Rock glacier types on Disko, Central West Greenland

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Lobate-, tongue-shaped-, and piedmont rock glaciers are described from the island Disko (53° W 70° N), central West Greeland. The study is based on interpretation of aerial photographs and preliminary field investigations. The lobate rock glacier type is classified as talus-derived and ice-cemented. Tongue-shaped- and piedmont rock glaciers are classified as glacier-derived and ice-cored.

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Geomorphological mapping in progress has shown rock glaciers to be aboundant on the island Disko, West Greeland (53°W 70°N). The purpose of the present paper is to draw attention to this locality and to describe the different geometrical types of rock glaciers occurring there. Further, the probable origin and significance of the different rock glacier types will be discussed.

The paper is based on field studies in the southern and western part of Disko (Fig. 1), and on examination of aerial photographs (1:55000 and 1:35000) covering the island.

The rock glaciers on Disko are all developed in talus material originating from tertiary basalts, which covers large parts of the island. In plan, the rock glaciers represent three geometrical types (as described by Wahrhaftig and Cox 1959): 1) *Lobate rock glaciers,* in which the length is less than the width; 2) *tongue-shaped rock glaciers,* in which the length is greater than the width; and 3) *piedmont rock glaciers,* which actually are tounge-shaped rock glaciers with a spatulate enlargement at the terminus. Lobate rock glaciers are relatively small forms (30-300 m long) and usually line the foot of cliffs and valley walls, while the two other types usually are considerably larger forms (500-6000 m long) and flow down valley axis (Fig. 2). From a genetical point of view, the observed rock glaciers may be classified as either A) *glacier-derived* and B) *talus-derived.* The geometrical type 1) is usually talus-derived, while 2) and 3) in most cases are glacier-derived. The talus-derived rock glaciers are supposed to be *ice-cemented,* that is, they contain debris cemented by interstitial ice and/or discrete ice lenses, while the glacier-derived rock glaciers are expected to be *ice-*

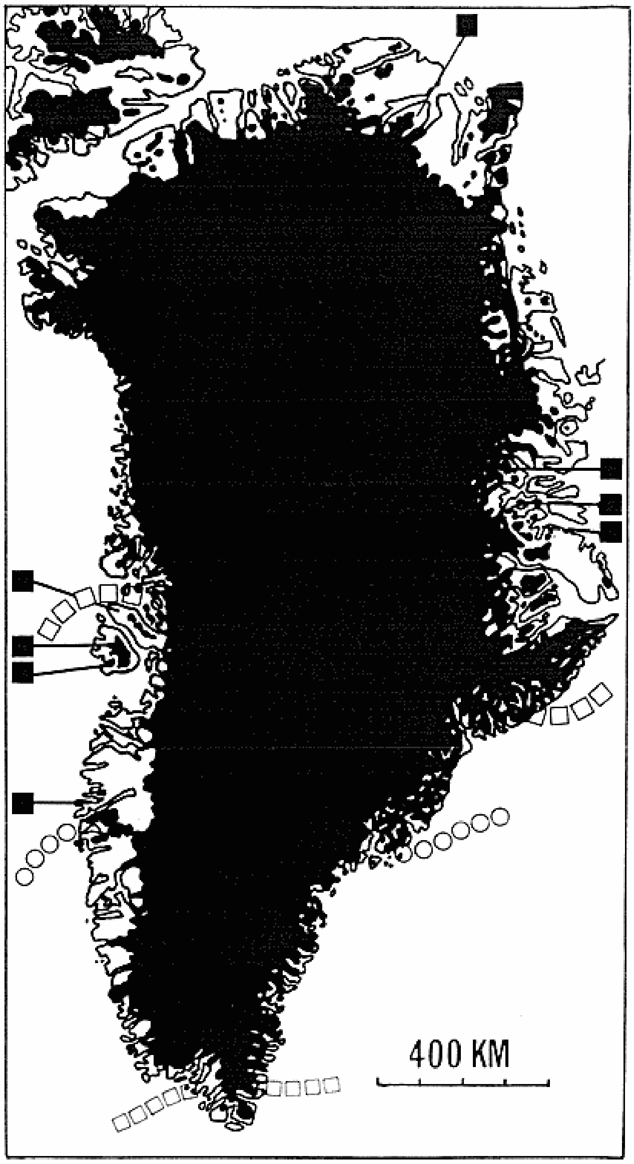

Fig. 1. Greenland. Map showing the present glaciation (black), as well as the southern limit for continous permafrost (large squares), discontinous permafrost (circles) and sporadic permafrost (small squares). Permafrost limits after Karte (1979). Known occurrences of rock glaciers are indicated by black squares.
Fig. 1. Grønland. Nuværende glaciation er vist med sort. Sydgrænse for kontinuert-, diskontinuert- og sporadisk permafrost er vist med hhv. store firkanter, cirkler og små firkanter. Permafrostgrænser efter Karte (1979). Kendte blokgletscherforekomster er angivet med sorte kvadrater.

