GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 62

GEOMORPHOLOGICAL OBSERVATIONS ON SERMERSÔQ

A CONTRIBUTION TO THE GEOMORPHOLOGY OF S. GREENLAND

BY

OEN ING SOEN

WITH 17 FIGURES AND 1 TABLE IN THE TEXT
AND 3 PLATES

Reprinted from
Meddelelser om Grønland, Bd 179, Nr. 5

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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Abstract

On the island of Sermersôq four erosion surfaces have been recognized, which are of regional importance in S Greenland. Their development is related to three cycles of erosion, interrupted by two glacial stages.

The high-level erosion surface at altitudes above 1000 m is the remnant of an old peneplane, which was formed during the oldest erosion cycle and uplifted in late Cretaceous or early Tertiary times. This uplift initiated a second erosion cycle in the course of which a main glacial stage intervened. In this glacial stage the ice-level in the main valleys (the present fjords) acted as the effective base level of erosion and this resulted in the formation of stretches of an intermediate-level erosion surface, which now occur along the main fjords at altitudes between 400 m and 650 m. An important lowering of effective base level of erosion occurred when in the subsequent interglacial stage the sea-level resumed its role as the effective base level of erosion. This event initiated a third erosion cycle in the course of which the low-level erosion surface, between 100 m and 250 m altitude, and the strandflat, a coastal platform below 50 m, were formed. The third erosion cycle was interrupted by a second glacial stage, which on Sermersôq has the localized character of a mountain glaciation; it is during this second glacial stage that the present day fretted upland morphology of central Sermersôq originated. Post-glacial vertical movements causing the emergence of the strandflat induced a rejuvenation of erosion and consequently the incision of this coastal platform and valley floors by recent rivers.

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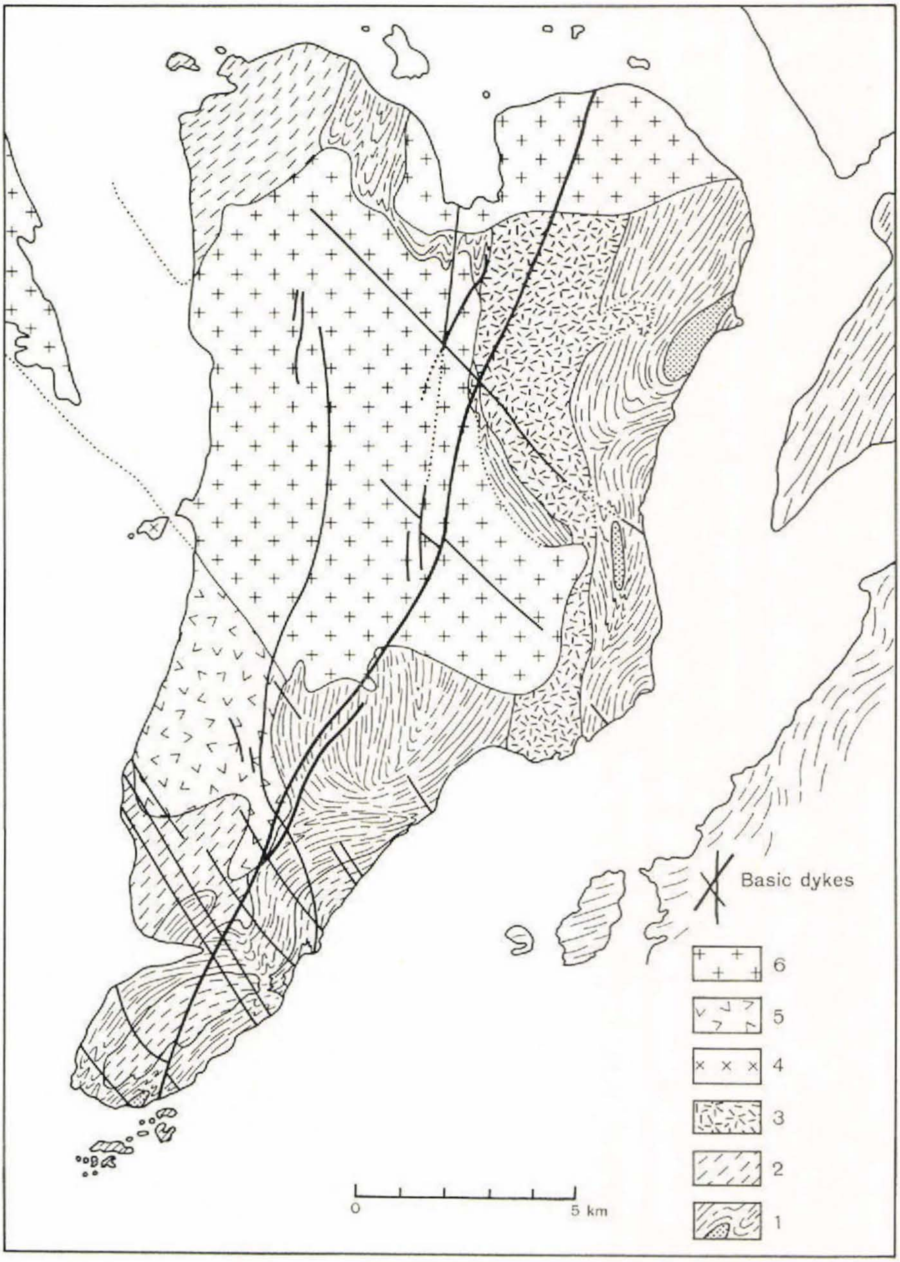

Fig. 1. Geological sketch map of Sermersôq. 1. Gneisses and mica schists with intercalations of granitic rocks (stippled). 2. Porphyroblastic granitic gneiss. 3–6. The younger granites. 3. Medium-grained foliated granite. 4. Coarsely porphyritic dark granite. 5. Coarse-grained porphyritic granite. 6. Coarse-grained coarsely porphyritic granite ("new granite").

I. GEOMORPHOLOGICAL OBSERVATIONS ON SERMERSÔQ

A. Introduction

The island of Sermersôq is one of the many islands which border the fjord-dissected Greenlandic coasts (Fig. 17 and Plate 1). It is situated in S Greenland, roughly between latitudes N 60° and 60°30′, and longitudes 45° and 45°30′ E. Kitdlavât (1273 m) in central Sermersôq is the highest point on the island, which has an area of over 150 square kilometers.

Geologically, the island of Sermersôq consists of granites, gneisses, and mica-schists, traversed by numerous basic dykes (Fig. 1). A coarsely porphyritic coarse-grained granite of monotonous appearance occupies the main part of N and central Sermersôq. The eastern and southern parts of the island consist mainly of strongly folded, steeply dipping gneisses and mica-schists. Most of the N–S and NW–SE directed valleys are developed along intrusions of basic dykes. E–W valley directions are mainly controlled by the presence of master joints or zones of close-spaced jointing. Important faults have not been observed.

A large part of the island shows a glacial morphology of the fretted upland type with ridges and peaks or horns formed by headward cirque extension. The almost unmodified imprints of recent glaciation are furthermore well displayed by many beautiful examples of cirques, horns, glacial valleys and lakes, moraine deposits, etc. Most of the valleys are now occupied by rivers, but the younger river erosion has not significantly modified the glacial character of the landscape.

The Napassorssuaq Gletscher is the only existing glacier of some importance on the island, but smaller cirque glaciers are common in the elevated interior of Sermersôq. The present day glaciers all face north, while the southward facing cirques are now deserted by the ice.

Of more regional interest than the above-mentioned geomorphological features is the recognition of four erosion surfaces on Sermersôq. These surfaces are of regional development in S Greenland. The present report is an attempt to relate the diverse glacial and interglacial morphological forms on Sermersôq with the erosion surfaces, and to correlate the latter with different cycles of erosion.

The author's investigations on Sermersôq in 1961 have been concerned mainly with the geology and petrology of the granites and gneisses. However, there are those inimitable evenings when the gloomy silhouettes of the mountains and valleys on Sermersôq appear sharply delineated against the moon-lit sky. As a rapidly moving cloud catches the spectator's attention, all of a sudden he will be fascinated by the sparkling play of changing forms in the sky contrasting against the sereneness of rock forms in the foreground. In this decor there was something intriguing about the land forms that appealed to the author and that led him to present this geomorphological account as a diversion from his petrological work.

The author is indebted to the Director of the Geological Survey of Greenland for his consent to publish this article. He wishes to thank his colleagues of the Survey for their interest and encouragement. Dr. A. L. SIMONS of the University of Amsterdam and Mr. A. WEIDICK of the Geological Survey of Greenland have read parts of the manuscript and have obliged the author by their most valuable comments. Sincere thanks are also due to Mr. JACK LARSEN, Copenhagen and the staff under his direction for skilful preparaion of the drawings and to Miss. A. VAN ARKEL, Amsterdam, for careful typing of the manuscript.

B. The erosion surfaces on Sermersôq

The four erosion surfaces on Sermersôq are referred to in the following as: the high-level erosion surface, the intermediate-level erosion surface, the low-level erosion surface, and the strandflat. Fig. 2 gives an idea of their distribution on the island.

Looking from the sea west of Sermersôq towards the island's west coast a beautiful view of the high-level erosion surface is obtained (Fig. 3). Here this surface appears as an almost flat surface forming high plateaus, which are dissected by glacial valleys. In central and NE Sermersôq, where a fretted upland morphology prevails, remnants of the same surface are found in the summit level of the peaks and ridges (Figs. 4, 6, 7 and 16). The summits in central and NE Sermersôq are generally between 900 and 1273 m high. In NW Sermersôq the plateaus are over 1100 m high; in a southern direction they become lower, and in S Sermersôq the highest top on the plateau north of Itivdleq is only 920 m high. These altitudes suggest a gentle southward or southwestward tilt of the high-level erosion surface.

