Holocene talus accumulation rates, – and their influence on rock glacier growth. A case study from Igpik, Disko – West Greenland

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The Igpik area is located ten km east of Godhavn on the southcoast of the island Disko. Geologically the area is dominated by Tertiary basalt formations.

A general geomorphological classification of this area, which covers approximately three square kms, has been made. Based on radiocarbon ages of former marine levels in the Disko Bugt area, the beginning of talus accumulation has been determined for two talus cones situated on raised beaches. They have ages of 5800 and 7900 ^{14}C y. B.P. Using theodolite readings, the volumes of three different talus cones have been determined and two average talus accumulation rates have been calculated for the cones located on raised beaches. These values are transformed into an average Holocene rockwall retreat rate of 0.0005 and 0.0015 m/year, respectively. The total volume of two lobate rock glaciers is calculated to be 2.2 mill. cu.m and as they are located inside 9000 years old local moraines, the average Holocene mass-transfer through the third talus cone has been estimated to $1.4 \cdot 10^6$ tons×m/sq.km/y. Finally the results are discussed, with reference to other areas, and as a possible threshhold for the initiation of rock glaciers.

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The study of slope processes, and especially the quantification of materials involved, took a great step forward with the work of Anders Rapp (1960a). Unfortunately his pioneering investigations in the Kärkevagge valley in northern Sweden could not be succeeded in two aspects. Primarily, the total Holocene rockwall retreat and subsequent talus accumulation could not be calculated due to the lack of well defined talus cones (Rapp, 1960a p. 115). Secondly, it was impossible to estimate exactly when the talus started to pile up (p. 88), which hindered the calculation of an average Holocene accumulation rate.

Another incentive to the present study was the work of Church et al. (1979) on Baffin Island in Arctic Canada. Their investigations on slope processes in an area dominated by gneiss and schistose rock types can be supplemented by our observations from a typical plateau-basalt area like Disko. The island of Disko is located less than 500 km east of Baffin Island, but exhibits a totally different geological setting, fig. 1. This study gives an opportunity to compare almost the same periglacial processes, working on different rock types.

The relative mass transfer, calculated as Rapp (1960 a) did, can be used to compare the mass transport in different areas. It was used by Barsch (1977) to evaluate the rock glacier transport compared with the total mass transport in the Swiss Alps. An attempt to estimate the mass transfer in the Igpik area, based on volume calculations, has been made.

Compared to the 8 years study by Rapp the present study is based on only 8 days of work in the field. In connection to a field course in »Arctic Geomorphology«, a research programme was conducted during the end of July 1983.

The background for this study was a geomorphological classification of the Igpik area (see fig. 2), based on aerial photographs, according to a method used by e.g. Wahrhaftig and Cox (1959), Outcalt and Benedict (1965), and Smith (1973). Especially the terminology of White (1981), appeared to be applicable, leaving only the glacial and marine forms as a matter of discussion. White proposed a classification scheme for non catastrophic alpine mass-movement forms, thus including previous work by Rapp (1960a) and Church et al. (1979).

The field work was limited to a control of the map and a determination of the volumes of three different talus cones, using theodolite readings, in a manner similar to the one used by Rapp (1960b).

Igpik is the name of a characteristic coastal cliff, which already centuries ago attracted whalers so much that they decided to settle down there. On the raised beaches there are remnants of their former dwelling-places. The Igpik area has not been subject to a geomorphological investigation of this kind before, although the area has been visited and described shortly as early as 1898 (Steenstrup, 1900). Another participant in that expedition was the botanist M. P. Porsild, who described an ecological succession of plant species on the raised beach ridges at Igpik (Porsild, 1901).

THE STUDY AREA

From the climate registrations in Godhavn (10 km west of Igpik), the annual precipitation is 391 mm, and the mean annual air temperature is -3.2°C with a maximum in July (8.0°C) and a minimum in february (-13.9°C) (Müller, 1980). The island of Disko is located in the zone of discontinuous permafrost according to Karte (1979).