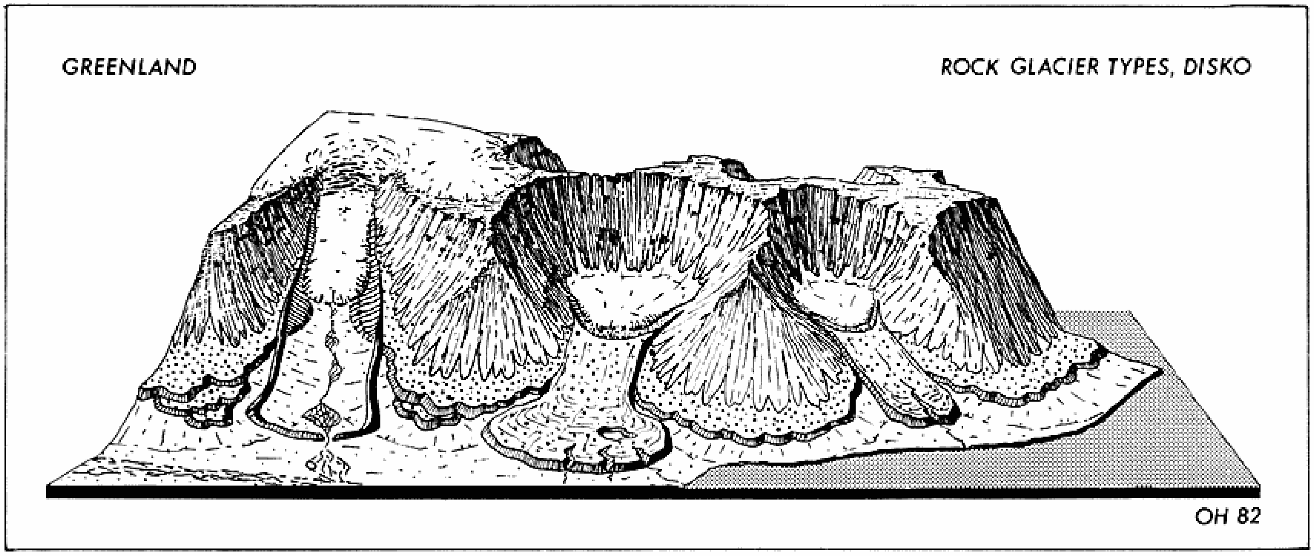

Fig. 2. Idealized diagram showing the three geometrical rock glacier types represented on Disko. Lobate rock glaciers are lining the foot of cliffs and valley walls. Tongue-shaped rock glaciers (right) and piedmont rock glaciers (center) originate in partly ice-filled cirques with mountain walls rising high above. In contrast to this, only lobate rock glaciers are usually found in a valley, where the upper end is glacierized (left). The landscape rises to height about 900-1200 m.a.s.

Fig. 2. Blokdiagram visende blokgletschertyper på Disko, Grønland. Lobate blokgletschere optræder ved bjergsidernes fod. En tungeformet blokgletscher ses til højre, midt i billedet ses en piedmont blokgletshcer. I dale, hvis øvre ende er isdækket (til venstre) findes kun den lobate blokgletschertype.

cored, containing a core of glacier ice, possibly with a large englacial load of talus, and mantled by debris (see also Potter 1972). This hypothesis, however, needs further field investigations to be tested.

The first paper on what is now called rock glaciers was published by Steenstrup (1883) in Danish language, describing glaciers and associated features from Greenland. The first papers in English language on rock glaciers appear to be those by Spencer (1900), speaking about »a peculiar form of talus«, and Rohn (1900), speaking about »talus slopes that flow«. Capps (1910) was, however, the first to use the term rock glacier.

Although it thus is about hundred years since the first description of rock glaciers in Greeland was presented by Steenstrup (1883), further descriptions are relatively few and the knowledge on the distribution of rock glaciers in Greenland is far from complete. Apart from the above mentioned paper by Steenstrup (1883), rock glaciers in Greenland are mentioned in Barton (1897), Drygalsky (1897), Steenstrup (1901), Weidick (1968), Beschel and Weidick (1973), Humlum (ed., 1977 and 1980), Donner (1978) and in Funder & Petersen (1980). The most detailed discussion on rock glaciers are that found in Weidick (1968), who considered rock glaciers to be derived from stagnant, debris-covered glacier ice, isolated from the lateral margins of late-glacial glaciers. Also Barton (1897) suggested a genetic relationship between glaciers/moraines and rock glaciers.

From the above-mentioned literature, rock glaciers are known from the Umanak district, around the Disko Bugt, and from a southern site near Holsteinsborg (Fig. 1), all in West Greenland. In East Greenland rock glaciers are described from Geologfjord (73°N, Funder and Petersen 1980). From the examination of aerial photos, the author has identified rock glaciers near Independence Fjord (North Greenland) and in the Mestersvig district (East Greeland).

Rock glaciers are usually considered a periglacial phenomena, indicating the presence of permafrost, at least in connection with active rock glaciers (Barsch 1977 and 1978, Barsch et.al. 1979, Haeberli et al. 1979). For this reason, increased knowledge of rock glacier types present in Greenland and their present state of activity, will have significance for arctic periglacial research. Also from a hydrological point of view, a more detailed knowledge of the distribution of rock glaciers in Greenland is desirable, as runoff from rock glaciers in other parts of the world is known to be substantial, perhaps larger than that from glaciers in the same area (Corte 1978). In this respect, further field investigations concerning the type and volume of ice contained in the rock glaciers will have considerable interest.

