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The dynamics and rate of denudation of glaciated and non-glaciated catchments, central Spitsbergen

ABSTRACT: In the 1985 ablation season studies were made of the dynamics and size of the transport of suspended and dissolved material in a glaciated drainage basin (the Ebbaelva) and an unglaciated one (the *Dynamiskbekken*) in the central part of West Spitsbergen island. The dynamics of runoff, the exhaustion of sources of transportable suspended material, hysteretic effects during floods, the share of genetic type of water differing in the mineralisation level and chemical content, as well as the role of rain waters in mobilising soluble salts, are the principal factors of transport dynamics. The extremaly warm ablation season caused the extent of denudation to exceed the estimates made so far.

Key words: Arctic, Spitsbergen, fluvial transport, denudation

Introduction

The research on the dynamics and rates of contemporary morphogenetic processes under the polar conditions of Spitsbergen is rather fragmentary. Because of obvious difficulties there are no long observation series, and the data collected are often incomparible for methodical reasons. Polish geomorphological studies provide valuable documentary material in this respect, very often of more then regional significance (*e.g.* Baranowski 1977, Czeppe 1966, Jahn 1961, Pękala 1980, Pulina 1984).

The denudation system of the polar zone is described in terms of dominant and secondary processes which determine the character and rate of its operation. The regional denudation of a drainage basin in the polar zone is still poorly understood. We have not yet acquired full information on the mechanics as well as temporal and spatial determinants of fluvial transport processes. The solution of these problems is difficult and costly as it requires years of stationary studies in chosen representative types of polar drainage basins.

In proglacial and nival streams relatively best known is the dynamics of suspended sediment transport (Fenn *et al.* 1985, Hammer and Smith 1982, Østrem 1975, Richards 1984). In the temporal approach, the variability of material load is connected with a number of constant, periodic and accidental factors, such as runoff dynamics, seasonal variation in sediment availability, hysteretic effects during floods, sudden release of local sediment resources within a glacier and its foreland, impact of precipitation, etc. In the spatial approach, hydro-climatic, morphological and geological factors come to the fore. Of particular importance is the lasting negative water balance of the majority of glaciated drainage basins induced by the tendency to the glacial recession prevalent in the Northern Hemisphere in the 20th century. This phenomenon crucially contributes to the differences in the range and dynamics of denudation processes in glaciated and non-glaciated drainage basins (Pulina *et al.* 1984a, 1984b, Pulina 1986).

Of primary importance for the chemical denudation of polar drainage basins is the intensity of physical and chemical weathering of various rocks in the different types of the polar climate as well as the quantity and availability of water in the ablation season. The most influential factor is here a cryochemical phenomenon causing a periodic increase in water mineralisation and the precipitation of soluble salts in the cold season (Drozdowski 1982, Pulina 1984).

There are relatively fewest data on the bedload transport (Walling and Webb 1987), in spite of its considerable share in the denudation balance (Hammer and Smith 1982).

The studies conducted thus far are basically restricted to the spring-summer ablation season. Yearly measurements in two drainage basins in the Hornsund area (Pulina *et al.* 1984a, 1984b, Pulina 1986) demonstrated an active role of the winter season in the processes of chemical denudation under the subpolar climate of the western coast of Spitsbergen.

The present study seeks mainly to analyse the dynamics of suspended and dissolved material transport in the ablation season in a glaciated drainage basin and in one devoid of an ice cover. Regional denudation indices of the catchments were calculated for the observation period. The basic methodological assumption was that the water leaving a catchment defines the load of dissolved and suspended material drained from the whole of it. At the same time the values obtained well reflect the character of the morphogenetic processes taking place in the whole of the catchment.

Characteristics of the study area

The research on the functioning of a contemporary denudation system of the polar zone in a short-time period, (10^0, 10^1 days) was conducted in two drainage basins situated on the eastern coast of Petuniabukta (Fig. 1). The two drainage basins chosen were taken to be representative of the polar zone. According to Pulina's (1986) calssification, they belong to the first and third types of Spitsbergen basins respectively, namely:

1) The *Dynamiskbekken* drainage basin with an area of 1.42 km² and nival-permafrost supply represents the an non-glaciated basin at the sea coast situated on uplifted marine terraces and the slopes of coastal mountains.