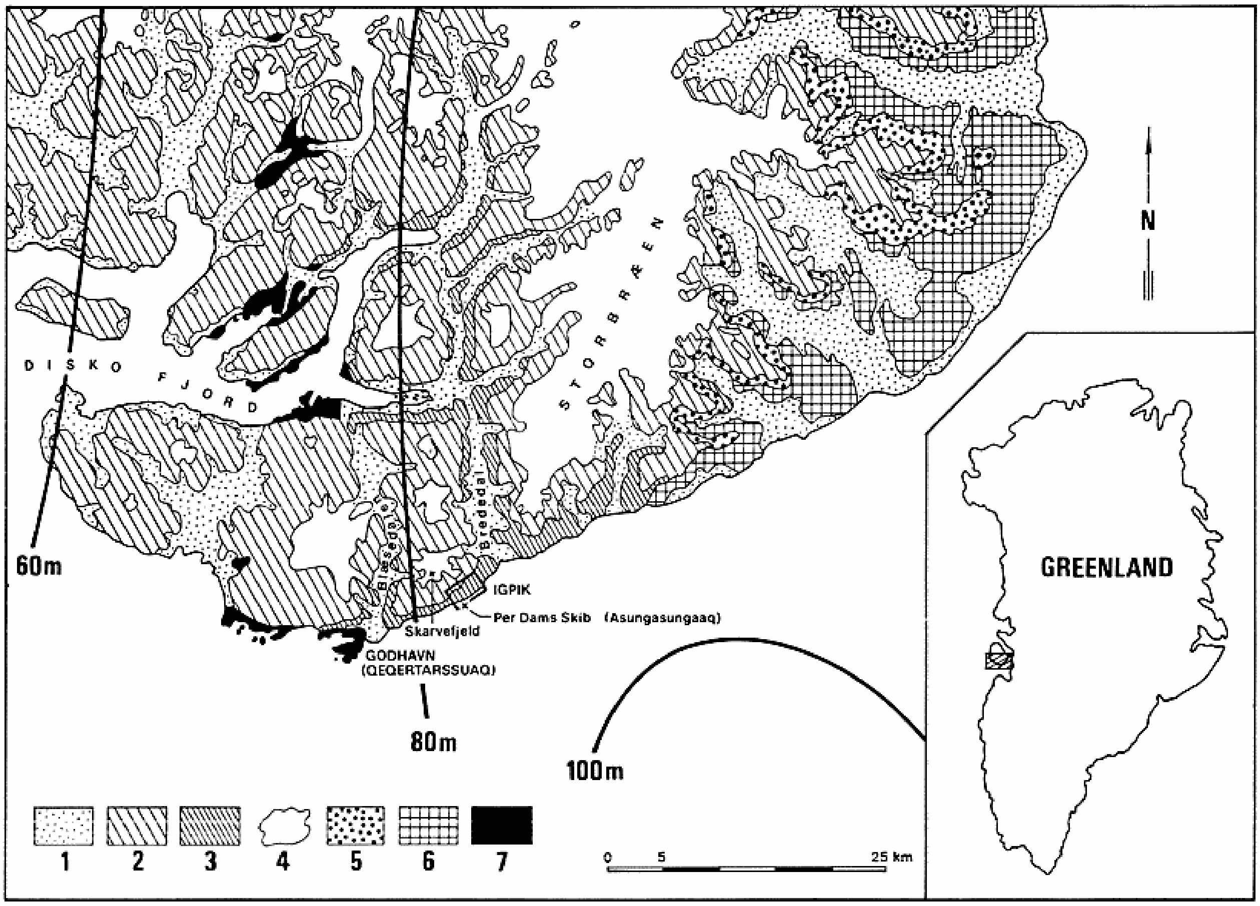


Fig. 1. Geological map of the southern part of Disko, with isolines showing relative Postglacial emergence and with names of localities mentioned in the text.
1: Quarternary sediments 2: Tertiary plateau basalt
3: Tertiary basalt breccia and pillow lava
4: Glacier ice 5: Tertiary sediments 6: Cretaceous sediments 7: Precambrian gneiss.
(Compiled from Escher & Watt, 1976).

Fig. 1. Geologisk kort over den sydlige del af Disko med isolinier for den relative Postglaciale landhævning og stednavne nævnt i teksten.
1: Sedimenter fra Kvartær 2: Tertiær plateau basalt
3: Tertiær basaltbreccie og pudelava
4: Gletscher is 5: Sedimenter fra Tertiær 6: Sedimenter fra Kridt 7: Prækambrisk gneiss.

As the actual study area is exposed towards the south, with high encircling walls to the northwest, north and northeast, only few periglacial forms are to be seen, as compared to similar valley sides nearby, with north exposition.

The Igpik area is a 4000 m long and 1400 m wide wedgeshaped incision into the Skarvefjeld plateau, fig. 2 and 3. Physiographically it is divided into two areas. A lower-lying complex of marine terraces, 20-80 m a.s.l. with a central lagoon located in an elongate depression, and a cirque valley with bottom level 200 m a.s.l., and its backwall rising to 800 m a.s.l.

The central area around the lagoon forms a depression in the beach ridge plain, and the outline of a relic tombolo can be seen east of the lagoon, fig. 2. The flat eastern triangle is mainly dominated by sheets of gelifluction, hiding the relic beach ridges. Frostbound layers of a fine-grained black deposit with sharp angled stones intermixed, were detected 50 cm below ground, 60 m a.s.l. at point Av, fig. 3. Sorted stone circles were seen on the shores of the lagoon, and sorted stone stripes in the valley north of cone A.

The geology of Igpik is, apart from the underlying Precambrian basement, exclusively built up in basalt formations of Tertiary age. The lower part is a basalt breccia with inclusions of pillow lava and agglomerates. The upper lava formation is plateau basalt deposited through few and large extrusions. In between the individual lava flows in the upper lava formation, weathering of volcanic ash took place, which today gives the plateau basalts their characteristic shift between layers of basalt and layers of red volcanic clays. As the geology is fairly simple (see fig. 1) with only two rock types present, the area has been formed into three major steps, due to various exogenic processes, fig. 4.

Fig. 2. Enlargement of aerial photograph with some morphological features marked. Arrows indicate positions from where fig. 5 and 6 have been taken. (Geodetic Institute A. 48/86, copyright).
Fig. 2. Forstørrelse af flyfoto med enkelte morfologiske elementer indtegnet og markering af hvorfra fig. 5 og 6 er taget.

