto were already in existence at the time of the visits of L. KOCH (1928, p. 226), but trim lines around the ice margin in the Thule area indicate a slight recession of the Inland ice since around ca. 1900, as already reported by T. M. GRIFFITHS (1960, p. 9).

Locality 2: The interior part of the Nugssuaq peninsula.

Numerous ice cliffs and steep ramps have been observed at heights of about 500 m on the margin of the Inland ice, both north and south of the big glacier lobe which projects toward the interior part of the Nugssuaq peninsula.

The ice cliffs and steep ramps are between 20 and 40 metres high, and face toward directions between northwest and southwest. A steep ramp just to the south of the big glacier lobe is shown in fig. 3.

In a morphological sense, only a few and very weakly developed shear moraines are found in the area. Most of the ice margin is in contact with either ice-dammed lakes or with marginal melt water channels. However, close to the big glacier lobe, there is a distinct difference between the real steep ramps or ice cliffs and calving walls which are undercut by streams. The latter are characterized by jagged, fractures surfaces, while the other ice cliffs-steep ramps are characterized by smooth, sometimes horizontally fluted surfaces and gradually pass laterally into the normal type of contact between glacier and ice free land.

The marginal area is dominated by boulder terrain, but without development of real marginal moraines from recent historical times. This can be concluded from the development of a trim line, within which the absence

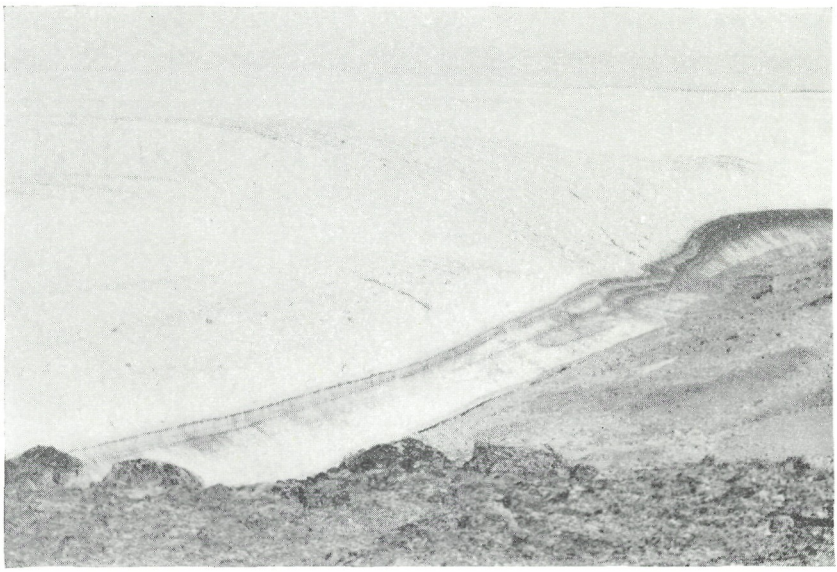

Fig. 3. Margin of the Inland ice in the middle part of the Nugssuaq peninsula. phot. A. Weidick 12/8 1961.

of lichens except on the outermost few metres, must indicate that at least until ca. 1900 A. D. the ice margin must have been 10–20 metres higher than the present level (R. BESCHEL 1961, p. 1057–60).

Concerning climatic conditions, the nearest weather stations are situated at Ikerasaq and Jakobshavn. Ikerasaq in Umanak district has an annual mean temperature of $\div 6°$ C, while Jakobshavn has an annual mean temperature on $\div 5{,}6°$ C and mean annual precipitation of 231 mm.

Assuming a mean lapse rate for temperature of $0.7°$ C/100 m the mean annual temperature near the ice ramp must be about $\div 9°$ C, while the precipitation at this locality is probably under about 200 mm. The sparse vegetation indicates that the precipitation must be rather slight.

Nothing is known about the prevailing wind direction and velocities on this locality, but it must be presumed that conditions are dominated by powerful eastern winds from the Inland ice. The smoothed fluted forms of the steep ramps or ice cliff mentioned above, seem to indicate that wind action is at least partly responsible for the ice margin morphology. The erosional forms here are very similar to those observed in the sandstone areas in the Disko Bugt region and in the nepheline syenites in the northern parts of the Julianehåb district.