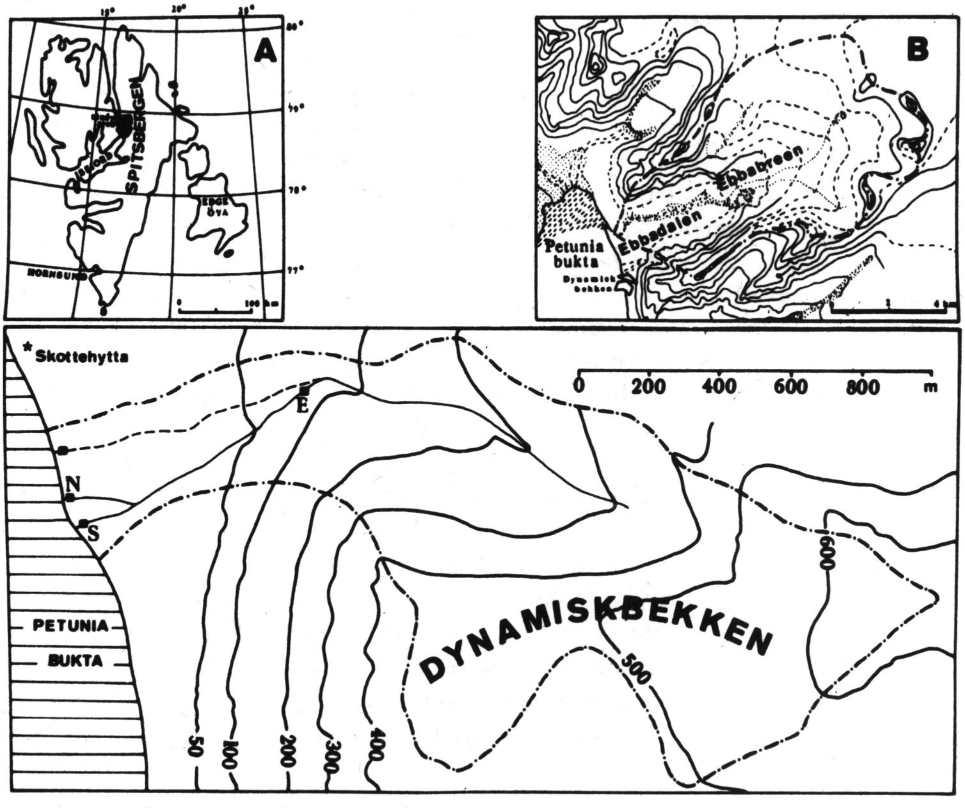


Fig. 1. Location of the drainage basins under study (A). Basins of the Ebbaelva (B, arrow indicates the location of the *Dynamiskbekken*) and the *Dynamiskbekken* (C). Water gauging stations and the Skottehytta meteorological station are indicated

2) The Ebbaelva drainage basin with an area of 51.5 km^2, supplied mostly through the ablation of glacier ice and, to a lesser extent, the melting of snow and the active layer, represents the third type of Spitsbergen basins. They embrace glaciated valleys of coastal mountains with glaciers ending on the land. A characteristic feature of these drainage basins is the fact that the glacier margin is at a distance from the end moraine, with a closed inner outwash plain being thus formed on its foreland.

The range and methods of research

To realise the research programme, a field hydrochemical laboratory was set up at Skottehytta (Fig. 1) as well as a meteorological station near to the hut. Hydrometric crossections were chosen on which gauging rods were installed and from which water was sampled.

Meteorological studies

The meteorological station was located on an uplifted marine terrace at an altitude of 8 m above mean sea-level, at a distance of 80 m from the coast of Petuniabukta and 600 m from the foot of the Wordiekamen massif slopes (Fig. 2). Meteorological observations were made four times a day, at 1.00, 7.00, 13.00, and 19.00 LMT from 28 June to 26 July 1985.

The measurements embraced air temperature, relative air humidity, direction and velocity of wind, total and dispersed radiation, precipitation, evaporation of free water surface, and soil temperature at a depth of 5, 10, 20 and 50 cm in the tundra and an uncovered soil. Near the soil temperature stations the depth of the occurence of the permafrost top was measured every few days. Air temperature and humidity was measured in a meteorological cage by means of an August psychrometer and registered using a termohygrograph. Wind direction was determined using an 8-directional wind rose, while its velocity was measured by means of a Robinson anemometer at 2 m altitude. Total and dispersed radiation was measured at 2 m altitude using a Janiszewski pyranometr. Evaporation of free water surface was registered with a help of a Lambrecht evaporograph, also installed at an altitude of 2 m. Precipitation was measured using a Hellmann rain-gauge.