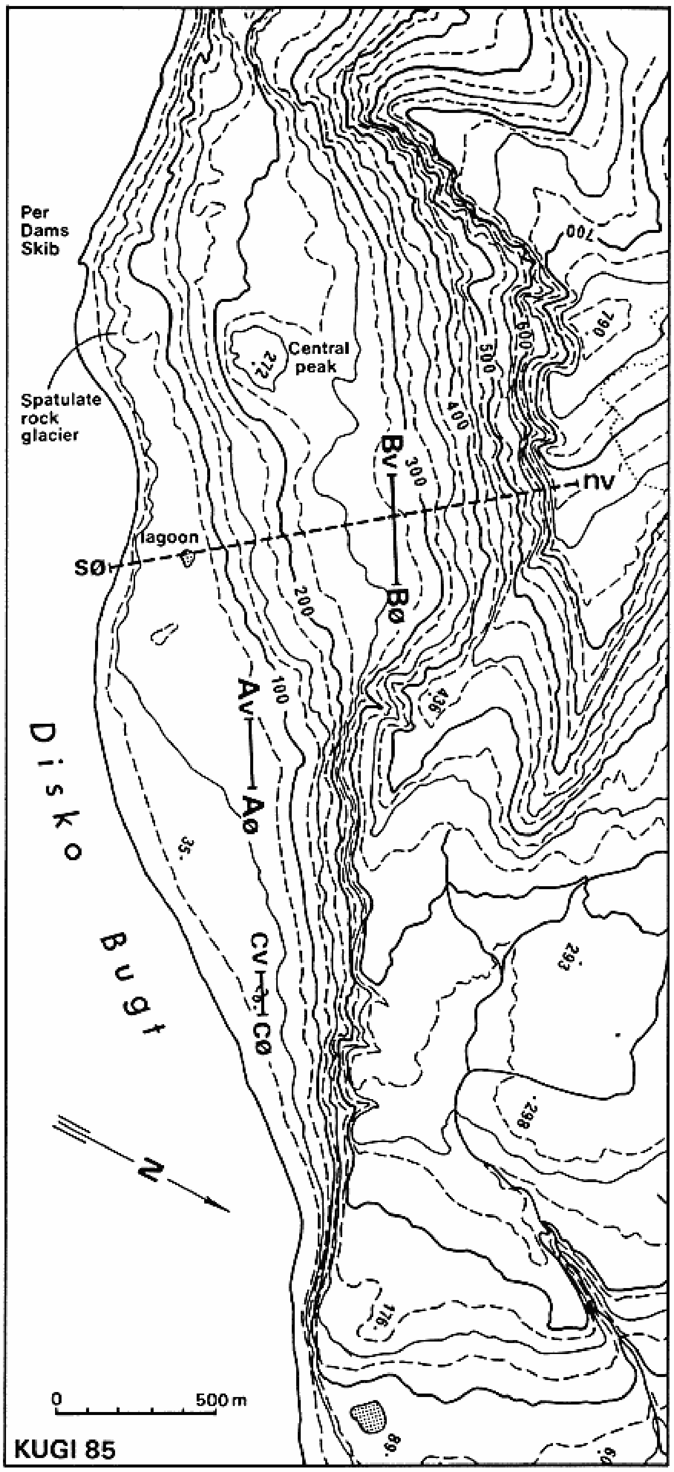


Fig. 3. Topographical map of the Igpik area with measuring grid and profile line (fig. 4: SØ-NV) inserted. (Drawn photogrammetrically by Jørgen Nielsen, Geogra. Inst., Univ. Cph., 1983).
Fig. 3. Topografisk kort over Igpik området med basislinier og profillinie (fig. 4: SØ-NV) indtegnet.

The first vertical jump is the recent coast cliff, formed by marine action during the open water period from May to December. The second step is formed in pillow breccia and is probably a result of repeated glacial erosion, during the Quaternary, by large outlet glaciers from the Inland Ice. The third vertical jump is formed in plateau basalts, interlayered with red clays of weathering or volcanic origin. The backwall of this cirque valley has been steepened by glacial erosion. The weathering of the rockwalls is mainly a result of hydrofracturing and frost action (Selby, 1982). The weathered material is transported by two processes, rockfall and avalanches. The geomorphological process of talus accumulation is weathering-limited, (Carson & Kirkby, 1972) which means that the accumulated material/time can be expressed as the weathering rate, and hence as the rockwall-retreat rate.

a) The first step

Today it is the sea, which keeps the cliffs in shape. The western part has up to 90 m high cliffs in unconsolidated material; the average height, however, is between 60 and 70 m, where the cliff exposes a core of pillow breccia. These Tertiary submarine vulcanic extrusions also make up the 15-20 m high sea stack, called Per Dams Skib. The tombolo, which has grown behind the sea stack, shows leeside erosion to the east, indicating a dominant longshore transport by waves from the west.

To the east, the cliff seems to be inactive at present. It is formed in raised beach ridges, consisting of rounded pebbles and cobbles. The cliff which reaches 76 m a.s.l. southeast of the lagoon, is inclined to the east, reaching 22 m a.s.l., where it joins a 200 m high vertical cliff.

It is noteworthy that no talus has been built up at the cliff foot. All material is washed away by the sea immediately after arrival leaving only a narrow pebble beach.

b) The second step

The second steep slope unit extends westwards from the vertical cliff mentioned above. It is formed in homogenous breccia, leading to a rather uniform surface morphology. Only where faults are present in the rock, clefts have been eroded. These can be seen in connection to talus cones a-c, fig. 2.

From cone A to below the central peak, there is a block slope (White, 1981), with no talus accummulation at the foot. In the western part of the area, west of the central peak, the steepness decreases, and step 2 vanish because of glacial erosion and later upfill of rock glacier material.

c) The third step

This rockwall extends in a semicircle around the central peak. As the layers of red clay and silts interbedded between the individual lava flows are easily removed, there is a continuous undercutting of the plateau basalt layers. The protruding layers of basalt, which are characteristic all over Disko, has traditionally been given the name »Trap layers«.