Talus derived lobate rock glaciers

Lobate rock glaciers have in the literature been referred to as talus piles (Cross and Howe 1905), talus glaciers (Crawford 1913; Smith 1973), superimposed talus fans (Behre 1933), small rock streams (Kesseli 1941), glaciers enterres Lliboutry 1961), protalus lobes (Richmond 1962), valley-wall rock glaciers (Outcalt and Benecict 1965), talus rock glaciers (Johnson 1975) and protalus rock glaciers (Gray

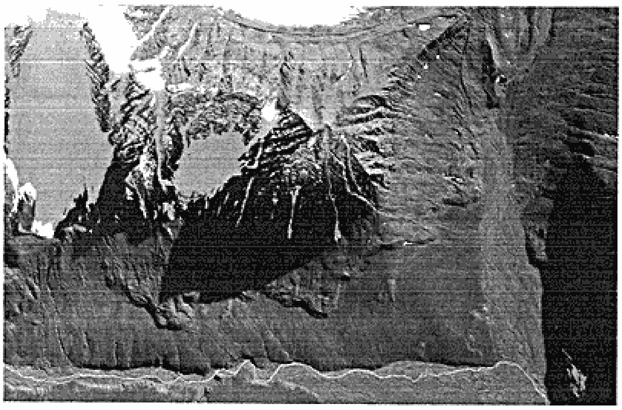

Fig. 3. Large lobate rock glaciers in the central Disko. North is toward the bottom of the picture. 1964.08.27. Reproduced with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:45000.

Fig. 3. Store lobate blokgletschere, central Disko. Omtrentlig målestok 1:45000.

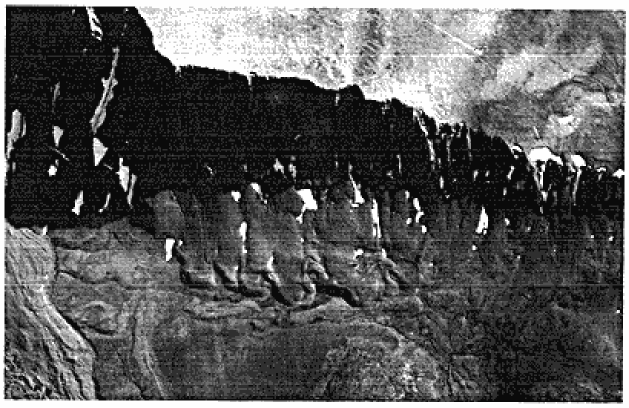

Fig. 4. Small lobate rock glaciers in southwestern Disko. North is toward the bottom of the picture. 1962.08.18. Reproduced with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:10000.

Fig. 4. Små lobate blokgletschere, sydvestlige Disko. Omtrentlig målestok 1:10000.

1970). The term lobate rock glacier was introduced by Domaradzki (1951), and has since gained footing as general designation for this rock glacier type (see e.g. Wahrhaftig and Cox 1959; Porter 1966; Blagbrough and Farkas 1968; White 1976; Ellis and Calkin 1979; Swett, Hambrey and Johnson 1980; White 1981; Humlum 1982), even though several of the above mentioned designations still are in current use.

Lobate rock glaciers on Disko are 30-300 m long, their thickness is 10-30 m, frontal slope 35-50°, upper surface slope 5-25° away from the adjoining valley wall, possibly a surface depression is found in the upper part of the rock glacier. A surface relief of 2-5 m consisting of ridges and furrows may be found on large lobate rock glaciers (Fig. 3), while smaller rock glaciers usually display a simpler surface topography (Fig. 4). Possibly two or three generations of lobate rock glaciers appear to be superimposed on each other (Fig. 2 and 4), resulting in a complex topography. Particularly large lobate rock glaciers are found beneath prominent chutes in the free wall above, probably reflecting the increased talus input on the slopes below. The lobate rock glaciers on Disko locate mainly along valley walls exposed to the north, while south-facing slopes lack lobate rock glaciers and in addition are characterized by relatively gentle gradients (Fig. 5). All lobate rock glaciers are developed from the lower part of talus slopes. No glaciers are found at their upstream end at present, and there are no signs of the former existence of small glaciers in this position. Lobate rock glaciers on Disko therefore appear to be entirely talus-derived.