Apart from the standard hours of measurement, a round-the-clock hourly registration of the meteorological elements was undertaken four times (on July 1, 8, 13 and 15).

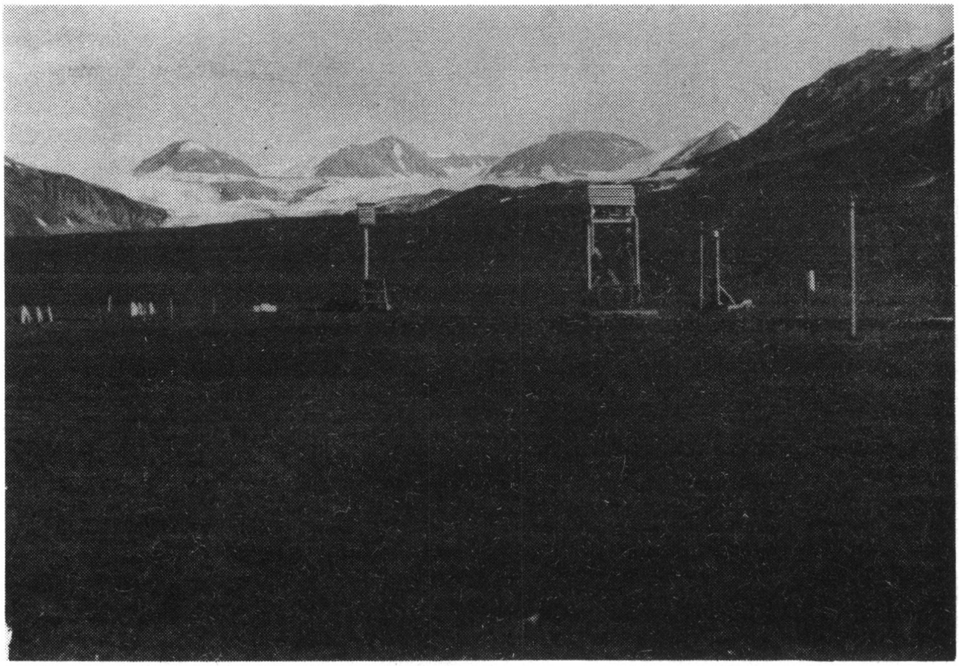


Fig. 2. The Skottehytta meteorological station in the Ebbaelva valley. In the background the Bastionfjellet, Jacksonfjellet and Flemingfjellet nunataks. The Hultberget massif on the left, the Wordiekamen Massif on the right

Hydrological and geomorphological studies

Hydrological studies included observations of the water stage and were carried out at four stations at least twice a day (8.00 and 20.00). One station was situated in the outlet section of Ebbaelva (some 0.5 km above its outlet into the fiord, to eliminate the influence of the tide, Fig. 3). The remaining three stations were located in the *Dynamiskbekken* catchment, in upper part of the alluvial fan and in the outlet crosscross-sections of two channels coming into the fiord (Fig. 1). The measurements of the Ebbaelva were carried out from 29 June to 23 July, and of the Dynamiskbekken to 17 July.

The measurements made in the gauging stations during the observation period and at different water stages covered discharge, using a hydrometric current meter in the Ebbaelva channel and floats or stains in the *Dynamiskbekken*. On two occasions of hydrological mapping the discharge was measured in two cross-sections situated above the alluvial fan. When applying the float method, the following reduction coefficients were adopted depending on the type of channel: for the ice trough, 0.825, for the station at the valley mouth and the upper part of the fan, 0.55 (profile E, Fig. 1), and for the