Between cone A and B, there is an arête dividing the Igpik area from another cirque valley, fig 2. From cone B to I the rockwall has been formed into 8 rockfall funnels (Rapp, 1960b). At the top of the Trap layers is a 90 deg. break in slope angle, giving way to what is known as the »Tertiary Surface« of Disko. It is characterized by wide, shallow valleys, indicating only slight modification during the Quaternary.

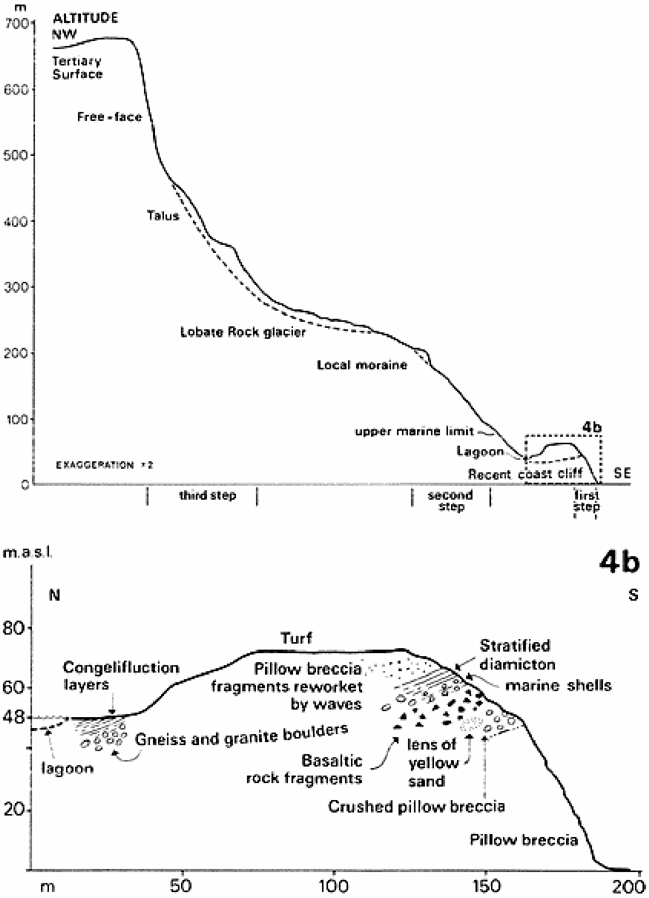


Fig. 4. A southeast-northwest profile section from recent coast to »Tertiary Surface« with morphological features marked. Inserted is an enlargement of coastnear part, showing the complex Quarternary deposits. Next to the lagoon a pit was dug to 90 cm below ground. Layers of sand and pepples were seen, and in the bottom of the pit, several gneiss and granite boulders showed up. Location, see fig. 3. (Compiled from topographical map and field sketches).

Fig. 4. Et sydøst-nordvest profil fra den recente kyst til den »Tertiære Overflade«, med de morfologiske elementer markeret. Indsat er en forstørrelse af den kystnære del visende de komplekse kvartære aflejringer. I et 90 cm dybt hul, gravet ved lagunen, sås lag af sand og sten. I bunden fandtes adskillige gneiss- og granitblokke. Placering, se fig. 3.

Fig. 5. Photo showing spatulate rock glacier in cross section. Note person for scale. The cross section shows a trough- shaped depression in the breccia, filled with light-coloured sand and silt, which contains numerous gneiss and granite boulders in a crude bedding pattern. Upon the horizontal surface in appr. 60 m a.s.l. lies the fossil rock glacier. It has a blocky bottom layer, with a thickness of several meters. In the middle there is a finer matrix, dominated by red clays. The upper part of the rock glacier consists of basaltic blocks up to one meter in diameter. In the right-hand part of the figure is an altimeter scale (Paulin). (Photo taken by Niels Nielsen, date: 830731).

Fig. 5. Billede visende tungeformet blok gletcher i tværsnit. Bemærk personen midt i billedet. Tværsnittet viser en trugformet fordybning i basalt brecciaen, fyldt med sand og silt samt gneiss og granitblokke med grov lagdelt struktur. Ovenpå det horisontale lag ca. 60 m.o.h. ligger den fossile blokgletcher. Den består nederst af et blokrigt lag, ca. 2 m tykt. Blokgletscherens centrale del domineres af rødt ler og silt, medens overfladen er dækket af basaltiske blokke op til een meter i diameter. I højre del af billedet ses en altimeter skala.

METHODS

This part is based on field investigations and photographs. The slope angles have been sighted with a »Silva compass/clinometer« from positions beside the cones. The various heights have been determined with a Paulin altimeter, read from maps, and supplemented with intersection readings, using a Wild T16 theodolite.

Classification of the talus cones

Three cones were selected, because they were thought to represent the result of various mass wasting processes in the area. The B cone is typical of the cones in the western part of the investigated area, where rockfall dominates and the c cone is typical of the cones a-d, which extend across the raised beach ridges, and are fed from a marked cleft. Cone A is unique as regards the mixing of source area types, having both a rockfall funnel in plateau basalts and a cleft in the breccia.

When working on and in front of the cones, it was possible to get an impression of their recent activity. The c cone was inactive, as regards blockfalls, during the period 26-27. of July 1983. Detailed investigations on the cone could be performed without fear of rockfall activity.

As regards cone A, there was one major blockfall on the 28. of July, but as the block only reached the upper convex part of the cone, after bounching a few times, it was possible to make traverses on the lower part of the cone.

When the intersection readings to cone B were made on the 30. of July a number of blockfalls were heard. As some of these extended to near the talus foot, no detailed investigations were made on the cone proper.