Most of the area of the high-level erosion surface on Sermersôq is occupied by granites, which show a well developed exfoliation and an

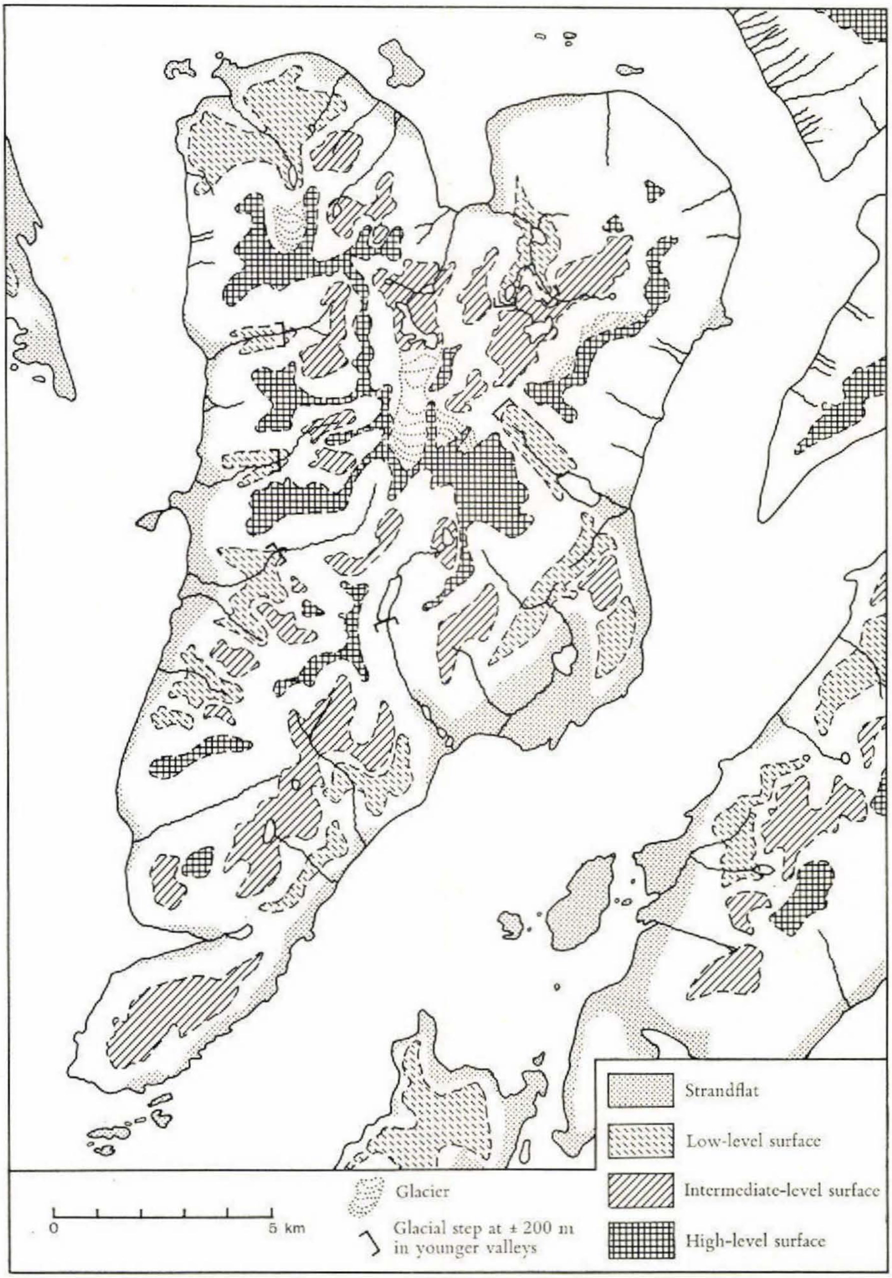

Fig. 2. The distribution of the four erosion surfaces on Sermersôq.

apparent liability to disintegration into blocks and finer-grained debris. The flatness of the plateaus on Sermersôq is accentuated by the presence of a cover of debris of variable thickness. Locally, where the high-level

Fig. 3. The high-level erosion surface on northwestern Sermersôq viewed from the sea. The valley on the right-hand side of the picture is Kûgârssûk. In this region the high-level erosion surface forms high plateaus with an average altitude of about 1000 m.

erosion surface has been stripped of this cover of debris, the remnants of a subdued landscape with gentle hills, characteristic of a pre-glacial mature landscape, often appear. This observation suggests that the high plateaus on Sermersôq were covered by thin plateau glaciers or stagnant ice caps exerting a protective effect, rather than by actively eroding ice.

The intermediate-level erosion surface is defined by a top level, plains, and a cirque and valley floor level at altitudes between 400 and 700 m (Figs. 5, 6, 7 and 16). This surface is developed as a plateau on the peninsula Kangeq, S Sermersôq; it is also observable as small plains on parts of north and northwest Sermersôq and on the peninsula Ikâríssat, E Sermersôq. It is not extensively developed in other parts of the island, but it often forms the highest level on several smaller islands around Sermersôq. The floor of a few cirques is at a somewhat lower altitude, near 350 m.

The low-level erosion surface is formed by low plains with altitudes between 100 and 250 m, but occasionally showing tops over 350 m high (Figs. 6 and 16). The latter tops apparently represent remnants of the intermediate-level erosion surface. The low-level plains occur mostly near the coasts, and they often form a gently seaward sloping terrace, separated from the intermediate-level erosion surface by steep slopes (NW Sermersôq, Ikâríssat). Furthermore, parts of the plain and broad floors of the morphologically younger glacial valleys (p. 13) are also part of the low-level erosion surface. These valleys show a characteristic

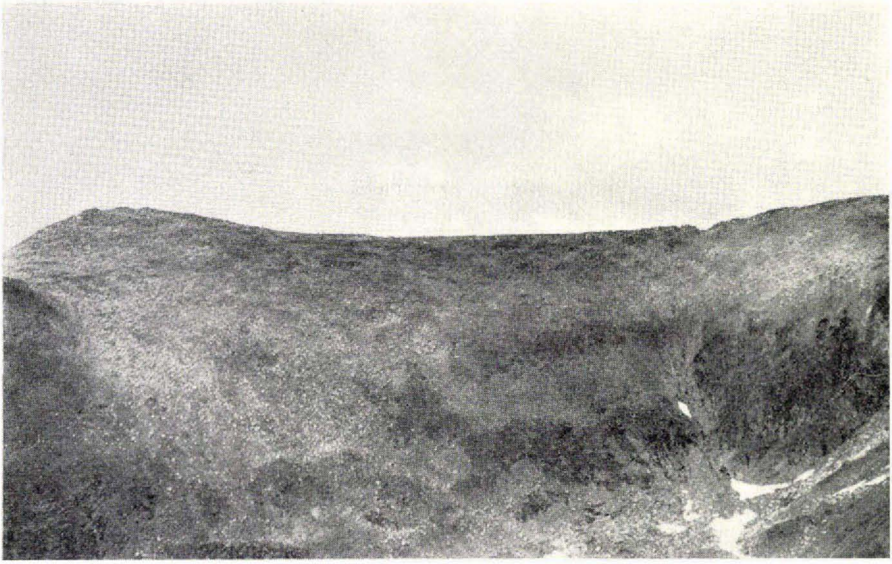

Fig. 4. The high-level erosion surface west of Qôrorssuasik viewed from the south. Here a remnant of the high-level surface is represented by a long, ENE–WSW trending ridge, about 1000 m high with an almost level crest line.

Fig. 5. The Itivdleq valley (right) and the peninsula south of this valley. The peninsula forms the southern part of Sermersôq and shows the intermediate-level erosion surface developed as a plateau with an average altitude near 600 m. In the foreground part of the strandflat is seen (photo K. Ellitsgaard-Rasmussen).

Fig. 6. The strandflat at Ikâríssat viewed from the south. Away from the observer steep slopes separate the strandflat from small local flats belonging to the low- and intermediate-level erosion surfaces. In the background a summit level of over 1000 m indicates the high-level surface. (photo K. ELLITSGAARD-RASMUSSEN).

step at an altitude of 300–350 m; at this point the valley floor descends steeply to 200–250 m (waterfalls), and then slopes gradually to sea level.

The strandflat is formed by strips lower than 50 m, which occur regularly along the coasts of the island (Figs. 5, 6, 11 and 14). On Sermersôq the strandflat has its widest extension on the peninsula of Ikâríssat (Fig. 6), where it extends more than 2 km inland. Here the strandflat shows typical mammillated forms, characteristic of a formerly glaciated surface. The strandflat is also well developed along the east coast of the peninsula Kangeq, S Sermersôq, where it forms a terrace-like strip of low land, about 100 m broad. Along the west coast of Sermersôq rounded beach boulders are found on the strandflat at levels between 20 and 50 m, at a distance of about 150 m from the present coast line. Small strips of strandflat are also discernible at the heads of small fjords, which form the drowned mouths of glacial valleys such as Itivdleq and the valley at Kangerdluatsiaq. Along the steep coastal cliffs of NW Sermersôq a strandflat has not developed.

The plateaus and plains belonging to the different erosion surfaces are generally separated from each other by steep slopes or cliffs and they may be designated as stepped erosion surfaces.

Fig. 7. The high ridges of northern east Sermersôq with summits near 1000 m as viewed from the west. In the foreground is part of the intermediate-level erosion surface.

C. The glacial valleys of Sermersôq

1) Characteristics of the glacial valleys on Sermersôq; the distinction of morphologically younger and older glacial valleys

A number of glacial valleys on Sermersôq have their debouchures at the level of the strandflat and characteristic glacial steps in their longitudinal profiles (Figs. 11, 12 and 16). End moraines of the glaciers which occupied these valleys are found on and near the strandflat; they indicate oscillations of the glacier tongues near the present valley debouchures. The strandflat is not dissected by these valleys, which have apparently been glaciated in a period broadly contemporaneous with the formation of the strandflat (pp. 31–32).

In the present paper two glacial stages[1]) are distinguished on Sermersôq. The first glacial stage is older than the strandflat, whereas the second glacial stage occurred after the forming of the strandflat was initiated. The valleys with debouchures at strandflat level and with

[1]) The term glacial stage is used with regard to conditions on Sermersôq. Times of great extension of the fjord and mountain glaciers on Sermersôq are referred to as glacial stages, and times of restricted extension of these glaciers as interglacial stages.