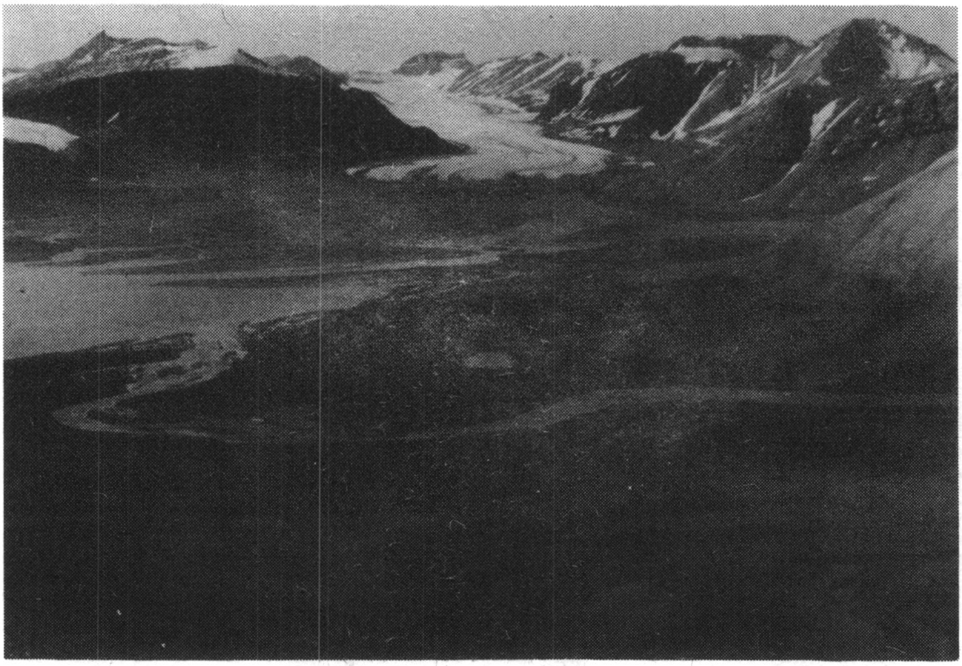


Fig. 3. The upper part of the Ebbaelva valley, the marginal zone of the Ebbabreen and the Bertrambreen on the Hultberget massif

outlet profiles, 0.66 (profiles N and S). In order to establish the diurnal hydrological cycles of the streams under investigation, on four occasions (July 1, 8, 13 and 15) measurements were taken every 1 to 3 hours depending on the meteorological and hydrological situation.

While measuring the water stage, its temperature was registred and its samples taken. The samples were used to determine the suspended sediment concentration with the help of the weight method (Brański 1968) and the dissolved material concentration by means of the conductometric method with automatic temperature compensation. The total of dissolved substances (TDS) was determined on the basis of the relationship between conductivity (SEC) and dry residue calculated from Stankowska's data (this volume). For 24 samples of water taken from different localities (streams, tundra lakelets and proglacial lakes) in the Petuniabukta area, with conductivity ranging from 28 to 1070 $\mu S\ cm^{-1}$ at 25°C, the following linear regression equation [1] was determined:

$$TDS = 0.883\ SEC - 7.113 \qquad (r = 0.991, \alpha < 0.001) \qquad [1]$$

The 95% confidence interval for the regression coefficient equals $0.830 < 0.883 < 0.936$. The values lie at the upper limit of the range given by Dojlido (1980) and Gregory and Walling (1973) for natural waters. In the hut the reaction and the oxidation-reduction potential of water was also measured using the potentiometric method. The chemical macro-composition of water was determined by titration following Markowicz and Pulina (1979).

Twice, on July 3 and 10, hydrological and hydrochemical mapping was carried out in the *Dynamiskbekken* drainage basin in order to determine the sources of weathered material transported by the stream. All hydrological phenomena were registered (including the snow cover) and 46 samples of water and snow taken for analysis.

24 samples of the material transported in the suspended sediment load (18 from the Ebbaelva and 4 from the *Dynamiskbekken*) were selected to be analysed for the size distribution of particles on a Sartorius sedimentation balance. The results were plotted in the form of cumulative curves on the probability diagrams graduated in phi units and calculations were performed of the graphical parameters of grain size distribution after Folk and Ward (1957) and of sorting index gamma after Zwoliński (1984). In order to determine extreme diameter values beyond of a cumulative curve, the method of extrapolation of the tail segments of the curves was applied.

Four samples of suspended material from each, the Ebbaelva and *Dynamiskbekken*, were used for thermal analysis in a Derivatograph-System of F. Paulik, J. Paulik and L. Erdey, which also supplied the results of termogravimetric analysis (TG and DTG) and of differential thermal analysis (DTA). Before measurement, the samples were put in a desiccator to obtain the same constant humidity. Weighed portions of 1 g, heating speed of $11^\circ \mathrm{min}^{-1}$ and the same amplification were used for all the samples. The sensitivity of DTA was 1/5, DTG 1/5, and TG 200 mg.