It was not possible to determine any correlation between blockfall activity and e.g. time of day or sunlight warming the rock outcrops in the source areas, probably because of to few observations.

The resulting classification is listed in table 1. p. 38.

Classification of rock glaciers

In the Igpik area, two types of rock glaciers are represented. The oldest one was tongue-shaped, with a former spatulate terminus. By now it is assumed to be without interstitial ice and is partly removed by the sea. This gives an opportunity to see, in cross section, the lower part of it. As there are marine deposits underlying it with littoral sediments in the upper part, it is possible to determine the period of activity, knowing the age of this former sea level, fig. 5.

On the aerial photograph, it is possible to distinguish two generations of this spatulate rock glacier, fig 2. The outermost part, which may have a marine erosion scar 80 m a.s.l., and a younger one inside the rims of the first. The surface morphology is characterized by longitudinal furrows, some being excavated by running water.

Lobate rock glaciers no. 1-5 are the other type in the Igpik area, fig 2. The surface morphology is characterized by transversal furrows and ridges. As no fresh debris indicating movement is seen on any side of rock glaciers 2 and 4. these can be classified as inactive (Wahrhaftig and Cox, 1959, p. 424).

On the other hand, rock glaciers no. 3 and 5 have steep fronts, without lichens, but no sharp angle between the front and upper surface. Accordingly they are classified as reactivated lobate rock glaciers (Wahrhaftig and Cox, 1959, p. 427-8).

Rock glacier no. 1 is classified as active for the following reasons: There is a sharp angle between the upper surface and the front. The front, which exposes a matrix of red clay and silt, stands with an angle of 42 deg. In the front there is a horizontal line, below which the matrix has a darker colour due to wetting, fig. 6. The very unstable talus at the foot of the front has a slope angle of 31 deg.

Calculation of rock glacier volumes

In this study we have only made the volume calculations on rock glaciers nos. 2 and 3, as these are located inside the local moraine, giving an maximum age of the rock glaciers, and as they have a regular configuration, fig. 2.

The total width of the rock glaciers is measured on fig. 2 to be on the average 440 m. The length is measured from the talus foot to the southern upper edge of of the rock glaciers, giving an average of 250 m. According to Wahrhaftig and Cox (1959) and Barsch (1977), a low value of mean thickness can be set to 20 m. This gives a total volume of 2,200,000 cu.m.

Measurement of talus volumes

As mentioned in a previous section, three cones were chosen, because they represent three kinds of mass-wasting processes, which all lead to talus cones when channeled. The method applied here, however, is the same for all three.

In front of each cone, a base line was established between two fixed points. Via intersection readings, a number of characteristic blocks on the cone (usually 5-7) were defined in a three dimensional sphere. In addition, a couple of points on the free-face were measured to support the photogrammetric map. Where outcrops of rock existed in the vicinity of a cone, their exact position was determined too.

Fig. 6. Photo showing lobate rock glacier no. 1 in center, talus cone A to the right and block slope to the left. Notice the source-area, i.e. the plateau basalts in the background of the photo (upper left part). Front view. Height of rock glacier is 80 m. (Photo taken by Povl Frich date: 830728).

Fig. 6. Billede visende lobat blokgletcher nr. 1, talus kegle A til højre og block slop'en til venstre. Bemærk kilde-området d.v.s. plateau basalterne i baggrunden af billedet (øverst til venstre). Set forfra. Blokgletcherens højde er 80 m.

Table 1

CLASSIFICATION SCHEME (based on White, 1981)

	CONE A	CONE B	CONE c
SOURCE AREA	cleft in breccia (height 70m) + rockfall funnel in basalts (height 180m)	rockfall funnel in basalts (height 210m)	cleft in breccia (height 170m) chute connecting cleft with cone
TALUS CONE	inclination 30 - 31 deg. convex upper part with fall sorting concave lower part with none to moderate sorting debris flow channel along eastern edge of cone vegetation in stripes	inclination 33 -34 deg. almost straight profile with fall-sorting throughout avalanche-track along eastern edge of cone no vegetation	inclination 20 -25 deg. concave profile throughout no sorting multiple erosion scars on upper part of cone wholly vegetated except in erosion scars
TALUS FOOT	boulder protected debris tails fringe of coarser debris encircling base dense willow vegetation	avalanche fan tongues protalus rampart lobate rockglacier birch 'lawn'	debris flow deposits (sorted) willow and grasses
TYPE	avalanche talus cone	coalescing rockfall talus cone/ cones	alluvial talus debris cone

Table 2 A & B

RESULTS

A RECESSION RATE (meter/year)

cone	cone volume cu.m	acc. period years	acc. rate cu.m/y.	source area sq.m	rec. rate m/y
A	500000	7900	63 (44)	30000	0.0015
B	325000	5000?	65?(46)	25000	0.0018?
c	50000	5800	9 (6)	13000	0.0005
B+ C+ D/2	3.1 mill. *	9000?	344 (241)?	100000	0.0024?

* Including rock glacier 2 and 3.
() Reduced with an estimated pore volume of 30 %.

B MASS TRANSFER (meter*tons/q.km/year *6,000,000)

	hor. m	ver.m	mass t *10 6	q.km	years	mass transfer hor.	mass transfer ver.
RG	650 a	490 a	4.4 c	0.45*0.8	9000	0.9	0.7
T	500 b	480 b	1.6 c-d	0.45*0.5	5000	0.7	0.7
together						1.6	1.4

RG: Rock Glacier
T: Talus
a: The distance is calculated as the length from cresttop to the center of the rock glacier mass.
b: Likewise, to the center of the talus mass.
c: Calculated as mass=vol*bulk density. The bulk density is set to 2.0 t/cu.m.
d: The estimated mass of talus cone B, C and D/2.