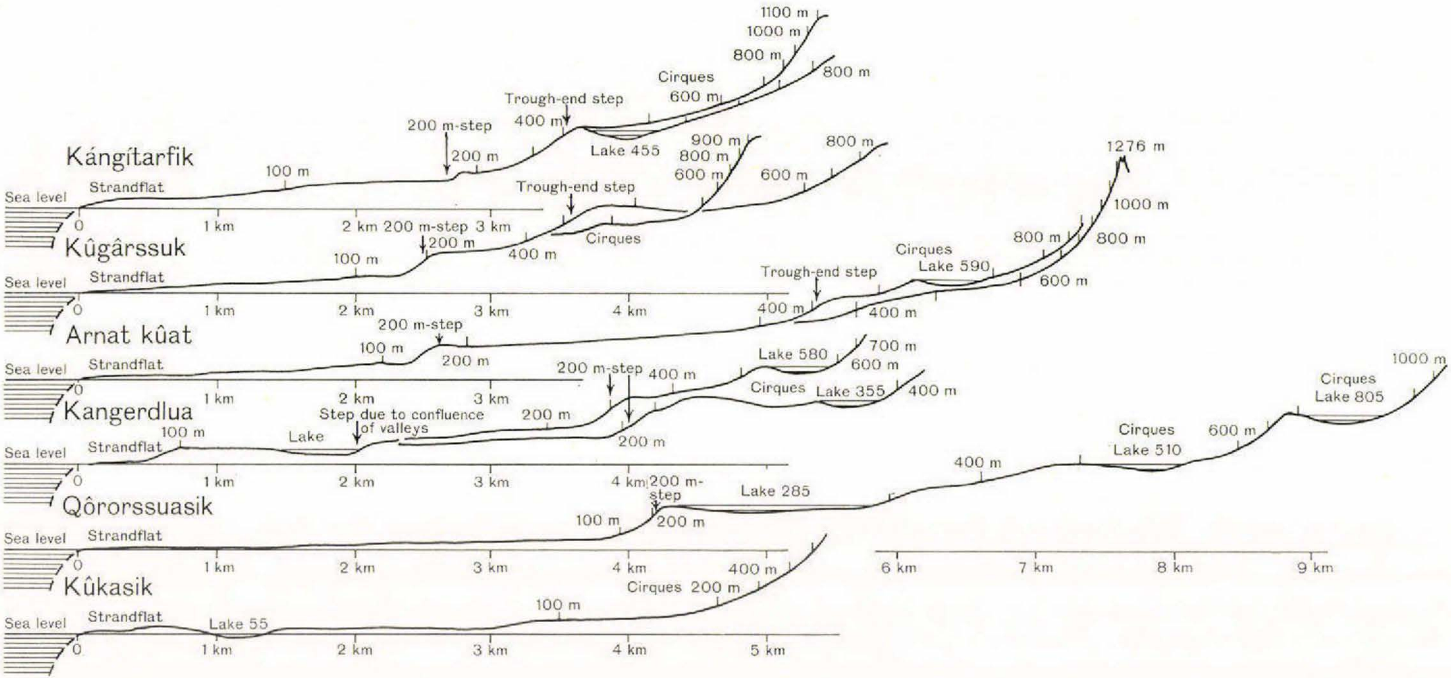

Fig. 8. Longitudinal profiles of younger valleys on Sermersôq.

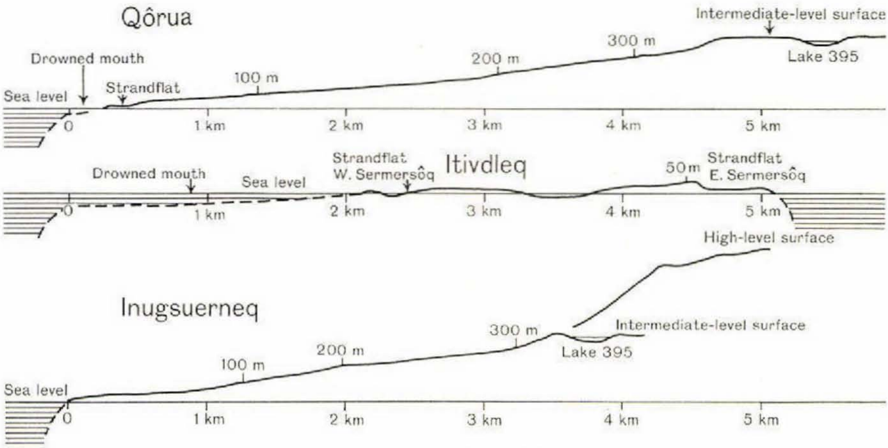

Fig. 9. Longitudinal profiles of typical older valleys on Sermersôq.

steps have acquired these distinctive characteristics in a period after the first and main glacial stage, and they will conveniently be referred to as the younger glacial valleys.

Examples of younger glacial valleys are Kángítarfik[1]), Kûgârssuk (Fig. 12) and Arnat kûat on W Sermersôq, Qôrorssuasik and Kûkasik (Fig. 11) on E Sermersôq, and the valley SE of Kangerdlua on N Sermersôq (Fig. 16). They have the following distinguishing features (Figs. 8 and 10).

1) They have their debouchures at the level of the strandflat (see above).
2) Their longitudinal profiles are characterized by steps. The most typical of which occurs at about 200–300 m (pp. 16–18).
3) Their headlands are formed by the fretted uplands in the elevated interior of the island.
4) Their cross-sections are pronouncedly U-shaped. Hanging valleys are well developed and modifications of glacial characteristics by later fluvial erosion do not appear significant.

Among the other glacial valleys, the valleys of Itivdleq (Fig. 5) and Qôrua (Fig. 13) on S Sermersôq show contrasting features compared with the younger valleys (Figs. 9 and 10).

1) The downstream parts of the Itivdleq and Qôrua valleys are deepened at a level below that of the strandflat and the present sea level. Consequently these valleys have their debouchures in a bay or small fjord, which represents the drowned valley mouths. The small strip of strandflat along the small fjord forming the western end of the

[1]) Geographical names on Sermersôq are indicated on Plate 1.

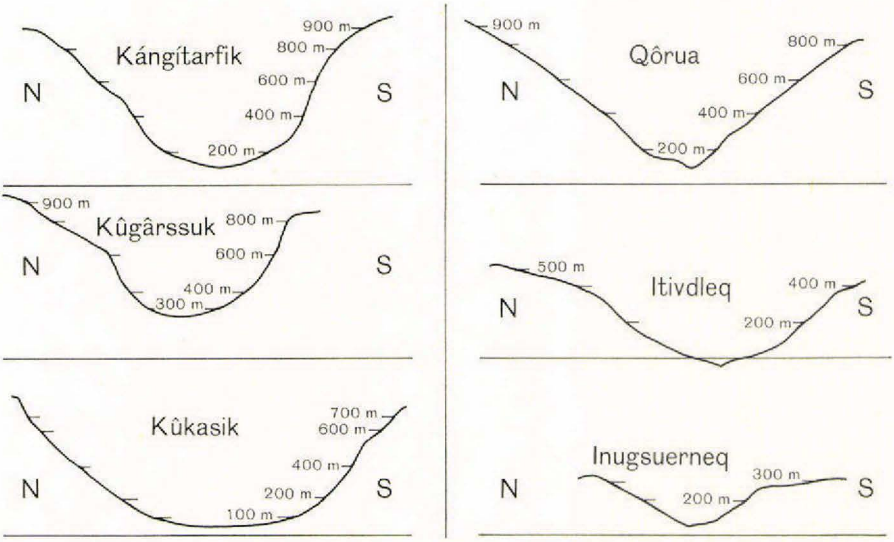

Fig. 10. Some typical cross profiles of younger and older valleys on Sermersôq.

Itivdleq valley is apparently formed after this fjord. No end moraines have been found in the valley.

2) The Qôrua and Itivdleq valleys do not show steps; their longitudinal profiles appear more graded.
3) The headlands of the Qôrua and Itivdleq valleys do not belong to the elevated parts of the island. The headlands of the Qôrua valley belong to the intermediate-level erosion surface, while the former Itivdleq glacier was a side-branch of the former Qôrnoq fjord glacier.
4) Cross-sections of the Qôrua and Itivdleq are more V-shaped. Modifications of hanging valleys by river erosion are more pronounced compared with the younger valleys.

The Qôrua and Itivdleq valleys were not glaciated during the second glacial stage and they owe their glacial forms mainly to the first glacial stage (p. 22). They may be designated as typical older valleys. The valley at Inugsuerneq, although not deepened below strandflat level, may also be referred to as a typical older valley with more graded longitudinal profile without steps, headlands formed by plains of the intermediate-level erosion surface, V-rather than U-shaped cross-sections, and no hanging side valleys.

The Kangerdluatsiaq and Napassorssuaq valleys (Fig. 14) on N Sermersôq have characteristics in common with the younger as well as with the older glacial valleys. They show the following characteristics of the typical older glacial valleys.

Fig. 11. The mouth of Kûkasik, a younger valley in E Sermersôq. The valley has its debouchure at the level of the strandflat; end moraines occur on the strandflat, which is apparently not affected by the younger glaciers.

1) Their outlets appear as drowned valley mouths, deepened below strandflat level.
2) As far as exposed, they do not show steps in longitudinal profile.

They have the following features in common with the younger valleys.

1) Their headlands belong to the elevated fretted uplands of central Sermersôq.
2) They show U-shaped cross-sections and almost no modifications by later fluvial erosion.

The following characteristic should also be noted.

The Napassorssuaq and Kangerdluatsiaq valleys are still partly occupied by northward facing cirque or valley glaciers.

The Napassorssuaq and Kangerdluatsiaq valleys were excavated mainly during the first glacial stage (p. 22). They have remained filled with glaciers during most of the time since the main glacial stage and have escaped interglacial and later modifications. Although their history differs from that of the typical older valleys they may, for convenience, also be referred to as older valleys.

Fig. 12. Kûgârssuk, a typical younger valley in W Sermersôq. At the confluence of the two side-valleys near the valley head a first step is discernible at about 400 m (compare with Fig. 8). The waterfall in the central part of the picture marks a typical step descending from about 200 m to about 125 m. Note the typical U-shaped cross profile and the headland belonging to the high-level erosion surface; compare with Fig. 13. (photo W. S. WATT).

2) The glacial steps in the younger glacial valleys

Fig. 8 shows longitudinal profiles of the younger glacial valleys on Sermersôq. They are characterized by the occurrence of a number of pronounced steps.

In Kángítarfik, Kûgârssuk (Fig. 12) and Arnat kûat a step at the trough-head marks the descent from the cirque level at 400–550 m to an altitude of 300–400 m. Waterfalls mark a second step where the valley floor descends from 200–300 m to 150–200 m. The latter step is designated as the 200 m step. The valley SE of Kangerdlua lacks a trough-head step, but the 200 m step is well developed (Fig. 15). Qôrorssuasik in S Sermersôq shows stepped cirques at 805 and 510 m besides a 200 m step. Kûkasik in W Sermersôq has two small steps at the trough-head, but it is the only younger valley lacking a well developed 200 m step.