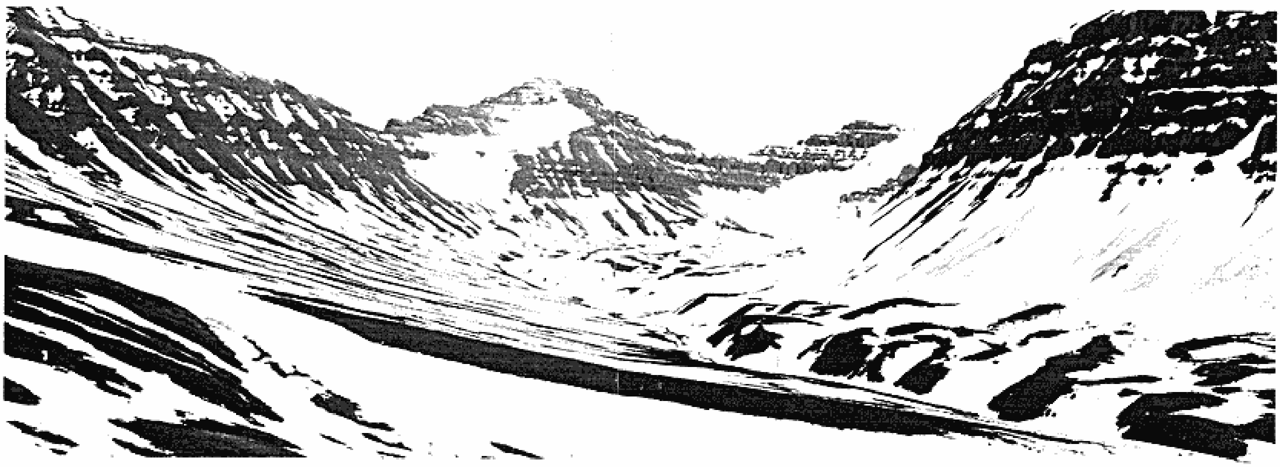

Fig. 5. Lobate rock glaciers extending from the foot of a north-exposed valley wall near Mellemfjord, West Disko. Note dirty snow avalanches on the talus slope above the rock glaciers. 1978.07.06. The rock glacier front is about 20 m high.

Fig. 5. Lobate blokgletschere ved foden af nordvendt bjergside, østlige Disko. Blokgletscherfronten er ca. 20 m høj.

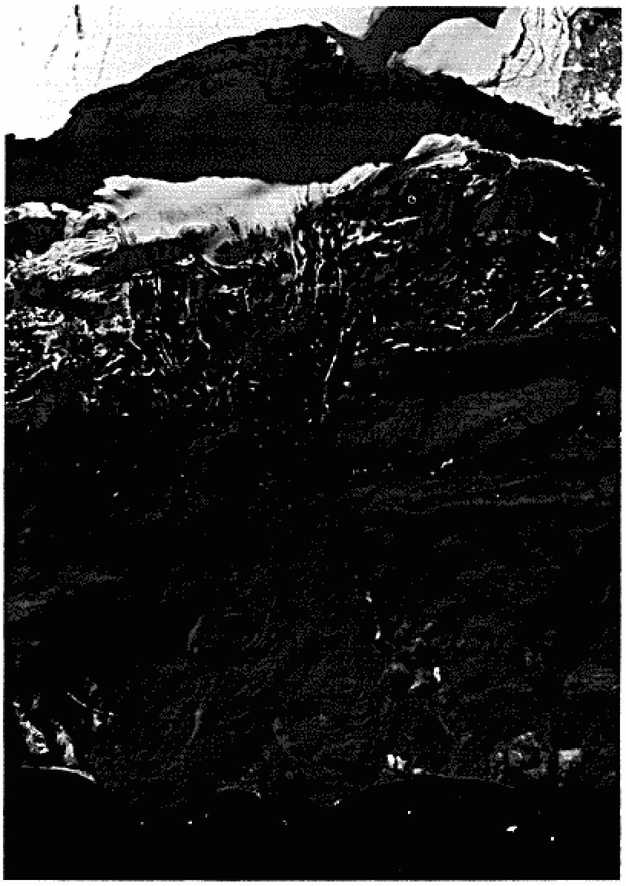

Fig. 6. Tongue-shaped rock glacier at the east coast of Disko. A small glacier is seen at the rock glacier head. Note conspicuous ridge-and-furrow pattern on the rock glacier surface. North is toward the right. 1964.08.29. Reproduced with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:45000.
Fig. 6. Tungeformet blokgletscher ved Diskos østkyst. Ved blokgletscherens øvre ende ses en lille gletshcer. Omtrentlig målestok 1:45000.

The individual lobate rock glaciers are covered by coarse blocky ruble, with a typical dimension of about 0.4-0.8 m. Natural sections in the lobate rock glaciers has shown that below this surface layer the interior is dominated by more fine-grained sediments, with some large blocks present. No detailed investigations on the stratigraphy have, however, been carried out. This applies to investigations on the type of ice content, as well. On lobate rock glaciers with surface depressions, »inner depressions«, temporary pools may exist, in which pockets of fine-grained sediments are deposited.

As both the inactive and fossil examples of lobate block glaciers do not display any signs of meandering surface furrows or collapsed pits, pointing at the former existence of a massive ice core (Vernon and Hughes 1966), the ice in this rock glacier type is assumed to be interstitial ice and perhaps discrete ice lenses only. The lobate rock glaciers on Disko thus appear to be ice-cemented.