The theodolite readings were made with an accuracy in the vertical within 0.1 m. This is well below the accuracy on determination of the mean sea level. As the coast of Disko has semidiurnal tide, two swash bars are formed in calm weather. From nautical tables, these levels are related to mean sea level, and subsequently the altitude of point cø (see fig. 3) was determined via trigonometrical levelling.

The length of the base line was from 168 to 360 m. It was optically read on a stage and could not be checked in the field due to lack of time.

The three dimensional coordinates were plotted on a map in scale 1:4,000, and with the help of sketches and photos obtained in the field contours were interpolated. The location of rock outcrops served as a background, on which the cones were implaced. Finally the total volume could be estimated by planimetering the areas shown in fig. 7.

The lower limit of the cone was set to be the mean altitude of the fixed points. The area of the free-face was calculated on the basis of simple geometric figures. The calculated free-face areas and cone volumes are listed in table 2A.

Estimation of mass transfer

To get an estimate of the mass transport and an opportunity to compare the area mass transport with other areas, the relative mass transfer (tons × meter/sq.km/year) used by Rapp (1960a) and Barsch (1977) is a tool.

The mass transfer can be calculated both as the vertical and horizontal transport, we have done both. But while Rapp (1960a) and Barsch (1977) calculated the mass transfer from measurements of registered mass transport occurrences, we had to make an estimate from the total post-glacial mass transport. Only talus and rock glaciers

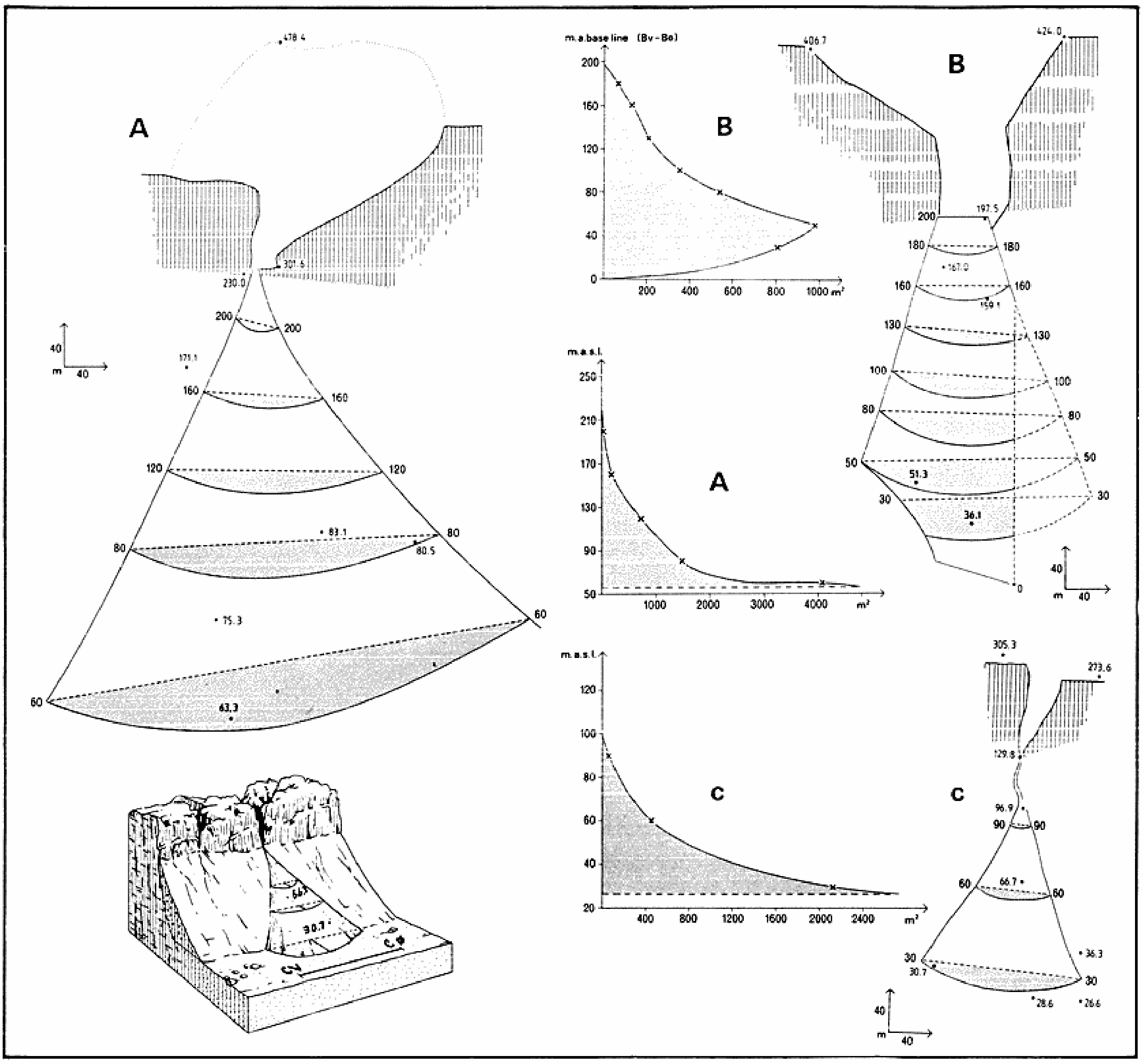


Fig. 7. Sketchmap showing three-dimensional coordinates from intersection readings to blocks on the cones A, B and c. In center: Area distribution curves for the same three cones. For explanation: See text.