Attention must also be paid to the erosional effect of snow (compare J. TROELSEN 1952, p. 221–222). At this locality the temperatures in the wintertime must very often be under about $\div 20$ and snow crystals could be of relatively higher hardness than the glacier ice (hardness after Mohs' scale: $\div 15°$C: 2–3, $\div 30°$C: 3–4, $\div 40°$C: 4 (P. SCHUMSKIJ 1955, p. 43)).

The area described above was first mapped by E. v. DRYGALSKI (1897, p. 120) who described ice cliffs about 30 metres in height.

Locality 3a: Tunorssuaq valley on Disko Island.

Near the town of Godhavn, between the valleys of Blæsedal and Brededal, is a small pass and valley called Tunorssuaq. The local firn cap on the basalt plateau of Skarvefjeld terminates here without any lobes in a steep ramp 20–30 metres high. The steep ramp faces towards north. Morphologically it can be described as a minor edition of the steep ramp of Camp Tuto at Thule: very close association between ice cliff and shear moraine and relatively small amounts of lateral drainage by extramarginal melt water streams. The steep ramp facing south gradually passes over to gentle ramp forms which appear to be the normal type of junction between ice and land at this height.

The locality is situated in an altitude of about 400 m. a. s. l.

The nearest meteorological station is Godhavn, having a mean annual temperature of about $-5°C$ and mean annual precipitation of 0,4 m. The area around the ice cliff must therefore be considered to have an annual mean temperature of $-8°C$ and very nearly the same precipitation as Godhavn.

Nothing is known about either the prevailing wind direction or velocity. However, the name Blæsedalen ("the windy valley") probably indicates severe winds along the valleys. Here as on the Nugssuaq peninsula, the form of the steep ramp gives the impression that the most important agent may be wind erosion, possibly abrasion and/or evaporation. This is evident from its situation; the ice margin forming a big part of the southern valley side of the Tunorssuaq valley.

It is known that the ice cliff was not present in 1894, at the time of the visit of T. C. CHAMBERLIN (1894, p. 787). Both from his information and the information given by H. RINK from 1849 (RINK 1857, special map of Godhavn marked: "Omgivelserne af Godhavn paa Disko"), it seems that a big glacier lobe from the plateau ice on the Skarvefjeld mountain has until this century filled most of the Tunorssuaq valley.

The same is indicated by the great terminal moraine which today stretches right across the valley. The area just behind this terminal moraine is bare of lichens, which is another indication that the valley has been covered by ice until this century.

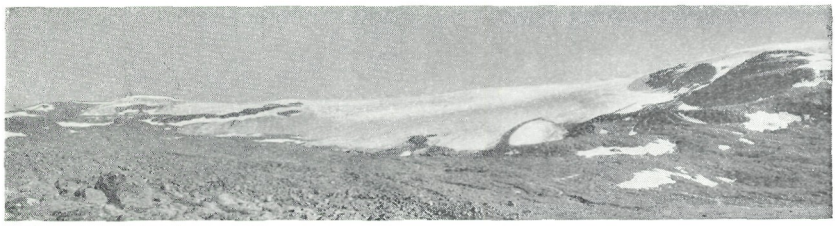

Fig. 4. Tunorssuaq valley, Godhavn. The ice margin seen from the north west. phot. A. Weidick 30/7 1961.

Locality 3b: The southernmost glacier on Lyngmarksfjeld (earlier: Lyngmarksbræ).

The locality is situated only ca. 5 kms north of the town of Godhavn. The terrain is very like that at Tunorssuaq, and as in the Tunorssuaq valley an earlier glacier lobe from an local ice cap, now found on Lyngmarksfjeld mountain, has been converted into a steep ramp like margin of the ice cap proper.

The lowermost point of the westerly facing, steep ramp (see fig. 5) is situated in 630 m. a. s. l. In earlier times the glacier lobe filled a small cirque (tributary to the Blæsedalen valley), but is today hanging on the margin of the high basalt plateau.

The form of the ice cap margin must in part be attributed to the position on the margin of the basalt plateau, but partly also to other agencies because the ice margin is not formed quite in accordance with the topography of ice free land. Neither shear moraines nor important extramarginal melt water streams are observed at this locality.

