Sediment Transport in a Proglacial Valley, Sermilik, East Greenland

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Detailed investigations of sediment transport have been carried out in a proglacial valley at the Mitdluagkat Glacier in East Greenland. The results from 1989, 1990 and 1991 have been compared with earlier measurements of sediment transport. The hydrologic regime will be described and the effect of the development of an icing on the fluvial transport will be discussed.

Keywords: *Sediment transport, proglacial valley, hydrology.*

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Field investigations in the area started in 1933 when Milthers photographed the terminus of the glacier and made some preliminary ablation measurements. Runoff from the glacier was studied as part of the International Geophysical Year Programme 1957-58. In 1970, a permanent field station was established, but an avalanche destroyed it in 1972 and delayed the research programme.

The studies of the climate and runoff by Valeur (1959), showed a daily variation from 2 m^3/sec. to 4 m^3/sec. due to the melting of the glacier. The runoff was strongly dependent on the rainfall as was clearly demonstrated, with maxima up to 12 m^3/sec. During the investigation period, a jøkullhlaup occurred with a maximum runoff of 75 m^3/sec., flooding the whole valley.

Studies on the fluvial sediment transport were initiated in 1972, Hasholt (1976). The variation in daily transport during the observation period was from 1200 t/d to 9 t/d. The maximum occurred after heavy rainfall. At the measuring cross- section, 21% of the total load was bed load, suspended and dissolved load made up 72% and 6% respectively.

The current research programme at the Mitdluagkat glacier has a system dynamic approach. The object of study is the drainage basin. It consists of the glacier and the non-glacierized areas surrounding it, as well as the proglacial valley ending in a delta, where the interaction with marine processes is being studied. Weathering, soil formation and geochemistry are also being studied within the same basin in order to compute chemical balances.

The project is sponsored by the Danish Natural Science Council and is being carried out by a multidisciplinary team of scientists.

The aims of the investigations undertaken in this part of the programme are to describe the morphology, hydrology and sediment transport in the proglacial valley. Physical processes and recent sediment transport are to be quantified in order to investigate the possibility of obtaining relationships that can be used in a model describing the long-term morphological evolution induced by climatic change.

METHODS

Stage and discharge are measured at the locations shown on the map, fig. 1. Stage is recorded by an Ott type XX recorder which may work for up to 3 months. Most often, it is started in July/August and stopped in October/November because the well runs dry or because of ice.

Discharge is measured by an Ott C 31 or Labor current meter. The method of computation is mid-section based on one to two velocity measurements per vertical.

Samples for determining the sediment concentration were collected at different places. The investigation in 1972,see Hasholt (1976), showed that a significant bed load component was present at the discharge cross-section. On the other hand, surface samples taken here gave a good estimate of the concentration of wash load. To determine an approximate total load samples were taken in the rapids below, see fig. 1, where the water was very well mixed.

Hand samples were collected at the different measuring sites by a depth-integrating sampler, Nilsson (1969). In order to describe the daily variation in the concentration, an ISCO 2700 automatic water sampler was installed at the rapids. The samples were also used for a calibration of indirect measurements of concentration carried out by an IR-light transmission sensor manufactured by Partech. If the calibration proved successful, very short-time fluctuations could also be studied. Intakes of ISCO and the IR-sensor were placed in the stream 1.5 m from the bank in order to avoid the influence of local bank erosion.

Conductivity was measured and the residue left by evaporating selected water samples was examined.

To avoid having to transport the large number of water samples, the latter were filtered in the field or at the Sermilik station. Pre-weighed filters were stored in plastic pockets such as those used by coin collectors. The bottles and the water were weighed by means of an O-Haus balance, 0.1 g. A field filtering unit may be operated by using a bicycle pump. A Millipore filtering unit was also used along with a hand vacuum pump. The water was filtered through 47 mm Whatman GF/F filters with a nominal retention diameter of 0.7μ.