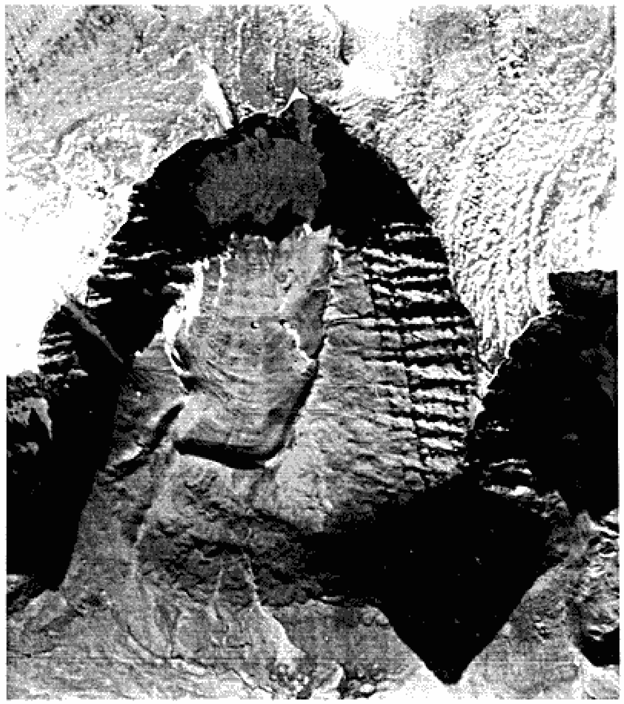

Fig. 7. Small tongue-shaped rock glacier near the west coast of Disko. Note the weak ridge pattern on the rock glacier surface. North is toward the bottom of picture. 1964.08.27. Reproduced with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:21000.
Fig. 7. Lille tungeformet blokgletscher, vestlige Disko. Omtrentlig målestok 1:21000.

Glacier-derived tongue-shaped rock glaciers

Tongue-shaped rock glaciers (Fig. 2) have in the literature been referred to as block streams (Domaradzki 1951) or just rock glaciers. Since the publication of the classical paper by Wahrhaftig and Cox (1959), the designation tounge-shaped rock glacier has however been almost universally used.

Tongue-shaped rock glaciers on Disko are 500-6000 m long, their thickness is about 20-75 m, frontal slope 35-50°, slope of the upper surface is depending on the topography of the underlying rock glacier bed.

All tongue-shaped rock glaciers on Disko are characterized by the presence of a glacier at the upstream end, and this rock glacier type is therefore classified as glacier-derived. The typical glacier at the rock glacier head is surrounded by prominent mountain cliffs, probably supplying the glacier with large amounts of talus material. The frequent observation from aerial photos of dirty snow avalanches on the glacier surface in the accumulation area lend support to this hypothesis. It is therefore assumed, that these glaciers contain an abnormalous large englacial load of talus material, presumably partly organized in discrete debris layers corresponding to the individual rock-fall events. It is furthermore hypothesized that following melt-out of some of this debris, a protecting surface layer consisting of coarse talus will be

Fig. 8. Tongue-shaped rock glaciers near Mellemfjord, West Disko. Note incised meandering furrows on the rock glacier surface. North is toward the lower right corner. 1964.08.27. Reproduced with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:50000.

Fig. 8. Tungeformede blokgletschere, vestlige Disko. Bemærk de meandrerende furer på deres overflade. Omtrentlig målestok 1:50000.

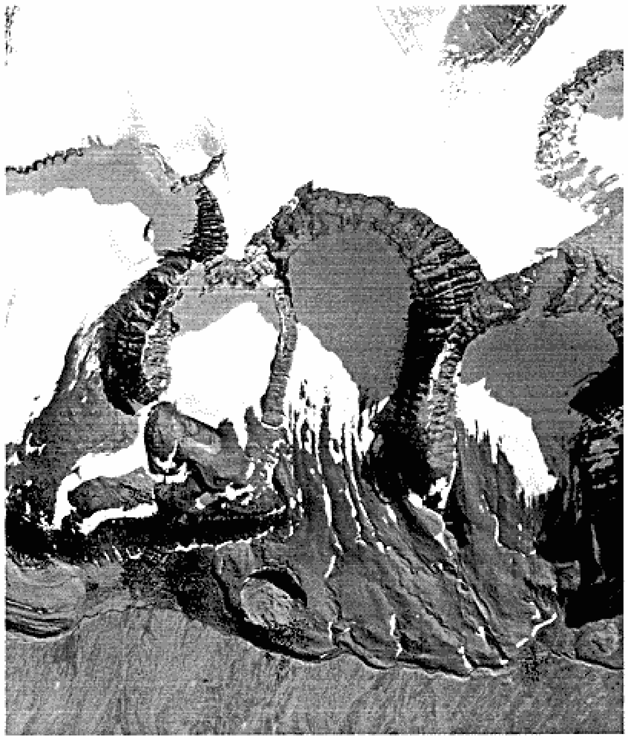

Fig. 9. Piedmont rock glaciers near Mellemfjord, West Disko. Note the large pit and the incised meandering furrows on the rock glacier surface. North is toward the bottom of the picture. 1964.08.27. Reproduced with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:37000.

Fig. 9. Piedmont blokgletschere, vestlige Disko. Omtrentlig målestok 1:37000.

formed, reducing further supraglacial melting. An important cause for reduced melting may be the operation of a Balch-ventilation process in this surface layer (Thomoson 1962). Tongue-shaped block glaciers are thus assumed to be ice-cored, containing a core of dirty glacier ice. The observation of meandering surface furrows and pits (see below) lend support to this assumption.