Meteorological data from the nearest station at Godhavn show that the locality under consideration must have a mean annual temperature of $\div 9°$ C. As was the case with the Tunorssuaq valley, nothing is known about the wind conditions.

Lyngmarksbræ has now nearly disappeared, but its history is relatively well known as the glacier is situated near to the town of Godhavn. It can be concluded from earlier sources, that a glacier tongue filled the valley in 1812 (K. L. GIESECKE 1910, p. 400), 1849 (H. RINK 1857) and 1870 (A. E.

Fig. 5. Lyngmarksfjeld glacier, Godhavn, seen from the south. phot. A. Weidick 19/7 1961.

NORDENSKJOLD). The same can be concluded with some confidence from observations of the glacier made 1893, 1897,1898,1912 and 1923. From Geodetic Institute's map sheet 1 :250.000, 69VI, Godhavn, the position of the glacier can be determined, although with some uncertainty for the years 1931–33. At that time a glacier tongue was still in existence, though much shorter than when recorded from earlier observations. Photographs from 1953 (aerial photographs) and from 1955 (the author) indicate that the steep ramp is now under formation. The dating of the initiation of the ramp formation must therefore be between 1933 and 1953, and it may be supposed that the last year is the more nearly correct.

Later photographs from 1960 (taken by civ. ing. A. STOCKFLETH, Ionospherestationen, Godhavn) and from 1961 (taken by the author), do not show measurable change of the steep ramp.

Attention must here be drawn to the planned photographing of the ice ramp every year on the initiative of the climatological section, Meteorological institute (mag. O. FRYDENLUND) and performed by ing. AXEL HANSEN, the magnetic observatory, Godhavn. There is therefore a good possibility that alterations of the steep ramp in future years can be closely followed.

Locality 4: Inland ice margin between Godthabsfjord and Søndre Isortoq.

A weak tendency for the formation of steep ramps can be seen in this area in which most commonly a gentle ramp morphology is dominant. The steep ramps can be seen especially in the area just north of the glacier Ujaragssuit pavat, and between here and a locality Qavdlunatsiait, situated 12 km to the north.

The area has not been personally inspected, but the impression of steep ramps has been gained from aerial photographs from 1948.

As in the Thule area, long stretches of the ice margin are characterized by shear moraines and rimmed by fringing glaciers. On the highest situated parts of the landscape where these are not found away from the ice margin, the steep ramps occur.

Away from the ice margin the landscape is a gently undulating gneissic rochees moutonnees area, and marginal moraines are not found along the margin of the Inland ice. The area is situated between 700 and 900 metres ab. s. l.

The very narrow trim line surrounding the Inland ice margin indicates a slight retreat or thinning out of the ice margin in most recent time. However, by a comparison of pictures from 1930 (taken by state geologist SIGURD HANSEN) and the aerial photographs from 1948 it is not possible to state the amount of retreat of the ice margin. A relatively large portion of the ice margin in this area is bordered by small lakes. The absence of calf ice in these lakes indicates a low rate of movement of the glacier fronts.

The nearest meteorological station is Qôrnoq, situated about 60 kms to the southwest. The mean temperature for this station is $\div 1{,}7°$C and the mean annual precipitation 0,4 m. The annual mean temperature near the steep ramp must therefore be between $\div 7°$ and $\div 8°$C.

Fig. 6. Iviangerqutit tasiat area, Julianehåb district. The ice margin seen from the south. phot. A. Weidick 27/7 1960.

Locality 5: Iviangerqutit tasiat area:

The locality is situated about 27 km east of the Narssarssuaq air base in the Julianehåb district. The steep ramp is shown on fig. 6.

The steep ramp is situated between 1100 and 1200 m. a. s. l., and forms the southern boundary between a nunatak and the local firn cover which farther to the east passes into the Julianehåb ice cap and the Inland ice.

The steep ramp forms the northernmost limit of a local ice cap. It faces an east-west running valley for a distance of a few hundred metres, of which it forms the southern side. The valley has no name but contains the lakes Iviangerqutit tasiat (WEIDICK 1963 p. 64). Farther to east and west the ice margin is of a more normal type; toward west, i. e. in the lower areas, the ice cap borders a gently undulating boulder terrain without moraines. The same is partly the case also in higher areas toward the east, where however some stretches of the ice margin form ice cliffs against ice dammed lakes. At altitudes between 1200 and 1400 m. a. s. l. the ice margin passes, by way of local firn patches, into a continous firn area.