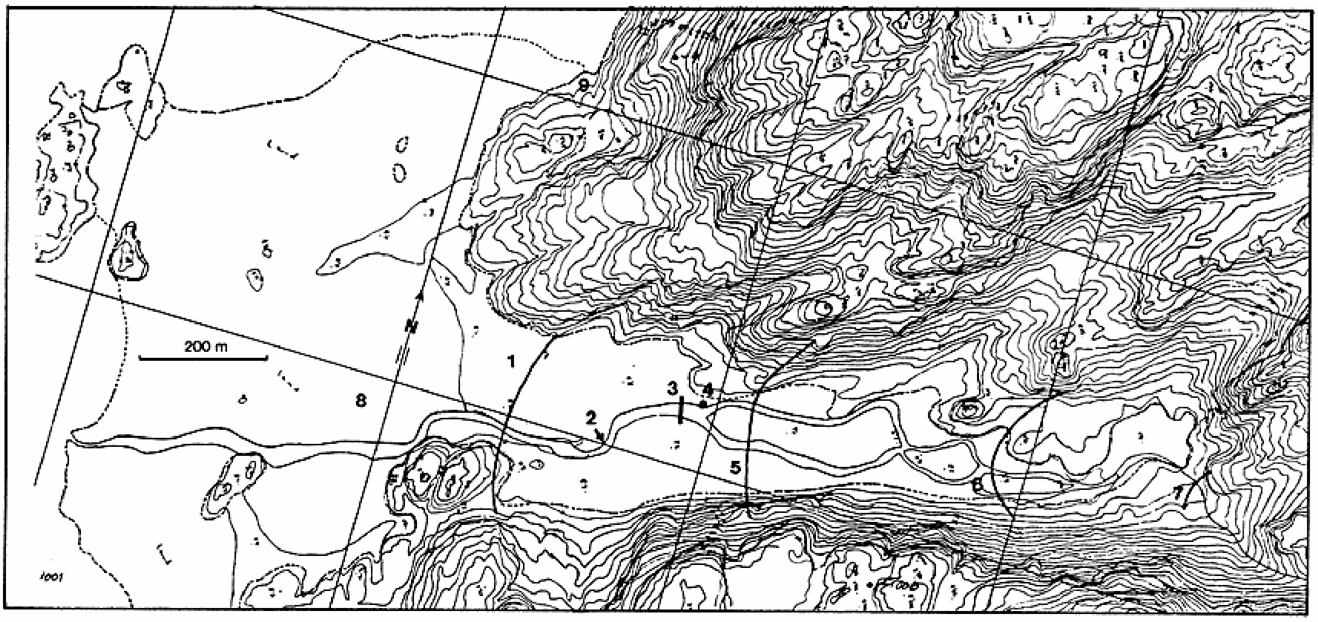

Fig. 1. 1. Terminal moraine. 2. Total load. 3. Discharge, wash load. 4. Gauging station. 5. Ice margin, 1933. 6. Ice margin, 1958, 7. Ice margin, 1970. 8. Delta. 9. Field station.

INTRODUCTORY DESCRIPTION OF THE VALLEY

The proglacial valley and its surroundings are shown on the map fig. 1, which is based on the aerial photo from 1972, see fig. 2. To the west, is a tidal delta. Near the high-tide coastline, terminal moraines mark the maximum advance of the glacier, which probably occurred in the 18th century. On the surface near the terminal moraines, several old stream channels can be recognized, but the recent outlet is carved 1-2 meters below the old channels and is obviously eroding backwards. The rapids that have hindered further downcutting were probably caused by a later terminal moraine now marked by large erratic blocks. Upstream from the discharge gauging station, the valley floor is covered by braided river deposits and has the character of an outwash plain delimited by steep valley sides consisting of solid rock. On the map fig. 1, the positions of the ice margin in 1933, 1958 and in 1970 are marked. In the aerial photo fig. 2, remnants of small terminal moraines and blocks can be seen across the valley indicating the position of the retreating ice margin. This part of the valley floor is quite even with a slope of about 1.5 ‰. At the upper end, there is an alluvial cone with a slope of about 10 ‰. The upper part of the cone is situated approximately where the ice margin was in 1970. Since then, the ice has retreated further, leaving a steep slope covered with large blocks from where the water from the glacier snout cascades downwards. Today, in 1991, the ice margin is situated approximately 150 above sea-level.