Fig. 7. Tredimensionale koordinater fundet ved fremskæring til blokke på kegle A, B og c. I midten: Hypsometriske kurver for de samme kegler. Forklaring på figurerne: Se teksten.

are regarded in the estimate. The mass transfer is calculated for rock glacier 2 and 3 and for the feeding area, i.e. cone B, C and part of cone D. The talus volume can only be a guess. The calculation is also a check on the recession rate for the B-cone, listed in table 2A and B.

THE GEOCHRONOLOGICAL DEVELOPMENT

At some time during the last Ice Age, climatic change led to local cirque glaciation in favourable places, such as the south coast of Disko, where windblown snow could accumulate. As the climate deteriorated, accumulation increased. We infer that two cirque glaciers developed and merged north of the central peak, fig. 2 & 3.

During the Sisimiut glaciation, correlating with the Late Wisconsinan (Kelly, in press), this glacier, through backwearing, eroded the plateau basalts more rapidly than the pillow breccia, building a platform on top of the breccia. At some later time during the Sisimiut glaciation, this glacier advanced down over the lower lying layers of breccia. The tongues preferably eroded along the faults in the breccia. As a result of this, the pillow breccia surface was formed into undulating surface-topography, which today can be seen in the coastal cliff as four troughshaped depressions in the breccia, fig. 5 & 2.

When the Sisimiut glaciation culminated, the iceshield over central Greenland reached its maximum size during the last Ice Age, and as a result of this, large outlet glaciers, loaded with gneiss and granite debris, filled the Disko Bugt. On their way west the ice streams met the south coast of Disko, and erratics from the Greenland mainland farther east were mixed with local debris of volcanic origin from Disko Island. This material was partly deposited as lateral moraines in the mouth of both Brededal and Blæsedal east and west of Igpik (O. Humlum, personal inf.).

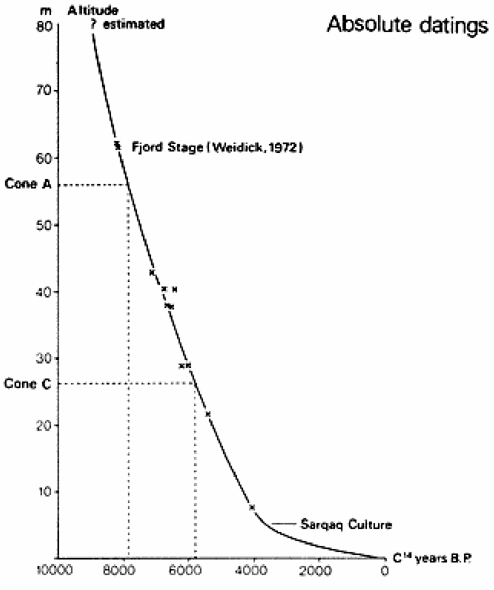
Several places in the coastal cliff there are lenses of yellow quartsitic sand. This sand, of Cretaceous age, is found in situ only to the east of Igpik, and must have been transported by the Disko Bugt glacier. Furthermore, the crushing of pillow lavas and subsequent accumulation of basalt fragments, not evidencing longtransport through glacier ice, points to a large local input of talus material on the glacier surface.

The marine shells found at c. 65 m a.s.l. (Mya truncata and Hiatella arctica, according to Funder, personal information, 1984) are found on top of the basalt fragments. As the shells are crushed with sharp fractures they cannot have been deposited in a beach facies, as such a marine environment leads to rolled or rounded fragments. Consequently the sea level must have been at least 70 m above the present one at the time of deposition.

The trough shaped depressions were filled with light couloured material from the Disko Bugt glacier and with material from icebergs. The diamict mentioned in fig 4 shows a large content of gneiss and granite erratics, a crude stratification and marine shells in the bottom, which indicate an origin as glacio-marine sediment. The Precambrian rock fragments were covered by local material, which the post-glacial sea rearranged as beach ridges from 76 m a.s.l. and down.

Between 13000 and 10000 y.B.P., when the Sisimiut ice sheet disintegrated (Kelly, in press), the Disko Bugt glacier started to retreat. At first by frontal melting but later with a calving front (because of the rapidly rising sea-level, which is documented in the late-glacial marine limit in this area). The upper marine limit, on the south coast of Disko is found between 80 and 90 m a.s.l, (Funder, personal comm. 1984).

An unpublished ^{14}C dating on organic sediments from a lake just east of Godhavn states that the outer part of Disko Bugt was icefree before 10000 y.B.P. (Funder, 1985 personal information). There are other indications pointing to an early deglaciation of the Disko Bugt area (Weidick, 1972, p. 24), as compared to other parts of West Greenland. This could be caused by the rapid disintegration of an ice shelf margin. The diamict (fig. 4) is also an argument in favor of a shelf hypothesis.



(After Donner and Jungner 1975)

Fig. 8. Curve showing relative Postglacial uplift in the Disko Bugt area. (Compiled from Donner and Jungner (1975), Donner (1978) and Weidick (1972).

Fig. 8. Kurve over den relative postglaciale landhævning i Disko Bugt området.