A surface relief of 2-5 m consisting of transverse ridges and furrows is found on many tongue-shaped rock glaciers (Fig. 6). Near the flanks this transverse pattern usually gives way to a few longitudinal ridges and furrows. The ridge-and-furrow pattern mostly occurs near the rock glacier terminus and below steep sections of the rock glaciers. The pattern thus appears to be associated parts of the rock glacier body characterized by decelerating/compressing flow, and may be interpreted as the surface expression of deformations/foldings in the rock glacier interior. This has earlier been proposed by Wahrhaftig and Cox (1959), who also considered the possibilities of overthrusting along closely spaced fault surfaces and annual cycles of growth as explanation of this conspicuous surface pattern. A less conspicuous transverse ridge-and-furrow pattern is found on some small tongue-shaped rock glaciers (Fig. 7). This pattern is thought to be a melt-out feature derived from prominent debris layers in the rock glacier ice core. Several tongue-shaped rock glaciers furthermore display meandering surface furrows and pits (Fig. 8), probably caused by melting of an interior massive ice core (Vernon and Hughes 1966) by flowing water.

The individual rock glaciers are covered by a coarse surface layer, below which more fine-grained sediment with dispersed large rock fragments are found, much the same as was described for the lobate rock glacier type. Until now, no detailed stratigraphic investigations have however been carried out.

Glacier-derived piedmont rock glaciers

What in the present paper is called piedmont rock glaciers (Fig. 2) has ealier been described by Wahrhaftig and Cox (1959) under the heading spatulate rock glaciers. The prefix »piedmont« is used here because of the well established corresponding use of this designation in connection with geometrical similar glaciers.

Piedmont rock glaciers on Disko are few, and they correspond closely to tongue-shaped rock glaciers with the exception of an abrupt widening near the terminus (Fig. 9). The typical piedmont rock glacier forms when a tongue-shaped rock glacier enters a trunk valley from a hanging valley or side valley, and there spreads laterally. A special type of piedmont rock glacier forms when a tongue-shaped rock glacier, because of a protruding obstacle in the rock glacier

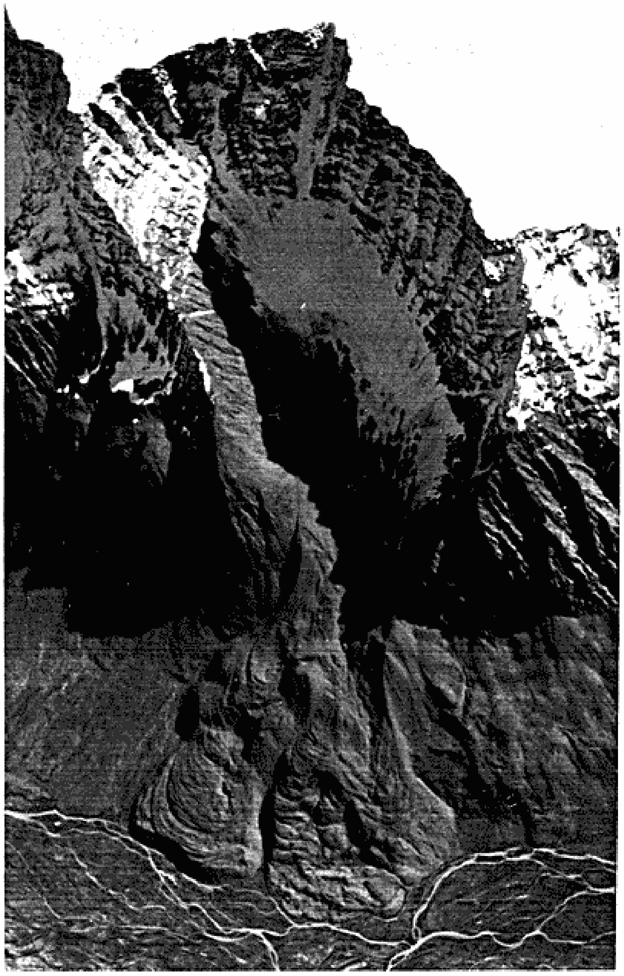

Fig. 10. Rock glacier with two lobes near Nordfjord, West Disko. The bifurcation may have been caused by a protruding height in the rock glacier bed. North is toward the lower right corner. 1964.08.27. Reproduces with permission A 592/82 of the Geodetic Institute, Denmark. Approximate scale 1:22000.

Fig. 10. Blokgletscher med to lober, vestlige Disko. Omtrentlig målestok 1:22000.

bed, develop two seperate tongues (Fig. 10).

Piedmont rock glaciers are as tongue-shaped rock glaciers glacier-derived, and probably contain a core of glacier ice with a large englacial load of talus material. Piedmont rock glaciers also display conspicuous ridge-and-furrow patterns, as well as deep surface furrows and pits.

The effect of snow cover on rock glaciers

Although no detailed investigations have been carried out on the rock glaciers during the winter period, a few observations on the distribution of the snow may give some ideas of the possible relation between the snow cover and the rock glaciers as permafrost features.