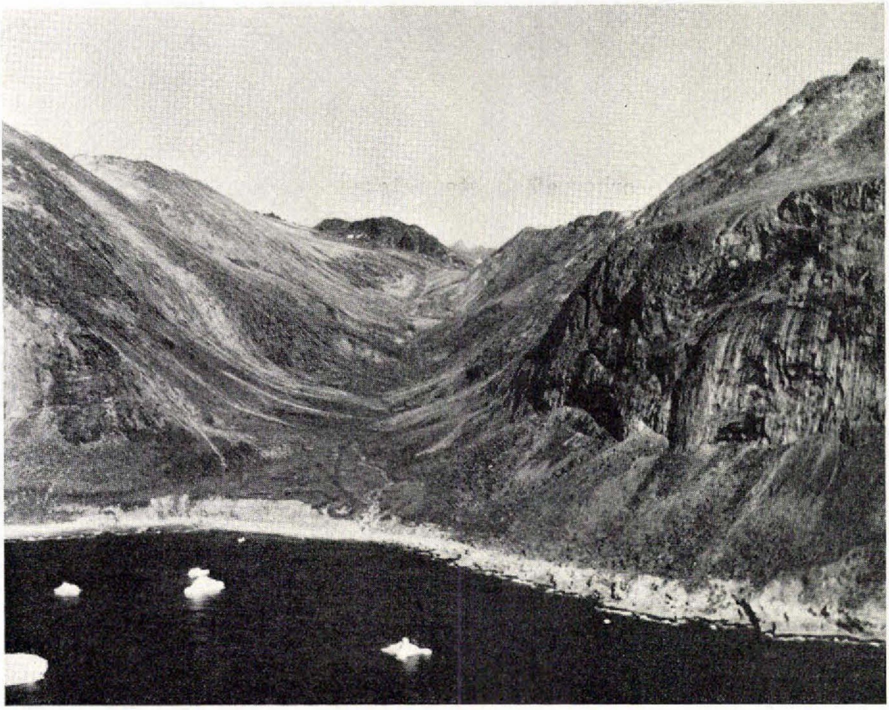

Fig. 13. Qôrua, a morphologically typical older valley in southern W Sermersôq. The valley's headlands belong to the intermediate-level erosion surface. Note also the graded longitudinal profile, the more strongly modified cross profile, and its debouchure in a bay; compare with Fig. 12. (photo W. S. WATT).

The trough-head step is obviously due to the confluence of converging cirques or valleys at the valley head (see for example COTTON 1947, pp. 253–271). The origin of the 200 m step is more intriguing. DE MARTONNE's conception of pre- or interglacial rejuvenation involving strong headward river erosion and the formation of knickpoints, which in a following glacial period are modified into steps (DE MARTONNE 1948, p. 908; SÖLCH 1935; NUSSBAUM 1938; CHARLESWORTH 1957, p. 328; KING 1959, and others) is favoured for the following reasons:

a) The 200 m steps are situated in the different valleys at comparable distances from the coast. In all valleys on W Sermersôq they occur at about 3 km from the coast, and in Qôrorssuasik on E Sermersôq and the valley SE of Kangerdlua on N Sermersôq at about 4 km from the coast (Fig. 8). By comparison with Qôrorssuasik the 200 m step in Kûkasik may also be expected at about 4 km from the coast, but at this site the trough-head step is found.

The occurrence of steps at fixed distances from the coast affords strong evidence for their origin as pre- or interglacial rejuvenation knickpoints. If an equal relief energy between headlands (in the present case the elevated central parts of Sermersôq) and a fixed base level is given, and if the pre- or interglacial headward erosion in the different valleys have been working on rocks of comparable hardness, the knickpoints might be expected at fixed distances from the coast. Headward erosion apparently worked at a faster rate in N and E Sermersôq (knickpoints at about 4 km from the coast) as compared with W Sermersôq (knickpoints at about 3 km from the coast). This inference is consistent with a conclusion reached later on other grounds, according to which the high-level erosion surface shows a S- or SW-ward tilt (pp. 24–25).

Alternative hypotheses fail to account for the occurrence of steps at fixed distances from the coast. Step formation by confluence of valleys is obviously not relevant as the 200 m step does not occur at sites of valley confluence. The steps occur mostly in granites which do not show any special structures, so that the formation of steps cannot be attributed to lithological features. A basic dike occurs at the site of the 200 m step in the Qôrorssuasik valley, but this dyke does not constitute a hard rock bar. Moreover, lithological or structural features (jointing) cannot be expected to occur at fixed distances from the coast. Headward erosion by glaciers depends on load and supply of the ice rather than on available relief energy and is not likely to result in steps at equal distances from the coast in the different valleys.

b) The occurrence of narrow strips of strandflat cut laterally in the fjord walls indicates an origin of the strandflat in a period after the modelling of the fjords by glaciers, that is after a main glacial stage. On the other hand, end moraines deposited on the strandflat at the debouchures of the younger valleys suggest a second glacial stage contemporaneous with or later than the formation of the strandflat. The inference that there have been two glacial stages and an intervening interglacial is corroborated by the observation that the downstream parts (below the 200 m step) of the younger valleys show graded profiles with a constant base level coinciding with the level of the strandflat (Fig. 8). This suggests that the downstream part of these valleys were incised by rivers and that the level of the strandflat coincided with the interglacial sea level.

With the sequence of glacial and interglacial stages deduced above the 200 m step in the younger valleys is conveniently explained as follows. At the height of the main glacial stage the surface of the valley glaciers on Sermersôq joined the ice surface in the fjords accordantly (see e. g., Gannett 1898; Davis 1900; Penck 1900; Gilbert 1904a and Cotton 1947, p. 227). The effective base level of erosion was then determined by this ice surface, which was presumably some hundred meters above the present level of the strandflat (the intermediate-level erosion surface at 500 m–600 m probably reflects this former base level of erosion, see p. 30). The disappearance of the fjord glaciers at the end of the main glacial stage caused a significant lowering of the effective base level of erosion with consequently a rejuvenation of the interglacial fluvial regime and the backward retreat of the knickpoints in the interglacial hanging valleys. These knickpoints were modified into steps during the second glacial stage.

The stepped cirques in some of the younger valleys (Qôrorssuasik) are apparently a comparatively recent feature connected with recent retreat of the snow line (Cotton 1947; Charlesworth 1957). Cirque formation is most active in the zone of the snow line, which since the end of the second glacial must have been progressively retreating from the older cirque level to the present level of cirque glaciers at altitudes above 900 m.

3) The valleys at Kangerdlua as an illustrative example of valley development on Sermersôq

The valley SE of Kangerdlua and the Napassorssuaq valley join each other at Kangerdlua (Figs. 14 and 15). At the junction of the two valleys an important glacial step is present; this step forms the headwall of Kangerdlua, a small fjord on N Sermersôq. As noted before (pp. 13–15), the valley SE of Kangerdlua and the Napassorssuaq valley differ in many aspects. The Napassorssuaq Gletscher is in a favourable N-ward facing position with regard to meteorological conditions (p. 24) and has persisted up to the present. Its downstream part has not been abandoned by the ice until recent times, and the broad, plane valley floor does not show marked irregularities. At Kangerdlua the Napassorssuaq valley appears as a hanging valley about 500 m above the strandflat level. On the other hand, the SE valley has been abandoned by the glaciers for quite a longer time. After a pronounced step between 350 and 200 m the valley floor descends gradually seawards until it joins the strandflat at Kangerdlua.

The diverging evolution of the two valleys at Kangerdlua can be accounted for by the following reconstructed sequence of events.

1) During the main glacial stage the valleys were occupied by a set of twin glaciers, whose confluence originated a step and an overdeepened basin in the valley floor.

2) In the succeeding interglacial stage the fjord glaciers retreated from the regions around Sermersôq. The overdeepened basin at Kangerdlua was flooded and a bay or small fjord was formed. The SE valley, abandoned by the ice, was subjected to rejuvenated headward river erosion and knickpoints were formed in the two interglacial rivers,

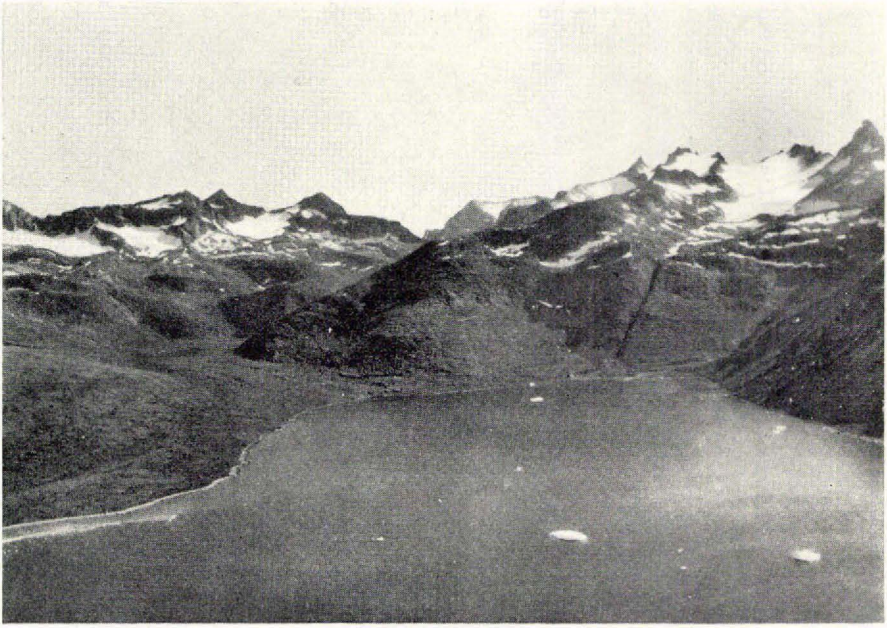

Fig. 14. Kangerdlua, north Sermersôq, viewed from the north. The bay is a drowned glacial step formed at the former confluence of the Napassorssuaq Gletscher (right-hand side of picture) and the glacier which occupied the southeastern valley (left-hand side of picture). The Napassorssuaq valley is a hanging valley, whereas the south eastern valley has its debouchure at the level of the strandflat. For further particulars seet he text. (photo W. S. WATT).

which occupied the same positions as the recent ones (Fig. 15). On the other hand, the Napassorssuaq Gletscher apparently persisted during this interglacial as at present. Its valley floor remained protected by the ice and no river incision and knickpoint formation took place.

3) A second glacial stage caused the modification into steps of the interglacial knickpoints in the SE valley. In this period both valleys at Kangerdlua were again filled with glaciers.

4) In the present interglacial the SE valley is again abandoned by the ice and reoccupied by rivers, which have not significantly modified the valley's glacial character. The Napassorssuaq Gletscher has eventually started to retreat and its valley appears as a hanging valley about 500 m above sea level; a gorge is forming rapidly.

4) The history of the glacial valleys and glaciations on Sermersôq

The differences between the older and younger valleys are grounds for the following conclusions.