The ice cliff and steep ramp at the Iviangerqutit tasiat are without either frontal moraines or real marginal melt water channels. Well developed shear moraines are observed in the areas just to the south and south-east of the steep ramp. The terrain at the glacier margin is similar to that of the boulder fields of the Thule area; as in the Thule area the boulders are mostly rounded, indicating the possibility of earlier fluviatile transport.

Nothing is known about the fluctuations of the glacier margin at this locality. However, both the trim line zone and earlier observations on the

lower glaciers in the area (WEIDICK 1959, pp. 36–45) indicate a major retreat in the area during this century.

The locality is situated about 27 km east of the nearest meteorological station Narssarssuaq, which has a mean annual temperature of +2°C, and a mean annual precipitation of 700 mm. It must be presumed that the area around Iviangerqutit tasiat therefore has a mean annual temperature of ÷6°C. The precipitation must be very similar to that of Narssarssuaq.

Conclusions

It must first be stressed, that only tentative conclusions can be drawn from these few examples.

Morphologically, the steep ramps referred to seem to be related to ice margins facing between west and north, i. e. those in which the limit of glaciation is commonly the lowest one in any single mountain group. However, the steep ramp now under formation at Lyngmarksfjeld, Disko, faces east. It must therefore be the situation near to the limit of glaciation which controls the formation of steep ramps rather than the degree of exposure.

Furthermore, in a morphological sense, these steep ramps seem to be related to areas of regular undulating ground moraines or to the edges of plateaux (sides of valleys) and not to real marginal or terminal moraines transverse to the valley direction. This may indicate a certain relationsship to wind erosion, whether this is caused by snow particle abrasion or by evaporation.

Extramarginal melt water streams and minor ice-dammed lakes are only occasionally observed. Undercutting in association with the steep ramps by meltwater streams therefore seems not to be an important agent of formation, but may in some cases be the initial cause of the formation of ice cliffs. Distinction must be made between ice cliffs proper, developed from (or being degraded to) steep ramps, and the normal calving ice fronts such as seen on ice margins facing ice dammed lakes. The latter type has been observed especially in the areas around localities 2 and 4 but is without significance in the present connection, having water erosion as the dominant agency of formation.

Well developed shear moraines are often observed in the same areas as ice cliffs and ice ramps, but shear moraines are also observed in lower areas without steep ramps, along nearly all or the greater part of the Inland ice margin of Greenland.

In a meteorological sense, the ice cliffs appear to be related to regions of cold ice, always being situated in the upper part of the ablation zone. It is of interest that shear moraines are to be found also in the lower parts of this zone. Precipitation apparently has little or no influence of the formation of steep ramps.

Although it cannot be shown conclusively, the explanation of BISHOP (1957, p. 9) that the ice cliff in Thule is formed by wind and water erosion together with control of the ice flow by the subglacial terrain, seems to be the best suited to the examples described here. It must be added however,

that the temperature of the ice seems also to be important. The relative importance of the different agencies must vary a little from the one locality to the other. The final solution of the question can be solved only by applying a standard survey technique to more cliffs and ice ramps. From these few examples however, steep ramps and ice cliffs must be expected to occur also in the southern parts of Greenland, the form primarily being related to a certain facies of the Inland ice.

Following from these conclusions that ice cliffs, steep ramps, and possibly shear moraines are controlled primarily by certain facies of the ice margin rather than by a geographical restriction to certain areas, a geomorphological mapping of the ice contact features in general, must be expected to furnish further evidence for the explanation of these phenomena.

DANSK RESUME

"Isskrænter" ("Steep ramps") er efter L. NOBLES en israndstype, dannende overgang mellem "isklinter" og den jævne tilslutning af isdækket til land, så ofte set ved den egentlige rand af en iskappe i nærheden af firngrænsen.

De her givne observationer fra Vestgrønland angiver ,at denne israndstype ikke er regionalt begrænset til Nordgrønland, men blot er afhængig af et koldt millieu (middeltemperatur for året må ved alle de observerede steder anslås til $\leq \div 6°$ C).