In the western part of the investigated area, the local glacier had character of an ice-cored, tongue-shaped, rockglacier, probably because the cirque glacier in this part was completely covered by rock material from the free-faces. A possible explanation of this difference between the eastern and western parts could be that the rock walls are generally higher in the western part compared to the eastern part. Furthermore there is a difference in exposure, which can explain the bigger production of rock material and cover of glacier ice.

Summing up, the following levels are important. The upper marine limit has probably been detected as an erosion scar on the flank of a spatulate rock glacier, having an altitude of 80 m a.s.l. The next level is 76 m a.s.l. and marks the highest-lying marine beach southeast of the lagoon. The 60 m level can be followed along the western part of the cliff, where it marks the level at which the second spatulate rock glacier reached the lower plateau.

Absolute Ages

The maximum age of cone A and c is determined by the age of the raised beaches underlying them. According to the curve in fig 8, this gives a maximum accumulation period for cone A of approximately 7900 ^{14}C years, and a time of initiation of the c-cone around 5800 ^{14}C y. B.P.

The accummulation of cone B could start only after the disappearance of the cirque glacier, which sets the maximum age of the cone. Both Denton and Karlén (1973), and Mörner (1973) have investigated this topic, and a rea-

Table 3. ROCKWALL RETREAT RATES, HOLOCENE AGE

LOCALITY	RETREAT (mm/y)			ROCKS	AUTHOR
	MIN	MAX	MEAN		
Spitsbergen Mt. Templet 10000 y.	0.34	0.5?		limestone, cherts sandstone	Rapp (1960b) p.88
Lappland: Karkevagge 1952-60	0.04	0.15		micashists limestone	Rapp (1960a)
The Austrian Alps: Zemmgrund 10000 y.			0.7-1.0	gneiss shist serpentine	Fuser (1954) p. 140 c.f. Rapp (1960a)
Brazil: Mambucaba 12 years		20	2	granite and gneiss ?	Freise (1933) pp.2,3
South Africa: recent time			1.5	granite?	King (1956) c.f. Rapp (1960a)
Arctic Canada: S.W. Ellesmere Island Holocene	0.5	0.8		dolomitic limestone	Souchez (1969) c.f. Washburn (1979) p.231
Yukon, Canada			0.02-0.17	quartzite, dolomite, limestone	Grey (1971) c.f. French (1976)
Yukon, Canada			0.01-0.03	syenite and diabase	Grey (1971) c.f. French (1976)
Igpik, Disko, West Greenland: Cone A 7900 y.			1.5	basalt pillow breccia	this study
Cone B 5000 y.			1.8-2.4	basalt	this study
Cone c 5900 y.			0.5	pillow breccia	this study

sonable guess would be a date around 4000 to 6000 y.B.P. At that time, which is also known as the Holocene climatic optimum, one could expect that the cirque-glacier totally disappeared from this area.

The local moraine system could be built up only after the Disko Bugt glacier's retreat. And it is therefore younger than c. 10000 y.B.P. A significant expansion of the ice cap on Disko took place c. 9000 y.B.P. (Funder & Simonarson, 1984 and Funder, personal comm. 1985) which may possibly correlate with the moraine at Igpik.

DISCUSSION

Rapp (1960a, p. 116) has made calculations and compilation of both recent and Holocene rockwall retreat rates from different parts of the world. In addition, we have compiled similar values from the literature since then. To compare our results with those from other areas and other rock types, the following scheme (table 3) is presented.

As regards the total Holocene rockwall retreat, some observations have been made, e.g. Smith (1973), who claims that the volume of lobate rock glaciers represents a cliff recession of 60 m. Rapp (1960b, p. 86) has calculated a total horizontal rockwall retreat of 20 m, based on the horizontal distance between protruding interfunnel rock outcrops, and the deepest parts of the funnels. Rapp (1960b, p. 54-8) probably was wrong in interpreting lobate rock glaciers as »glacial terraces« (Humlum, 1982a). Consequently he did not include the volumes of these rock glaciers at the talus foot, thus his conclusions on the ratio between Holocene and total rockwall retreat of 1 :5-6 are inconsistent. Consequently the above-mentioned rockwall retreat must be regarded as a total Holocene value.

On the other hand, the observations made by Rapp (1960 b) are valuable, as they document the presence of the first visible bulge on a talus cone, i.e. an embryonal rock glacier, which occurs on a talus cone situated below a rockfall funnel, where the rockwall has receded app. 20 m. This observation is in accordance with our calculations from the Igpik area, which indicate a threshold for the initiation of lobate rock-glaciers with a rockwall recession rate of between 15 and 20 m/10000 y. This threshold value is of course always dependant on the area of the free-face, and hence not as useful as the mass transfer values discussed below.

The retreat rates in the Igpik area are generally high compared with the other studies mentioned. The reason for the high retreat rates must be seeked in the high erodibility of the rock types represented. As the basalts are very susceptible to weathering, i.e. frost wedging (Selby, 1982), and the red layers of clay and silt can supply water during freezing, it is only the temperature oscillations that limit the weathering (Washburn, 1979 and Selby, 1982). The south exposition promotes frequent temperature oscillations.

Barsch (1977) lists some values for the mass transfer that Jaeckli found for the Swiss Alps, namely $78 \cdot 10^3$ tons×m/sq.km/y (vertical), and that Rapp found for Kärkevagge, namely $10 \cdot 10^3$ tons×m/sq.km/y (vertical). Compared with these, our estimated mass transfer, $1400 \cdot 10^3$ tons×m/sq km/y (vertical), is very high. The reason for this may be the high relief and the rock type, which, because of the high erodibility, produces much material – but it could also be caused by the rough estimation and the therefore following uncertainties in the figures.

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