Field investigations reveal the changing course of the braided river. Sometimes sink-holes are observed in the upper end of the valley floor, indicating the occurrence of ice covered with sediment.

When walking around in the valley, one can identify high-water marks up to roughly 1 m above the flood level found in July-August, and some fresh erosion scars can also be seen in areas that are above normal flood height. An explanation is presented below.

In general, the river issuing from the glacier has a typical glacial regime according to the classification by Pardé, Chorley (1971). Measurements of the discharge from a glacier-fed lake situated just south of the glacier show that melting starts in May and culminates in June. Due to its higher altitude, the maximum melting of the glacier will occur in June and early July. According to Stenborg (1970), melting is usually greater than the discharge in the beginning of the melting season,yet becomes less than it later on. This means that the maximum discharge probably occurs in late July or early August. Except for the discharge during the jökullhlaup in 1958, the maximum discharges that have been measured are not large enough to explain the high-water marks mentioned above.

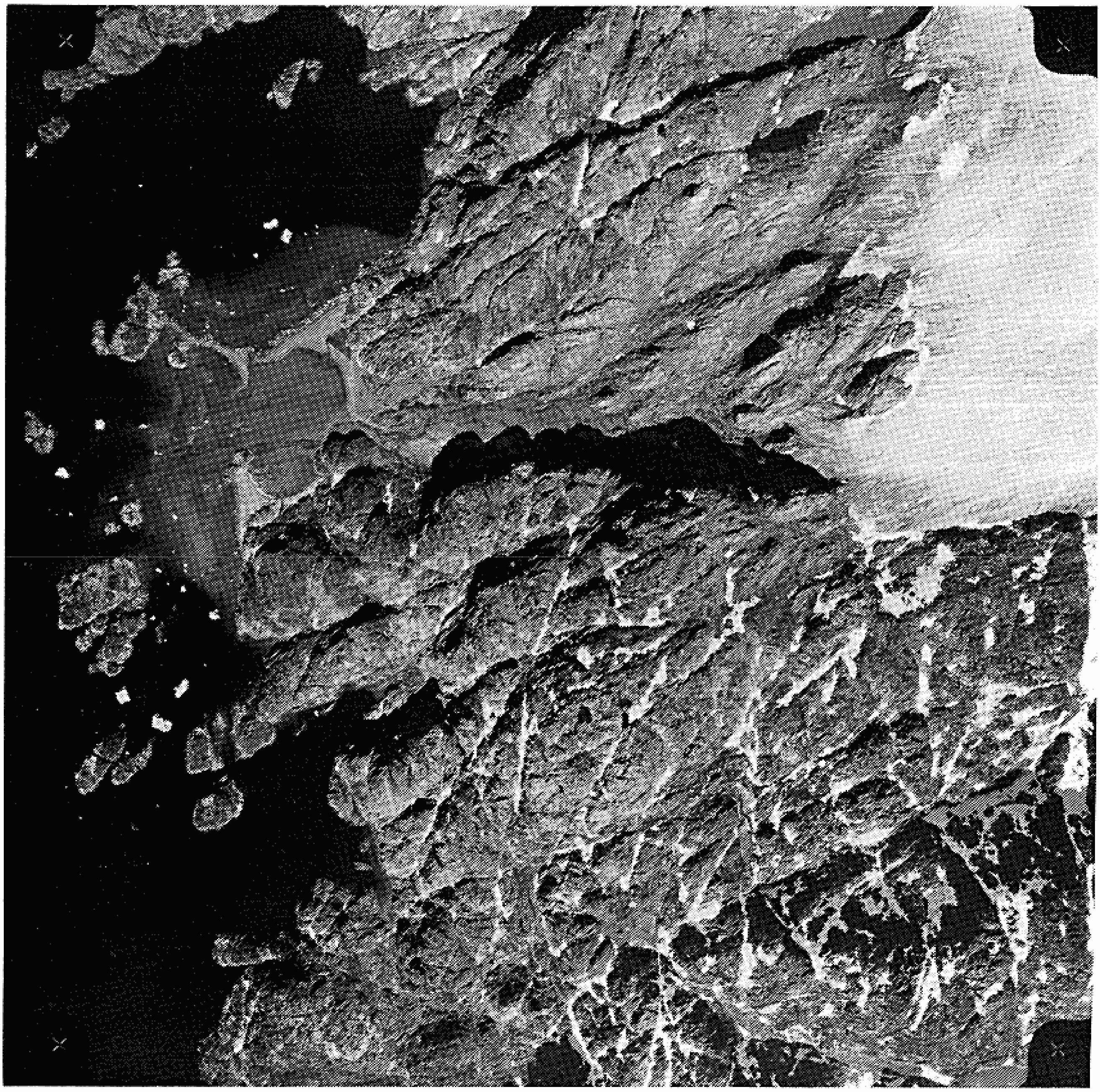

Fig. 2. Aerial photo, 1972 by Geodetic Institute.

ICING

Curiously, when the area was visited in March and May-June in 1977, it was observed that the valley had been covered by a sandwich consisting of snow and ice, interbedded with layers of sediment, see fig. 3. Water was running about half a meter above the normal flood level of August. A stage recorder well was installed, but it ran dry in less than one day because the water was cutting its way progressively downward through the layers. As the water reached the sediment layers, large and rapid changes in the sediment concentration could be observed. The 'sandwich' deposit was interpreted as an icing (naledi), developed by the melt-water of the temperate glacier. At first, it was believed that the formation of an icing in 1977 was a

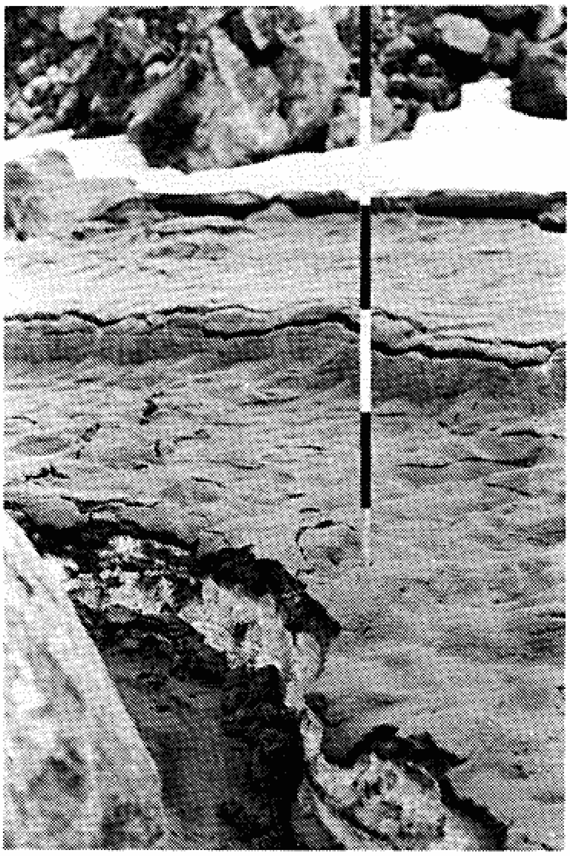

Fig. 3. Icing, June 1977. Photo N. Thingvad.