Yderligere frembyder isskrænterne ved alle de observerede steder træk, der antyder at vinderosion må have betydning for denne israndstypes udformning. Det omtrentlige tidspunkt for dannelsen af isskrænterne kan angives ved lokaliteterne 3a og 3b (Tunorssuaq og Blæsedalen på Disko Ø) til mellem 1940 og 1950, medens de ved Thule synes at have eksisteret i alle tilfælde før ca. 1920.

REFERENCES

BENSON, C., 1961. Stratigraphic studies in the snow and firn of the Greenland ice sheet. Folia Geographica Danica, Tom. IX, 1961, pp. 13–37.

BESCHEL, R., 1961. Dating rock surfaces by lichen growth and its application to glaciology and physiography (lichenometry). *In* C. A. RAUSCH (ed.). Geology of the Arctic. Toronto. University of Toronto Press pp. 1055–1062.

BISHOP, B. C., 1957. Shear moraines in the Thule area, Northwest Greenland. SIPRE Research Report 17.

CHAMBERLIN, T. V., 1895. Glacial studies in Greenland. The Journal of Geology, II, 1894, III, 1895.

DIAMOND, M., 1958. Air temperature and precipitation on the Greenland Ice Cap. SIPRE Research Report 43, 1958.

DRYGALSKI, E. v., 1897. Grönland-Expedition der Gesellschaft für Erdkunde zu Berlin, 1891–1893.

GIESECKE, K. L., 1910. Mineralogisches Reisejournal über Grönland. Meddelelser om Grønland vol. 35.

GOLDTWAITH, R., 1961. Regimen of an Ice Cliff on Land in Northwest Greenland. Folia Geographica Danica. Tom. IX, pp. 107–115.

GRIFFITHS, T. M., 1960. Glaciological investigations in the TUTO area of Greenland. SIPRE Technical Report 47.

KOCH, I. P. and WEGENER, A., 1930. Wissenschaftliche Ergebnisse der dänischen Expedition nach Dronning Louises-Land und quer über das Indlandseis von Nordgrönland 1912–13. Meddelelser om Grønland vol. 75.

KOCH, L., 1928. Contributions to the Glaciology of North Greenland. Meddelelser om Grønland vol. 65.

NOBLES, L. H., 1960. Glaciological Investigations, Nunatarssuaq Ice Ramp, Northwest Greenland. SIPRE Technical Report 66, 1960.

NOBLES, L. H., 1961. Structure of the ice cap margin, Northwestern Greenland. Folia Geographica Danica, Tom. IX, pp. 188–204.

NORDENSKJØLD, A. E., 1870. Redogörelse för en expedition till Grönland år 1870 af A. E. Nordenskjöld. Öfversigt af Kungl. Vet. — Ak. Förhandlingar 1870, p. 973.

PETERSEN, HELGE, 1950. Klima og Vejrtjeneste, "Grønlandsbogen", vol. 1, pp. 137–151.

RAUSCH, D. O., 1958. Ice Tunnel, Tuto Area, Greenland. SIPRE Technical Reports 44.

RINK, H., 1857. Grønland, geographisk og statistisk beskrevet. Vols. I–II.

SALISBURY, R. D., 1895. The Greenland Expedition of 1895. The Journal of Geology III, p. 890.

SCHUMSKIJ, P. A., 1955. Osnovy strukturnoge ledovedenija. Moskva.

SCHYTT, V., 1955. Glaciological Investigation in the Thule Ramp area. SIPRE Report 28.

TROELSEN, J. C., 1952. An experiment on the Nature of Wind Erosion, Conducted in Peary Land, North Greenland. Meddelelser fra Dansk Geologisk Forening, bd. 12, hefte 2.

WEERTMANN, J., 1961. Mechanism for the Formation of inner Moraines found near the Edge of cold Ice Caps and Ice Sheets. Journal of Glaciology, vol. 3, no. 30, pp. 965–978.

WEIDICK, A., 1959. Glacial Variations in West Greenland in historical Time, part 1. Meddelelser om Grønland vol. 158, 4 (GGU. Bulletin no. 18).

WEIDICK, A., 1963. Ice margin Features in the Julianehåb District, South Greenland. Meddelelser om Grønland vol. 165, 3 (in press).

Færdig fra trykkeriet den 14. januar 1963.