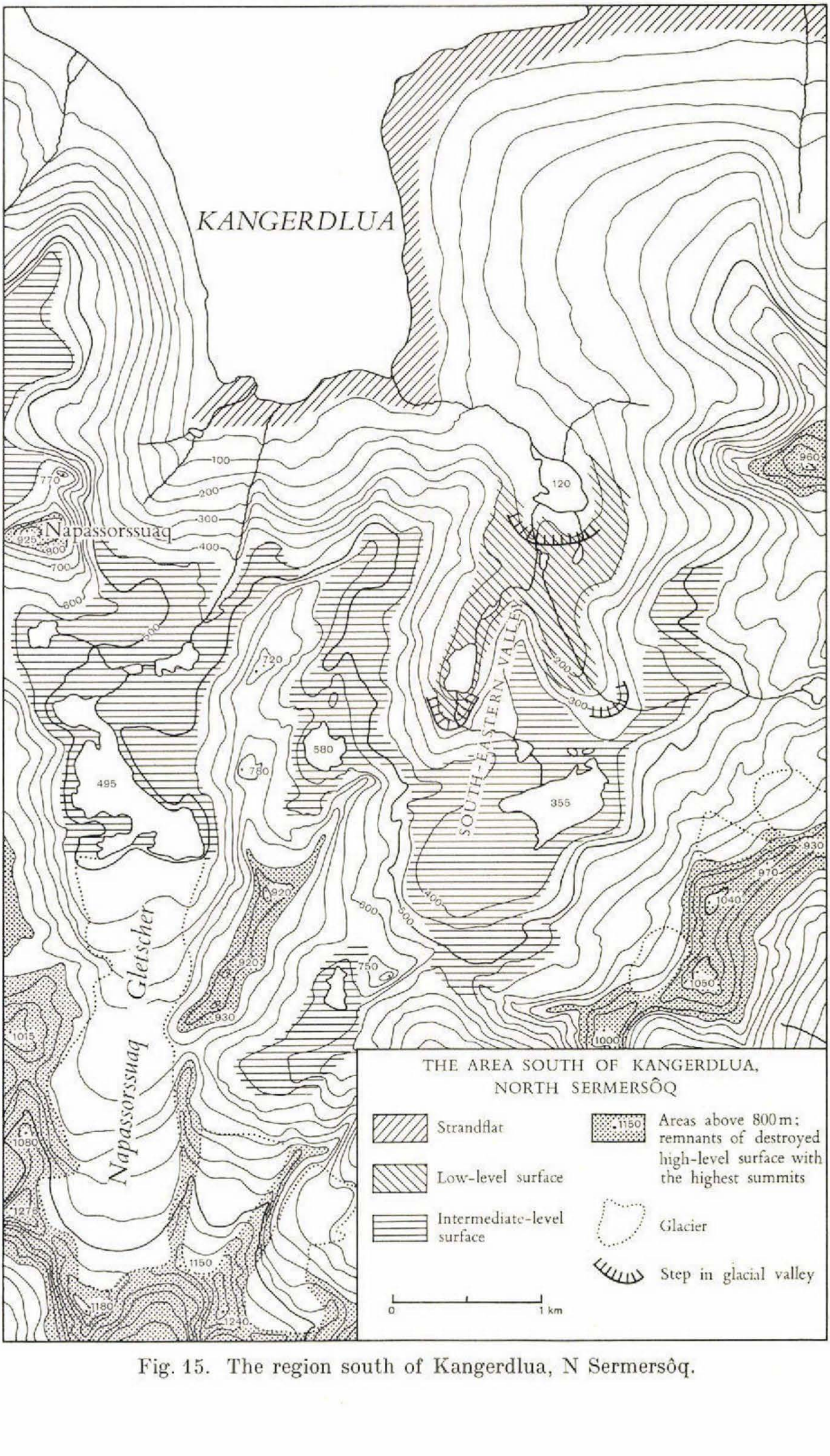

Fig. 15. The region south of Kangerdlua, N Sermersôq.

Of the two recognizable glacial stages the older is earlier than the strandflat. It is apparently the most important glacial stage characterized by the glaciation of the fjords. During this period the ice level in the fjords constituted the effective base level of erosion and was at least some hundred meters above the level of the strandflat. The surface of the valley glaciers on Sermersôq joined that of the fjord glaciers accordantly, while their floors were at different levels, depending on the rate of erosion of the respective glaciers. The Itivdleq valley, a side branch of the Qôrnoq fjord glacier, received ample supply from that source and consequently shows an appreciable overdeepening. The N-wards facing cirques in the headlands of the Kangerdluatsiaq and Napassorssuaq valleys also received a greater supply of snow, while the Napassorssuaq valley is joined at Kangerdlua by another valley from the SE, so that overdeepening is also to be expected in these valleys. The other valleys on Sermersôq were occupied by smaller glaciers and their floors apparently remained at higher levels.

In the subsequent interglacial stage the retreat of the fjord glaciers caused a drop in the effective base level of erosion from the former ice level in the fjords to the interglacial sea level. The downstream parts of the overdeepened valleys were flooded, whereas the smaller valleys appeared as hanging valleys above the interglacial sea level. In the latter valleys the rejuvenated headward river erosion caused the backward retreat of the knickpoints. Some valleys, as e. g. the Napassorssuaq valley, were not affected by the interglacial river erosion because their glaciers persisted during most of the interglacial and protected the valley floors from sub-aerial erosion.

In the second glacial stage the fjord glaciers again advanced to the environs of Sermersôq, but their ice level remained close to the level of the strandflat (pp. 31–32). Most valleys on Sermersôq were again glaciated. The interglacial river valleys with knickpoints were modified into younger valleys with glacial steps and debouchures at strandflat level. Other valleys have remained continuously filled with glaciers since the main glacial stage; they have persisted without significant modifications as older glacial valleys. A third group of valleys had their headlands already lowered below or close to the intermediate-level erosion surface during erosion in the main glacial and subsequent interglacial stages, and they were apparently not glaciated during the second glacial stage; these are the typical older valleys, characterized by more pronounced fluvial modification. The fact that the valleys with lowered headlands apparently escaped glaciation during the second glacial stage suggests that the latter glaciation had the more localized character of a mountain glaciation. The above considerations imply that the intermediate-level erosion surface is older than the second glacial stage.

II. SOME REGIONAL GEOMORPHOLOGICAL FEATURES IN GREENLAND

A. The fjord and valley system in S Greenland

1) Some characteristics of the fjord and valley system

The system of fjords and main valleys in the Ivigtut, Julianehåb, and Nanortalik regions show the following characteristics (Plate 2).

1) The main fjords and valleys show NE–SW and E–W directions; their consequent tributaries have NW–SE, and N–S directions.
2) The E–W main fjords and valleys generally coincide with important pre-Cambrian faults (examples: Sermiligârssuk, Tigssalûp ilua, Kúanit fjord, part of the Arsuk fjord, etc.).
3) NE–SW faults of equal importance as the E–W faults are not known in the region considered. The NE–SW fjords and valleys follow lithological and minor structural features, such as joints and minor faults, bedding and schistosity planes, dyke rocks and lithological boundaries. Demorest (1937, p. 41) has made similar observations in the Nûgssuaq region, W Greenland.
4) The NW–SE, E–W, and N–S consequent tributaries of the main fjords and valleys also follow similar lithological and minor structural features.
5) Many individual fjord systems show markedly asymmetric patterns instead of normal dendritic ones. Examples are Tigssalûp ilua, the Kúanit, Bredefjord, Igaliko Fjord, and Skovfjord, which show comparatively long and well developed side-fjords and -valleys on the northern side of the main fjords, but none or very few on the southern side. The islands and peninsulas between these fjords show straight N or NW coasts, but irregular S or SE coasts with many embayments. The divide of the drainage system on many of these islands and peninsulas is asymmetrically situated, being parallel and very close to the N coasts (peninsulas N and S of Tigssalûp ilua, Tôrnârssuk, etc.). Many peninsulas have presumably been divided into rows of islands by the headward recession of southward directed tributary valleys. However, around Sermersôq and the Sermilik and

Tasermiut fjords (Plate 3), an asymmetric development of the drainage pattern is not directly apparent. In these regions the E–W direction is strongly favoured and the occurrence of barbed valley junctions suggests frequent cases of piracy of NE–SW valleys by E–W ones. This is connected with a shifting of divides. The latter perhaps have developed in the interglacial stage.

6) The directions of the main fjords and valleys are often markedly oblique to the border of the present ice cap and the coasts.

The occurrence of E–W main fjords and valleys is easily understood as due to a pronounced direction of weakness determined by faults or fault zones. The reasons for occurrence of NE–SW main fjords and valleys and the predominance of S-ward directed valleys and fjords are, however, not so self-evident. Three possibilities will be considered below.

2) Possible factors controlling the development of the fjord and valley system

a) The predominance of NE winds may cause the accumulation of snow on the lee-side of cirques and mountains and give rise to SW-ward directed glaciers (GILBERT 1904b; HOPPE 1959; HOLDAR 1959). However, the present glaciers on Sermersôq all face north, and there are reasons to believe that during the previous interglacial the N-ward facing glaciers were also in the most favourable position for continued existence (pp. 19, 22). The orientation of cirque and other small glaciers may be influenced by wind directions, but this does not apply to the large fjord glaciers, which collect their ice from tributaries.

b) The situation of the ice cap N and E of the coastal regions (Plate 2 and Fig. 17) may explain the W- and SW-ward direction of flow of the main glaciers. However, where the border of the ice cap trends about N–S or E–W, the suppression of NW–SE valleys is not well understood. Furthermore, the asymmetric fjord systems and drainage patterns cannot be accounted for without resource to additional hypotheses.

c) Noting that the fjord-dissected high-level erosion surface on Sermersôq show a S- or SW-ward tilt (pp. 6 and 26), it may be suggested that the NE–SW fjords and valleys are consequent valleys developed on an initially SW-ward tilted surface. In this way the predominance of NE–SW valleys and fjords, the suppression of NW–SE directions, as well as the asymmetric development of fjord and drainage patterns can be satisfactorily explained in the following way.

On the pre-glacial SW-ward tilted high-level erosion surface in S Greenland a pre-glacial fluvial drainage pattern, consisting of a system

Fig. 16. View from the Kûkasik valley looking to the east. In the background the high-level erosion surface and patches of the intermediate-level erosion surface. Along the coast on the opposite side of the fjord the low-level erosion surface.

of SW-ward flowing consequent and E–W flowing subsequent main streams, developed. The subsequent E–W rivers were guided by main faults. The continued SW-ward tilting of the high-level erosion surface promoted the development of the S- and SW-ward flowing rivers and suppressed that of the N-ward flowing ones. This development resulted in asymmetric pre-glacial valley systems and drainage patterns showing a predominance of SW- and S-ward directed valleys. These drainage patterns were later inherited and accentuated by the system of fjords and glacial valleys.

The inference that the fjords and glacial valleys in S Greenland have developed after a pre-glacial fluvial drainage pattern is corroborated by other morphological features. For example, the peninsulas Ikâríssat and Nauligútoq along the E coast of Sermersôq are conveniently explained as spurs of older river valleys truncated by the fjord glaciers. Furthermore, the high-level erosion surface on Sermersôq often shows subdued pre-glacial landscape forms characterized by convexly rounded hills. Where these hills have been affected by later cirque erosion typical intersections of convex and concave surfaces have resulted (Davis 1909; Cotton 1947, 170–171).