Figure 11 shows a complex of rock glaciers in a locality near the west coast of Disko. The picture was taken in June 1978, before the summer melt had really begun. It appears as significant, that as a consequence of drifting snow all ridges in the ridge-and-furrow pattern on the rock glacier surface are almost bare. This obviously ensures that the rock glacier body emits heat to the atmosphere more efficiently than the surrounding valley bottom, which is covered by a insulating snow cover. Winter temperatures are therefore expected to penetrate to greater depths in rock glaciers than in the surrounding terrain. During the summer, cold air with high density stay trapped in the lower part of the coarse surface layer on the rock glaciers, thus preventing any significant warming of the rock glacier interior. The surroundings, which may lack a similar surface layer, are on the other hand warmed during the summer. In short, the ridge-and-furrow pattern on rock glaciers thus ensure the efficiency of the Balch ventilation process, and rock glaciers may as moving permafrost features invade areas without originally permafrost, and still be in stable overall thermal equilibrium with the surroundings. In this case, I would suggest that permafrost areas represented by rock glaciers should be designated as *allochtonous permafrost* in contrast to other types of permafrost, which should be designated as *autochtonous permafrost.*

Activity and age of rock glaciers

The preliminary investigations have indicated that rock glaciers on Disko probably represent all stages of activity; active, inactive and fossil. Following Barsch and King (1975), rock glaciers can be classified as: 1) active rock glaciers, which show an actual movement, 2) inactive rock glaciers, which still contain ice but no longer show any movement, and 3) fossil rock glaciers, which are ice free and more or less collapsed, depending on the former type of ice content.

It seems that the major part of rock glaciers on Disko at present are inactive or even fossil. Most of the supposed active rock glaciers are located in the central part of the island, but further field studies are needed to clarify the question about the present activity of rock glaciers on Disko.

A few supposed active rock glaciers occur in coastal areas along Mellemfjord and Nordfjord. These rock glaciers override Late-glacial and Holocene marine terraces, and even reach the present shore (Fig. 12) Due to the possible activity of some of these rock glaciers (steep front, standing at the angle of repose), the absence of prominent beach formations cut into the rock glacier front cannot with certainty be used as an argument against present relative emergence of the island, as has been done by Donner (1978).

The age of rock glaciers on Disko are not known with certainty. Donner (1978) proposed that rock glaciers at the west coast of the island were Neoglacial in age, i.e. formed after the Hypsithermal Interval, which culminated about 6000 years ago (Porter and Denton 1967, Sugden and John 1976). However, it is now realized that some Holocene phases of glacier expansion occurred before and during the Hypsithermal Interval (Denton and Karlén 1973, Sugden and

Fig. 11. Rock glaciers near Mellemfjord, West Disko. In the foreground the terminus of a piedmont rock glacier coming from the left is seen, while lobate rock glaciers line the valley walls in the background. The terrain rises about 800 m above the valley bottom. Ridges on the rock glacier surface are almost bare of snow. Seen toward the south. 1978.06.30.

Fig. 11. Blokgletschere i vintertilstand. I forgrunden ses terminus af en piedmont blokgletscher, kommende fra venstre, i baggrunden ses lobate blokgletschere. Vest Disko. Bemærk de snefrie områder på blokgletscherne.

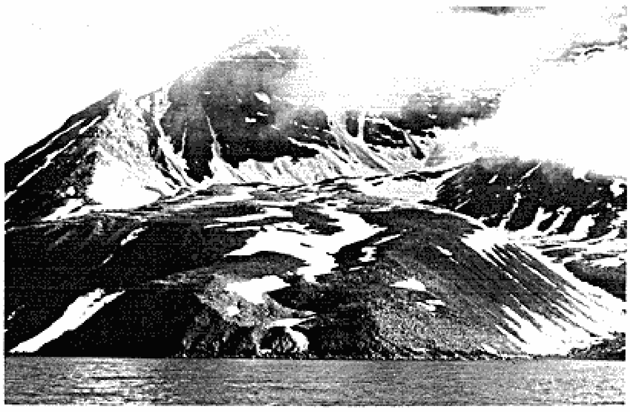

Fig. 12. Tongue-shaped rock glacier reaching the southern shore of Mellemfjord, West Disko. The cliffs in the background rises to about 1000 m.a.s. 1978.07.08.

Fig. 12. Tungeformet blokgletscher ved Mellemfjords sydkyst, vestlige Disko.

John 1976), so I would consider it problematic to use the close of the Hypsithermal Interval as the onset of rock glacier formation. I would rather consider it likely that the present rock glaciers on Disko gradually were formed during the major part of the Holocene, possibly interrupted by periods of relative warmth, where many rock glaciers were inactive or even fossil. Reactivation may later have been achieved by internal accumulation of ice after establishing of a local permafrost temperature regime due to the Balch ventilation effect. However, the relation between rock glacier activity and different climatic parameters is not well known, and climatic requirements for rock glacier activity may differ from requirements for glacier expansion. This is emphasized by observations on a locality at Lyngmarksbræen, southern Disko, where fossil lobate rock glaciers were overrun by a glacier in the last century. This locality will be desribed in greater detail in a later paper on glaciers, moraines and rock glaciers on Disko (Humlum, in prep.).