single event (see figs. 4, 5 and 6). Observations from 1990 and 1991 have since proved, however, that it is a normal phenomenon in the valley. Surveys along the margin of the glacier show that, at present, there are no depressions where an ice-dammed lake can be formed. It is therefore believed that recurrent icing is the cause of the observed high-water marks and erosion scars. In fact, some of the sink-holes can be explained by the sediment cover of icings instead of the melting of buried glacier ice. The normal seasonal cycle consists of a melting period from May to September, resulting in a maximum runoff in June-July. From October-November, meltwater produced by the basal melting forms an icing which is covered by snow during the winter. This regular cycle can be partly interrupted by heavy rainfall in connection with lows and by melting caused by Föhns. The sediment layers are believed to be formed during such extreme events. The part of the valley floor covered by the icing is roughly 160^3 m^2. The thickness is about 1 m, which gives a volume of 160^3 m^3. If this volume is divided by the time it takes to develop the icing, a rough estimate of the amount of basal melting beneath the glacier can be made;

Fig. 4. Icing, March 1977, near station 3. Photo N. Thingvad.

8 l/sec. (bottom topography is unknown, surface area is app. 10 sq.km.)

SEDIMENT TRANSPORT

The sediment transport to the valley is dependent on the degree of glacial abrasion and the amount of meltwater to carry the eroded material. The sediment transport to the delta depends on the contribution by the glacier and net erosion or deposition in the proglacial valley section. From observations and measurements of cross-sections, the valley floor seems to be rather stable. The level of the deepest point in the cross- section, where discharge was measured, was stable in 1989, 1990 and 1991. This would indicate that most of the sediment produced by glacial erosion is transported to the delta and the sea.

The results of the detailed investigations of the sediment transport are summarized in table 1. The mean hourly discharge is computed by the use of measured stage and the computed stage/discharge relationships. The measured and the computed discharge are used to establish concentration/discharge functions. The daily transport values are computed by the relationships mentioned above.

In 1990, the sediment transport was also computed by use of concentration values measured every second hour. It is seen that the difference between the transport, based on computed and measured concentration respectively only deviates by app. 3% for the whole period. It is also seen, however, that the maximum and minimum values deviate more. This is partly due to the fact that the concentration for the same discharge is higher at the rising stage and lower at the falling stage than indicated by the functions used. The correlation coefficient was low in 1990 because of the small range of concentration and discharge observations. There is a fair correlation between the IR-light transmission and the simultaneously

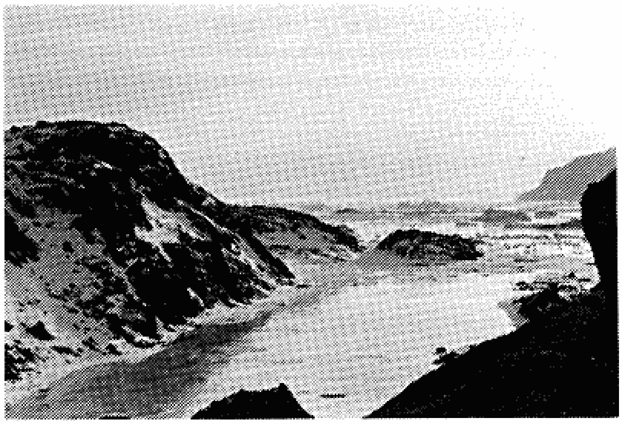

Fig. 5. Icing, March 1977. Photo N. Thingvad.

measured concentration, but the functions vary for the different periods. The results stress the importance of calibrating the measurements made by the IR-sensor. The IR-sensor is, however, very useful for studying short-term fluctuations in order to interpret the influence of different sources of sediment. Using sufficient calibration values,this method is also well suited for the computation of the transport value for the whole season. At the beginning of the runoff period, an IR-sensor with a range of 0-1500 ppm should be used.