The author has described a case in Portugal where the development of asymmetric river patterns is caused by a tilting of the land surface with consequent rejuvenation of the rivers flowing down the slope of the tilted surface (OEN 1958). On the other hand, the development of asymmetric valley patterns by glacial headward erosion (HELLAND 1875; JOHNSON 1904; TAYLOR 1914) is not easily conceivable because of the lack of base-level control in this process.

B. The regional distribution of erosion surfaces and some other geomorphological features in S Greenland

The regional occurrence of erosion surfaces in S Greenland has been noted by several authors. For example, WEGMANN (1938) has recognized a high area with summits between 800 m and 1800 m, an ancient level at an altitude of about 600 m, a lower level at about 300 m, and the strandflat. These four levels apparently correspond to the four erosion surfaces described in this paper. WEIDICK (in press) has reviewed the earlier works on this subject.

Plate 3 shows the distribution of the four levels in the area between Tasermiut and Bredefjord in S Greenland. The southward tilt of the high-level erosion surface is shown by its southward decreasing altitude; in the areas near the ice cap and north of Sermersôq the high-level erosion surface is above 1500 m, whereas its highest point on Sermersôq is at 1273 m. On the other hand, the intermediate- and low-level erosion surfaces and the strandflat do not show significant variations in altitudes. The intermediate-level erosion surface varies in altitude between 400 m and 700 m, but is mostly between 500 m and 650 m. The low-level erosion surface is mainly formed by strips with altitudes between 150 m and 250 m, but occasionally with tops above 300 m, while the strandflat comprises the coastal strips below 50 m.

The high-level erosion surface has its widest development in the areas near the inland ice and it presumably continues below the ice cap. However, the area situated between Julianehåb and Ivigtut (Plate 2 and Fig. 17) is characterized by the predominance of the intermediate- and low-level erosion surfaces and the strandflat. This area belongs to the Qagssimiut depression as recognized by WEGMANN (1938, pp. 125–126). According to WEGMANN (1938, p. 129) this depression was formed by crustal warping in a period later than the earliest peneplanation (the formation of our high-level erosion surface), but earlier than the formation of the strandflat. However, the intermediate- and low-level erosion surfaces are, like the strandflat, also levels of approximately constant altitude and traceable across the boundaries of the depression with the bordering high areas. Therefore the latter erosion surfaces must also be younger than the depression. The Qagssimiut depression presumably forms one of the S- or SW-ward tilted blocks, formed in connection

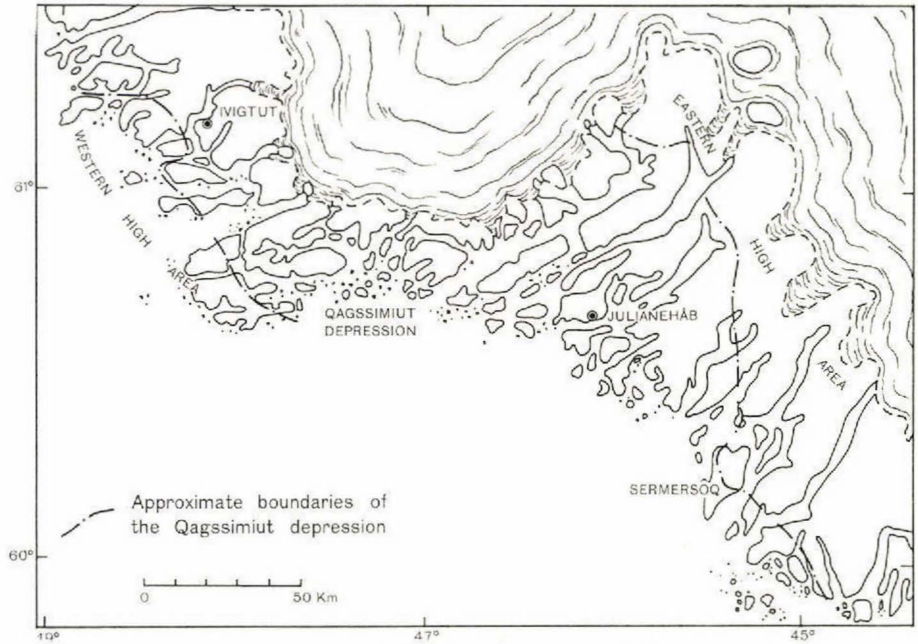

Fig. 17. The Qagssimiut depression according to C. E. WEGMANN (1938).

with the regional crustal uplifts in late Cretaceous to early Tertiary times (p. 29). In this depression the high-level erosion surface has been less elevated than in the bordering high areas and may not be distinguishable from the intermediate-level erosion surface.

Plate 3 also shows that the intermediate-level erosion surface is most extensively developed along the main fjords, especially near their debouchures.

Valleys of the same type as the younger valleys on Sermersôq are also of common occurrence in the regions surrounding that island. As indicated in Plate 3 almost all valleys with headlands belonging to the high-level erosion surface show a characteristic step as in the younger valleys on Sermersôq.

III. THE EROSION SURFACES ON SERMERSÔQ;
A DISCUSSION OF THEIR POSSIBLE ORIGIN

A. The high-level erosion surface

The high-level erosion surface represents the remnants of an old elevated peneplane, the precise age of which is as yet unknown.

In the graben zone of Igaliko (Ussing 1912; Wegmann 1938; Berthelsen 1961) the unfolded, non-metamorphic, Pre-Cambrian Gardar sandstone and intercalated volcanics have been deposited on an old surface, the sub-Gardar peneplane (Wegmann 1938, p. 61), which truncates the folded, metamorphosed and gneissified rocks of the older Pre-Cambrian Ketilidian sequence. Outside this graben Gardar sediments have hitherto not been found and it is believed that they have been removed by Post-Gardar erosion. It is possible that the high-level erosion surface, where it truncates the Ketilidian sequence represents partly the resurrected sub-Gardar peneplane. It may be compared, for example, with the resurrected sub-Cambrian peneplane in Norway (Strøm 1948, p. 19) or with the resurrected Pre-Cambrian peneplane underlying the Thule Formation in N Greenland (Koch 1935, pp. 7–8).

Although no precise data concerning the age of this (resurrected) peneplane can be given, some general considerations suggesting that it had been formed and at least partly elevated in pre-Cretaceous times may be presented.

a) The nearest younger sediments with which the high-level erosion surface can be compared occur in the Disko Bugt region, W Greenland. According to Koch (1929; 1935, pp. 105–113) a coastal landscape with gneiss plateaus 800–1000 m high, steep cliffs, and stretches of coastal low land already existed in the Disko Bugt region before the deposition of the Cretaceous. The Cretaceous-Tertiary sequence started with the deposition of coarse debris derived from the cliffs and plateaus along the foot of the cliffs, and proceeded with the deposition of delta and litoral sediments over the rest of the coastal low land. Thus, in the Disko Bugt region there exists a sub-Mesozoic surface or peneplane truncating the Pre-Cambrian, which had been elevated and dissected by valleys before the Cretaceous (Koch 1935, p. 107). An analysis of summit levels along the Greenlandic coasts has been attempted by

Koch (1923). Although at that time good topographic maps were not yet available, Koch's data show the existence in W and SW Greenland of an approximately level surface at an average altitude between 1000 and 1500 m. In the Disko area this high-level surface is interrupted by a depression due to pre-Tertiary faulting, in which Cretaceous and Tertiary sediments and basalts occur. This depression stretches below the inland ice across Greenland to Scoresby Sund on the east coast of Greenland. North of this depression the high-level surface again appears at about the same altitude as in the south, and it continues still further north, possibly to NW Greenland (Paterson 1951).

It may be concluded from the above that although it has not been proved in the field that the sub-Mesozoic surface in the Disko region can be correlated with the high-level erosion surface in S Greenland, the available evidence strongly suggest that this may well be the case. If this be true the high-level erosion surface in S Greenland should be considered as a pre-Cretaceous peneplane, the uplift of which started before or during the Cretaceous and most probably continued in the Tertiary.

b) Gardar acid plutonism in S Greenland is of the epizonal type as defined by Buddington (1959), according to whom epizonal plutons have consolidated at depths not exceeding 4 miles. The epizonal alkaline batholiths of Ilímaussaq (Ussing 1912) and Kûngnât (Upton 1960) are associated with ring dykes, while Gardar basic igneous rocks occur as sub-volcanic dykes and sills and as extrusive flows. From these general considerations the thickness of rocks that have overlain the presently exposed levels of Gardar plutonic rocks is estimated as not exceeding 5 km. As the country has been uplifted already since the late Pre-Cambrian (Koch 1935, pp. 120–121) no post-Pre-Cambrian sediments have been deposited. Menard (1961) has provided some estimates of the rate of regional erosion, which varies from 4,6 cm in 1000 years in the Mississippi region to about 20 cm in 1000 years in the Himalayas and Rocky Mountains. Taking an average value of 10 cm per 1000 year, the time necessary to erode 5 km of rock may be estimated at about 50 million years. Noting that the duration of the Cambrian is estimated at 80 million years, and that of the whole Paleozoic at 335 million years (Weller 1960), it seems probable that peneplanation of the post-Gardar land surface had already reached an advanced stage before the end of the Paleozoic.

B. The intermediate-level erosion surface

There is a relation between the distribution of the intermediate-level erosion surface and the fjord systems, as may be shown by the following examples from Sermersôq (for a more regional picture see Plate 3).

a) The intermediate-level erosion surface is most extensively developed in the southern part of Sermersôq, where the Itivdleq, Qôrua and Inugsuerneq are older valleys, glaciated only during the main glacial stage by tributaries or side-branches of the main fjord glaciers. In this period S Sermersôq formed a relatively small area surrounded on all sides by ice. The lowering of these small areas to the surrounding ice level may under favourable conditions be accomplished in a relatively short time by sub-aerial fluvial or fluvio-glacial erosion.

b) The intermediate-level erosion surface on the peninsula Ikâríssat borders directly to a main fjord. This peninsula can be regarded as a truncated spur of the pre-glacial valley now occupied by the fjord.

c) Isolated remnants of the intermediate-level erosion surface on NW Sermersôq also occur in a region dissected by older valleys (Kangerdluatsiaq, Kangerdlua) and bordering directly to a main fjord (Kanajormiut ikerasât).

d) In the interior parts of Sermersôq the intermediate-level erosion surface is formed only by a cirque level and by the broad floors of glacial valleys (Napassorssuaq valley). The fact that the cirques of older and younger valleys occur at an approximately constant level strongly suggests a control by a fixed level during the main glacial stage. In the latter period the level of accordance of ice surfaces at the junctions of the valley glaciers on Sermersôq with the main fjord glaciers presumably served as the approximate level below which no significant further excavation of the valley floors and cirques was possible. Therefore it is suggested that the altitude of the intermediate-level erosion surface corresponds roughly with the ice level in the fjords during the height of the main glacial stage.