ACKNOWLEDGMENTS

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RESUMÉ

På øen Disko, Vestgrønland, findes et stort antal blokgletschere. Blokgletschere er gletscherlignende terrænelementer, på overfladen dækket af meterstore blokke, og med et indre bestående af blokke, sten, grus, sand og is. Isen i blokgletschere kan forefindes som små overtræk på de enkelte bjergartsfragmenter, eller som massive islegemer med en oprindelse som gletscheris. Aktive blokgletschere er et periglacialt fænomen, indeholdende permafrost.

Blokgletscherne på Disko kan deles i de tre geomorfologiske grupper: Lobate blokgletschere, tungeformede blokgletschere samt piedmont blokgletschere (fig. 2). De lobate blokgletschere findes som udvækster fra foden af talusskråninger, mens tungeformede og piedmont blokgletschere er større og glider ned fra dale, i hvilke en lille gletscher findes, typisk omgivet af høje fjeldvægge. En stor talusproduktion fra fjeldvæggene synes at være forudsætning for blokgletschernes dannelse. Blokgletscherne på Disko formodes at være udviklet i løbet af holocæn, eventuelt afbrudt af milde klimaperioder, i hvilke mange blokgletschere var inaktive eller fossile.

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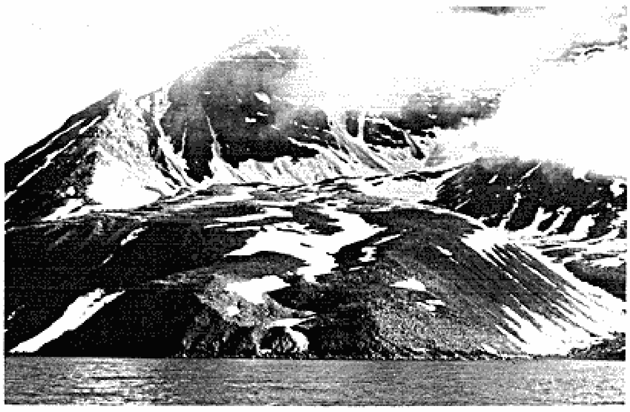

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På øen Disko, Vestgrønland, findes et stort antal blokgletschere. Blokgletschere er gletscherlignende terrænelementer, på overfladen dækket af meterstore blokke, og med et indre bestående af blokke, sten, grus, sand og is. Isen i blokgletschere kan forefindes som små overtræk på de enkelte bjergartsfragmenter, eller som massive islegemer med en oprindelse som gletscheris. Aktive blokgletschere er et periglacialt fænomen, indeholdende permafrost.

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Fig. 11. Rock glaciers near Mellemfjord, West Disko. In the foreground the terminus of a piedmont rock glacier coming from the left is seen, while lobate rock glaciers line the valley walls in the background. The terrain rises about 800 m above the valley bottom. Ridges on the rock glacier surface are almost bare of snow. Seen toward the south. 1978.06.30.

Fig. 11. Blokgletschere i vintertilstand. I forgrunden ses terminus af en piedmont blokgletscher, kommende fra venstre, i baggrunden ses lobate blokgletschere. Vest Disko. Bemærk de snefrie områder på blokgletscherne.

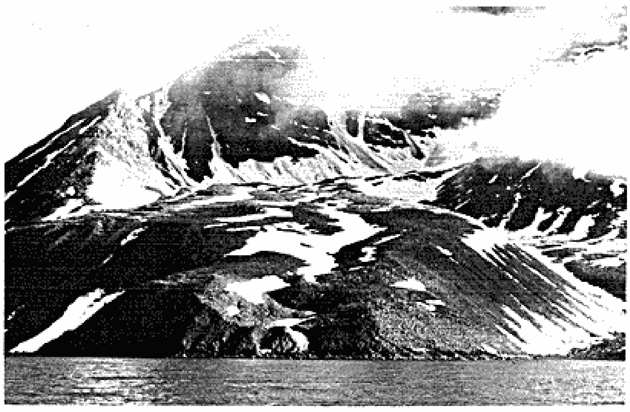

Fig. 12. Tongue-shaped rock glacier reaching the southern shore of Mellemfjord, West Disko. The cliffs in the background rises to about 1000 m.a.s. 1978.07.08.

Fig. 12. Tungeformet blokgletscher ved Mellemfjords sydkyst, vestlige Disko.

John 1976), so I would consider it problematic to use the close of the Hypsithermal Interval as the onset of rock glacier formation. I would rather consider it likely that the present rock glaciers on Disko gradually were formed during the major part of the Holocene, possibly interrupted by periods of relative warmth, where many rock glaciers were inactive or even fossil. Reactivation may later have been achieved by internal accumulation of ice after establishing of a local permafrost temperature regime due to the Balch ventilation effect. However, the relation between rock glacier activity and different climatic parameters is not well known, and climatic requirements for rock glacier activity may differ from requirements for glacier expansion. This is emphasized by observations on a locality at Lyngmarksbræen, southern Disko, where fossil lobate rock glaciers were overrun by a glacier in the last century. This locality will be desribed in greater detail in a later paper on glaciers, moraines and rock glaciers on Disko (Humlum, in prep.).

ACKNOWLEDGMENTS

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