Year	1989	1990		1991
Period	1707-2907	1608-2608		0908-2108
Discharge daily MEAN m^3/s	7.70	4.36		2.59
Discharge daily MAX m^3/s	11.44	5.77		3.95
Discharge daily MIN m^3/s	2.77	3.56		1.72
Sum $m^3 \cdot 10^3$	9317	4149		2907
Total Load MEAN t/d	431	21	21*	15
Total Load MAX t/d	1062	33	38*	25
Total Load MIN t/d	194	15	12*	9
Sum Tons	6039	235	229*	196
Discharge/stage				
Number of observations	5	5		3
Intercept	21.89	22.37		171.73
Power	2.619	2.738		6.229
Correlation coefficient r	0.995	0.985		0.973
Concentration/Discharge				
Number of observations	5	5		4
Intercept	26.75	20.65		51.25
Power	1.513	0.6608		0.2635
Correlation coefficient r	0.988	0.461		0.662
Concentration/Partech				
Number of observations	6	33		4
Intercept	-4.29	-28.34		-54.47
Multiplication	52.49	58.43		88.29
Correlation coefficient r	0.763	0.859		0.806
Wash load sum Tons	2618	203		177
c mg/l	281	49		61
Dissolved load sum Tons	158	37		
c mg/l	17	9		-

* Computed, hourly discharge and sediment concentration measured every second hour.

Table 1. Discharge and sediment transport in the Sermilik proglacial valley.

Fig. 6. Melting of icing, June 1977. Photo N. Thingvad.

The sum of the transport of wash load is computed based on mean concentration because the correlation between discharge and wash-load is poor. The proportion of washload increases when the discharge is low.

The dissolved load is also based on mean values. This component of the total transport is very low.

DISCUSSION

At the end of the glacier's mass balance year, the surface melting stops about the first of October. Water from basal melting and surface runoff caused by extreme rainfall and the Föhn effect causes the formation of an icing in the valley. Layers of sediment are found within the icing. When the melting starts, water will first run on the surface of the icing but soon the icing will begin to disintegrate and the water will follow complicated routes, sometimes cutting through to the sediments on the valley bottom. Initially , meltwater from the glacier will be stored in the snow on top of the glacier and in the crevasse system. Later, the surplus water will be released so that a flood appears in the period from late July to early August. Later, an equilibrium between the melt on the glacier and the runoff will be reached. At the end of the melting season, a recession occurs during which the reservoirs in the glacier are gradually emptied.

The measuring period in 1989 represents transport during the flood period, but because of the present lack of discharge measurements, it could not be determined whether this reflects the yearly max. The measuring periods in 1990 and 1991 covered the recession period.

The rather low transport values observed in 1990, compared to the discharge, indicate that the sediment reservoir was exhausted that year. In 1972, the average daily transport for a 44-day period in July-August was 167 tons with a maximum and minimum of 1200 t/d and 9t/d, respectively. Measurements from 1979, Hasholt (1979), showed an average daily transport of 136 tons with a maximum and minimum of 369 t/d and 15 t/d, respectively, for the month of August.

Considering the large seasonal variations, it is seen that the transport values for the years 1989, 1990 and 1991 are in the same order of magnitude as the earlier measurements, indicating rather stable sediment transport conditions.

The measurements give a rough estimate of the amount of sediment produced by glacial erosion. However, measurements covering a full year are still needed, especially for the beginning of the melting season in order to determine the relative importance of this period and the effect of the icing.

The measuring techniques used are sufficient to produce accurate values of sediment transport. The IR-transmission seems especially promising from the point of view of obtaining measurements for longer periods when the station is unmanned, provided the problems with power supply and data storage can be solved.

Using appropriate melt models, the runoff from the glacier should be computed as a function of climatic variables. In conjunction with the concentration/discharge functions presented here, the prototype of a model for the computation of yearly sediment transport could be developed. It is impossible, however, to model the transport during the disintegration of the icing, because of the stocastic nature of this process.

It is therefore important to cross-check the measured and computed transport values by other methods. Another way of investigating long-term variations in sediment transport would be to measure lake sedimentation. A preliminary investigation of this kind is planned for 1992.

ACKNOWLEDGEMENTS

This investigation has been sponsored by the Danish Natural Science Council. I am very grateful to my colleagues H.H. Christiansen, O. Humlum, B.H. Jakobsen and N. Nielsen for helping with the field-work and discussing the results.

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