Thus it is concluded that the intermediate-level erosion surface originated mainly contemporaneously with the glaciation of the fjords. The steep slopes, cliffs, and corrie walls separating the intermediate- from the high-level erosion surface suggest a process of cliff retreat by the action of cirque or cliff glaciers (SALISBURY 1895, pp. 887–889) and frost action as an explanation for the occurrence of the intermediate-level erosion surface as strips along the main fjords (SÖLCH 1938; COTTON 1947, pp. 284–299). Mammillated surfaces often indicate that the ice has eventually overflown large parts of the intermediate-level erosion surface, causing its further planation. However, it should be noted that the fjord systems have developed after a pre-glacial drainage pattern (p. 25–26), and the pre-glacial rivers presumably have already excavated broad valleys. The wearing down of the high-level erosion surface along the main valleys apparently started already in pre-glacial times (p. 33). GRØNLIE (1924, p. 114) has conceived a similar mode of formation for certain plateaus in Novaya Zemlya, as he explained them as "... due to the action of the great inland ice (or ices) that once overflowed the land, after a long preparatory work through weathering, winds and to some extent through river action above local base levels had taken place (AHLMANN 1918, pp. 643–644). A plateau levelled in that way may be called a glacial peneplane".

C. The strandflat

The arctic strandflat, a common feature along the arctic and Scandinavian coasts, has been described (COTTON 1947, pp. 195–196) as a partly submerged, rocky, coastal low land, very extensive in some regions, but trenched by fjords and straits and varying considerably in elevation from place to place. Its surface is notably roughened by glacial abrasion and at its back are steep cliffs, which descend to a sharp re-entrant angle at the base. The strandflat has been regarded either as a relic of the pre-glacial landscape (e.g., GILBERT 1904a; AHLMANN 1933; AHLMANN and LAURELL 1938; STRØM 1948; EVERS 1962) or the product of lateral corrasion or sapping in glacial periods (COTTON 1947, pp. 196–197). However, O. HOLTEDAHL (1960) and H. HOLTEDAHL (1960, 1962) have recently pointed out that the strandflat cannot be pre-glacial, for it has developed consequent to the entrenchement of the region by fjords. The observations in S Greenland support the latter thesis. Glacial erosion, marine abrasion, and sub-aerial erosion have been considered as important factors in strandflat formation. Extensive marine abrasion in pre- and interglacial periods is assumed by REUSCH (1901) and STRØM (1948), but considered as of minor importance by NANSEN (1922). The latter author has conceived a chiefly interglacial strandflat formation along a stable shore line, whereby frost action during the very cold time preceding each glacial stage is an important agency. O. HOLTEDAHL (1929, 1960), FLEMING (1940), DAHL (1947), and H. HOLTEDAHL (1959, 1960) stress the importance of backward working coastal, cliff and ice-foot or fringing glaciers.

The formation of the strandflat on Sermersôq and surrounding regions began at the end of the main glacial stage when the ice level in the fjords was significantly lowered. In this period of quickly shrinking glaciers strandflat formation may have been particularly active; the processes involved may have included epiglacial lateral corrasion and terrace cutting (BLACHE 1938) by melt-water streams (MANNERFELT 1945; HOPPE 1950; SCHYTT 1956; PRICE 1960), backward sapping by frost action, and cliff retreat due to the work of coastal and cliff glaciers. In the succeeding interglacial stage marine abrasion may or may not have been important. The accordant junctions of the valley floors of the younger glacial valleys with the strandflat indicate that during the renewed advance of the fjord glaciers during the second glacial stage the ice level did not rise appreciably above the strandflat level. The mammillated surface of the strandflat bears witness of occasional overflows of the fjord glaciers over the strandflat. During the second glacial stage favourable conditions for strandflat formation by similar agencies as mentioned above prevailed again and may have caused considerable enlargement of this coastal platform. The strandflat near Niaqornaq, at the debouchures of the Arnat kûat and Kûgârssuk valleys, W Sermersôq, apparently formed mainly in the second glacial stage by a process similar to that suggested by COTTON (1947, p. 198) for the strandflat at Angmagssalik, E Greenland. The latter is described as an ice-cut "pediment", which has the appearance of being developed by coalescing trough floors as the spurs between adjacent troughs have been sapped away by some process of lateral glacial corrasion. Finally, some post-glacial marine abrasion of the strandflat is indicated by elevated beaches, found on the strandflat in central W Sermersôq, about 150 m inland.

It is concluded that the strandflat was formed in the course of the interglacial and glacial stages following the main glacial stage. It reflects the approximate position of the coast lines, which have not been significantly changed since the end of the main glacial stage.

D. The low-level erosion surface

The low-level erosion surface may be considered as a lower and younger step or terrace occurring in association with the intermediate-level erosion surface. The residual mountains (up to 400 m high) protuding above the low-level erosion surface may be considered as remnants of the destructed intermediate-level erosion surface.

Since the lowering of an area to a surface of lower level is most easily accomplished by sub-aerial rather than by glacial agencies, it seems fair to assume that the low-level erosion surface has been formed mainly during the interglacial between the two glacial stages.

IV. EROSION CYCLES ON SERMERSÔQ

A. The first cycle of erosion

The erosion cycle operating in the period between the late Pre-Cambrian and the Mesozoic or Tertiary uplifts (p. 29) is here called the first post-Gardar erosion cycle. This first erosion cycle may have involved periods of rejuvenation with vigorous erosion alternating with periods of slower erosion, but as a result the land surface reached the mature stage of a peneplane possibly already before the Mesozoic.

The uplifting of this old peneplane has presumably occurred in stages and some parts of it may have been uplifted at a faster rate and for different amounts than other parts. Mesozoic and Tertiary epeirogenic movements involving regional faulting are known from E Greenland (Koch 1935, pp. 147–150) and they have undoubtedly also affected S Greenland. Thus the high-level erosion surface in S Greenland shows depressions and other differences in altitude. In the areas under consideration a SW-ward tilt of the high-level surface is often apparent.

B. The second cycle of erosion

1) The pre-glacial stage of the second erosion cycle

The uplift of the old peneplane of the first erosion cycle initiated the second cycle of erosion, which started with normal fluvial erosion. This uplift has been most active in the period before the gradual extension of continental glaciation gradually changed the fluvial erosion into fluvio-glacial, and eventually into glacial erosion. The pre-glacial rivers soon excavated a system of deep and broad valleys, which due to the SW-ward tilt of the high-level erosion surface formed an asymmetric drainage system showing a predominance of S-ward flowing streams (pp. 24–25). This asymmetric pre-glacial drainage system is inherited by the present system of fjords and glacial valleys. For a proper appraisal of the rôle of glacial erosion it has to be born in mind that appreciable relief development may already has taken place in pre-glacial times and that the pre-glacial surface was not the flat surface of the old peneplane of earlier erosion cycles.

2) The main glacial stage

With the extension of glacial conditions the fjord glaciers advanced towards the coasts, choosing their way along the pre-glacial river valleys. The chief modifications of the latter valleys into fjords and glacial valleys include (1) an increase in width; (2) a change of V- into U-cross profile; (3) a cutting-off of terminal portions of tributary valleys, and thus an elevation of their embouchures; (4) an intensification of certain irregularities of gradient in valley floor and the excavation of rock basins; (5) the truncation of spurs and a straighthening of the valley course (see for example, McGEE 1894; COTTON 1947). A considerable amount of overdeepening by the main fjords must be assumed.

The pre-glacial topography is an important factor in determining the further course of relief development. Between the deeply incised pre-glacial river valleys portions of the uplifted old peneplane were preserved as highly elevated remnants. Soon after the extension of glacial conditions these elevated areas became situated above the snow line and covered by protective plateau glaciers and stagnant ice sheets. Only by this concept of glacial protection (TAYLOR 1914; ODELL 1937; DEMOREST 1939; GLENN 1941; COTTON 1947, p. 310; STRØM 1948, discussions by VAUGHAN LEWIS and ODELL, pp. 24, 26) can the preservation of large parts of the old peneplane be understood. On the other hand, more or less extensive strips along the main pre-glacial valleys may have been worn down by the pre-glacial erosion. For long times during the main glacial stage these areas remained situated between the ice level in the fjords and the snow line and subject to fluvio-glacial erosion. This tended to a further lowering of the areas along the main valleys to the level of the ice in the fjords, which was the temporary effective base level of erosion. Eventually these strips of lowered areas were overflown by the ice when glacial conditions reached a maximum. The intermediate-level erosion surface is thus further planated and modelled by glacial agencies.

The retreat of the fjord glaciers at the end of the main glacial stage caused a significant drop of effective base level of erosion from the former ice niveau in the fjords to the interglacial sea level. Thus, with the interglacial stage, a third cycle of erosion was inaugurated. Contemporaneous uplift is not a necessary condition for the initiation of this new erosion cycle.

In the transition period between the main glacial stage and the succeeding interglacial the fjord glaciers were shrinking quickly and eventually the fjord valleys were flooded by the sea. In this period the formation of the strandflat was initiated (p. 31).

C. The third cycle of erosion

1) The interglacial stage

The third cycle of erosion started with rejuvenated, vigorous, interglacial river erosion in the inter-fjord regions. The disappearing mountain glaciers on Sermersôq had left hanging valleys above the interglacial sea level. Strong headward river erosion in these valleys caused the backward retreat of the knickpoints to a certain distance inland. Below these knickpoints the valleys have acquired graded longitudinal profiles. Formation of the strandflat may have continued in this period by marine abrasion and/or frost action. The destruction of the intermediate-level erosion surface by interglacial erosion caused the formation of the gently coastward sloping low-level erosion surface (p. 32).

2) The second glacial stage

The second glacial stage is characterized by a mountain glaciation. The valleys with headlands above the snow line were again filled with glaciers, but the other valleys with already lowered headlands were not glaciated. In the latter valleys fluvial erosion continued modifying the older glacial valleys into graded river valleys. On the other hand, in the renewedly glaciated valleys fluvial erosion was interrupted and the knickpoints were fixed and modified into glacial steps (pp. 17–18).

The mammillated surface of some of the broader strips of the strandflat indicates that this coastal platform has occasionally been overflown by the ice of the fjords. This cannot have occurred during the main glacial stage, which is prior to strandflat formation. Therefore it must have happened during the second glacial stage, which is thus also marked by a renewed advance of the fjord glaciers. However, during most of the time of the second glacial stage the ice level in the fjords cannot have been appreciably higher than strandflat level (p. 32). As discussed before, the strandflat has undergone considerable enlargement in this glacial stage.

The fretted uplands of central Sermersôq are also a feature of the second glacial stage (during the main glacial stage the high-level plateaus were protected by an ice cover). Cirque erosion is believed to be most effective when related to a mountain glaciation and a snow line (Cotton 1947). These conditions were realized on Sermersôq during the second glacial stage. In this period rapid cirque recession has caused the enlargement of older cirques and the formation of new ones, resulting in the present day broad cirque floors with sharp peaks and ridges in between them. With the waning of glacial conditions the snow line progressively retreated to higher levels, giving rise to the formation of cirque stairways in some of the younger glacial valleys.

Exfoliation joints in the granites and other rocks on Sermersôq strikingly follow the topography and morphological forms of the second glacial stage, and therefore, they must have originated in this period (OEN 1965).

3) Recent emergence of the strandflat

Raised beaches about 150 m inland on the strandflat on W Sermersôq indicate recent oscillations of sea level relative to the land during the present inter- or post-glacial period. The strandflat, now largely emerged, was formerly submerged over large parts. The recent rejuvenation of erosion has mainly involved the incision of the glacial valley floors and the strandflat by recent rivers.

Table 1. *The geomorphic development of Sermersôq.*

FIRST CYCLE OF EROSION	Emergence of land in the late Pre-Cambrian followed by long periods of crustal stability and erosion, eventually resulting in the formation of a peneplane.	PRE-GLACIAL PERIOD
	Uplifting of the old peneplane (high-level erosion surface) accompanied by crustal warping or regional block faulting resulting in the formation of SW-ward tilted crustal blocks.	
SECOND CYCLE OF EROSION	Initiation of a new erosion cycle consequent upon the uplift of the old land. Rapid incision of broad and deep valleys and development of an asymmetric fluvial drainage system on the SW-ward tilted old surface.	
	Advance of glaciers towards the coasts along the pre-glacial valleys and modification of the latter into glacial and fjord valleys. Preservation under a protective ice cover of certain portions of the high-level erosion surface which were situated above the snow line. At the same time destruction of other portions of the same surface situated below the snow line and formation of the intermediate-level erosion surface by fluvioglacial and glacial agencies along the main valleys.	MAIN GLACIAL STAGE ON SERMER-SÔQ
	Retreat of the fjord glaciers from the coastal areas and consequently a drop in effective base level of erosion from the former ice level in the fjords to the interglacial sea level. Initiation of a new erosion cycle. Formation of the strandflat.	
THIRD CYCLE OF EROSION	Rejuvenated strong interglacial river erosion causing the backward retreat of knickpoints in the ice-abandoned hanging valleys on Sermersôq. Destruction of portions of the intermediate-level erosion surface and formation of the low-level erosion surface. Enlargement of the strandflat.	INTER-GLACIAL STAGE ON SERMER-SÔQ
	Mountain glaciation on Sermersôq and modification of interglacial river valleys into younger valleys with steps. Sculpture of the fretted upland morphology of central Sermersôq. Enlargement of the strandflat. Sheeting (exfoliation) in the granites.	SECOND GLACIAL STAGE ON SERMER-SÔQ
	Emergence of the strandflat and incision by recent rivers and torrents.	RECENT INTER-OR POST-GLACIAL STAGE

V. CONCLUDING REMARKS

The main conclusions of this paper with regard to the geomorphic development of Sermersôq are summarized in table 1. Since the erosion surfaces and other geomorphological features described from Sermersôq seem to occur on a regional scale in S Greenland, the sequence of events indicated in the table may apply for wider regions in S Greenland.

It appears that the intermediate and lower erosion levels have their most extensive development in the coastal areas, and that they are insignificantly developed in many areas closer to the present border of the inland ice. As Wegmann (1938, p. 125) has stated, the inland ice seems previously to have covered larger portions of the high landscape, but it did not spread to its outermost parts, which were consequently sculptured by more local glaciers. It is suggested that the line of demarcation between the lower coastal areas and the higher inland areas coincides approximately with the border of the great inland ice in former periods. The absence of the low-level erosion surface and the strandflat in the inland high-level areas indicates that in the latter areas an interglacial and second glacial stage cannot be distinguished; these areas have presumably been continuously glaciated from the beginning of the first glacial stage to their comparatively recent deglaciation.

The dating of the high-level erosion surface and that of certain younger doleritic dykes of possible Tertiary age (Berthelsen 1961) are interrelated problems. These dykes are truncated by the high-level erosion surface and they cannot be younger than the latter surface. Provided that the correlation of the high-level surface in S Greenland with the sub-mesozoic surface in the Disko region is correct (pp. 28–29) the doleritic dykes in S Greenland are not likely to be of similar age as the Tertiary dykes in the Disko region. In the latter region faulting and uplift took place in the Cretaceous and Tertiary, contemporaneous with or before the intrusion of the dykes and the outpouring of magma over the surface. In S Greenland no Tertiary lavas are known. Alternatively, if the contemporaneity of the dolerites in the Disko region and in S Greenland is postulated, the high-level erosion surface in S Greenland should be ascribed a late Tertiary age. In that case a considerable amount of erosion in the early Tertiary must be assumed to account for the absence of lavas in S Greenland and for the truncation of the dykes by the high-level erosion surface.

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Færdig fra trykkeriet den 31. december 1965.

Plate 1

Topographic map of Sermersôq. (By courtesy of the Geodætisk Institut, Copenhagen).

MEDD. OM GRØNL. BD. 179. NR. 5. [OEN ING SOEN]. PL. 1

Plate 2

The fjords in the region between Ivigtut and Julianehåb, S Greenland. Geological data (incomplete) after unpublished maps compiled by J. H. ALLAART, A. BERTHELSEN and T. C. R. PULVERTAFT from reports by geologists of the Geological Survey of Greenland.

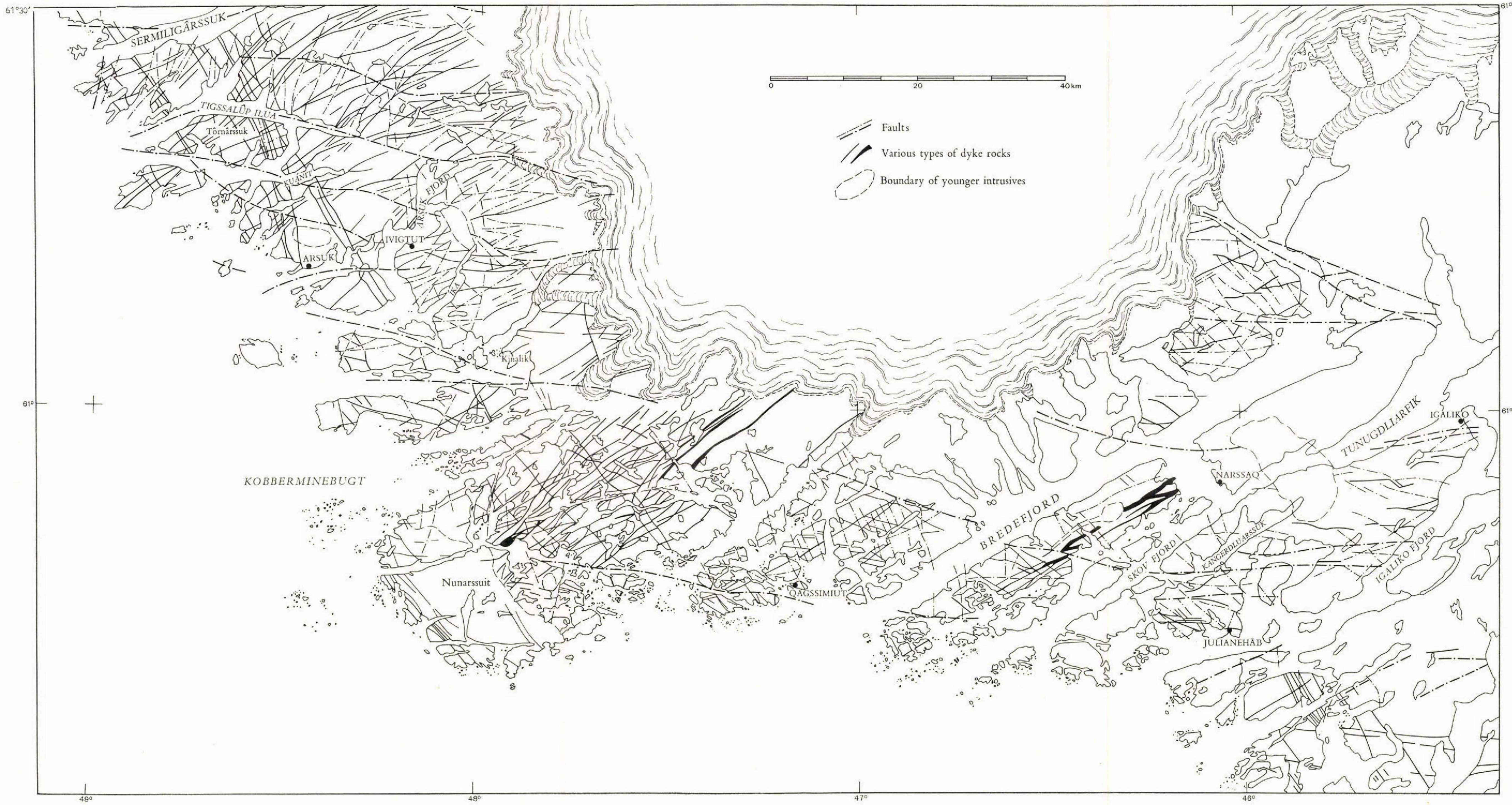
61°30'
61°30'
61°
61°
49°
48°
47°
46°
0
20
40 km
Faults
Various types of dyke rocks
Boundary of younger intrusives
SERMILIGÅRSSUK
TIGSSALÛP ILUA
Tôrnârssuk
IVIGTUT
ARSUK
ARSUK FJORD
Kinalik
KOBBERMINEBUGT
Nunarssuit
QAGSSIMIUT
BREDEFJORD
SKOV FJORD
NARSSAQ
TUNUGDLIARFIK
IGALIKO
IGALIKO FJORD
JULIANEHÅB

Plate 3

The distribution of the four erosion surfaces in the Nanortalik and Julianehåb regions, S Greenland. The interpretation is based on 1:20,000 topographical maps provided by the Geodætisk Institut, Copenhagen.


47°
46°
45°
61°
60°30'
60°
ICE CAP
ICE CAP
BREDEFJORD
IGALIKO FJORD
HIGH-LEVEL SURFACE
HIGH-LEVEL SURFACE
TASERMIUT
QÔRNOQ
SERMERSÔQ
0
10
40km
High-level surface
Intermediate-level surface
Low-level surface
Strandflat
Step in younger glacial valley