Physical geographic controls of the contemporary denudation system of the Ebbaelva and *Dynamiskbekken* catchments

Geology and geomorphology

The Ebbaelva drains two glaciers covering some 52% of the drainage basin area (Figs 1, 4). Ebbabreen is a valley glacier and Bertrambreen a fjeld one. About 10% of the area is occupied by nunataks: Flemingfjellet, Jacksonfjellet (1124.5 m a.s.l. — the highest point of the basin) and Bastionfjellet. The rest goes to non-glaciated fragments of the massifs of Wordiekammen. De Geerfjellet, McCabefjellet, Hultberget and Løvehovden, and an expansive valley (about 4 km^2). The mean elevation of the basin amounts to 500 m above sea-level, and the mean slope to 7° (Fig. 5). The topographic watershed of the drainage basin in its glaciated part runs along a long section of the glacier's surface, where it is marked by a clear break of slope. This poses

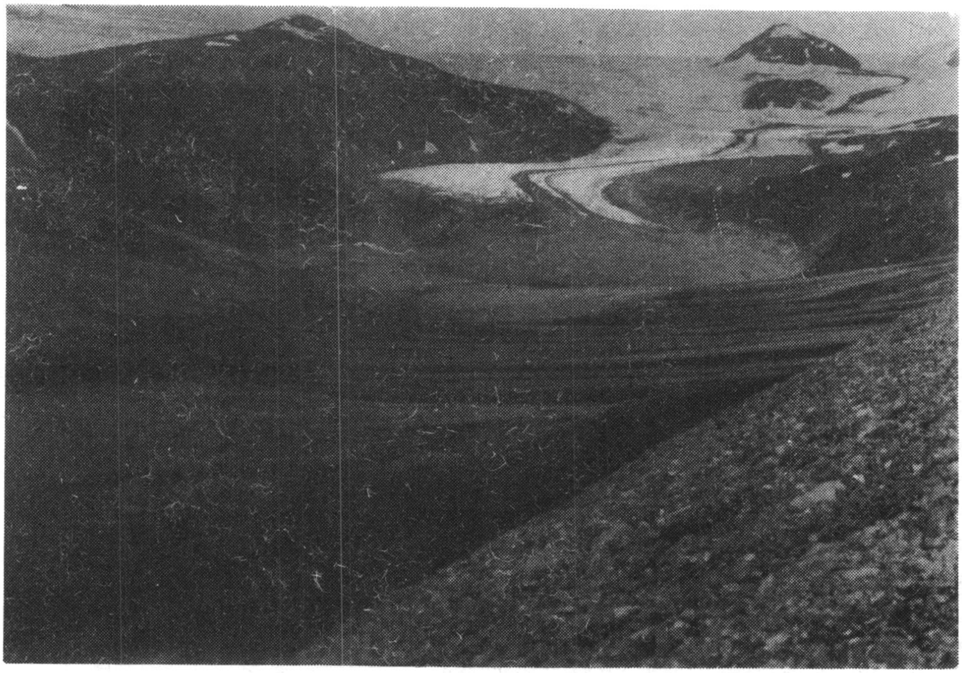


Fig. 4. The lower part of the Ebbaelva valley

the question of whether what we deal with here is a hydrologically closed drainage basin. However, the deep recession of the Ebbabreen seems to prove that the flow of ice from the Lomonosovfonna plays a negligible role in the catchment's water balance. The ice masses from the Lomonosovfonna supply mainly the Nordenskiöldbreen and Mitag-Leifflerbreen glaciers, whose margins are still in the sea.

The geological structure of this area is dominated by sedimentary rocks of the Permo-Carboniferous complex (sandstones, conglomerates, limestones, gypsum, black coal). There are also Cambrian-Ordovician crystalline and metamorphic rocks of the Hecla-Hoek formation (biotyte granites, porphyries, migmatites, quartzites and quartzitic slates as well as amphibolites). Rock bars built of resistant Hecla-Hoek rocks form a narrowing in the valley resulting in a steep slope in the marginal zone of the Ebbabreen and probably also in the fast rate of its recession caused by restraining the free flow of ice. Vast areas are occupied by Quaternary deposits: slope, glacial, glacio-fluvial and marine deposits (Kłysz 1985, Kłysz *et al. this volume*, Kostrzewski *et al. unpubl.*, Kostrzewski and Zwoliński 1988). Slopes with structural steps and well-developed talus cones are cut by periodically drained gullies with extensive alluvial fans formed at their outlets.

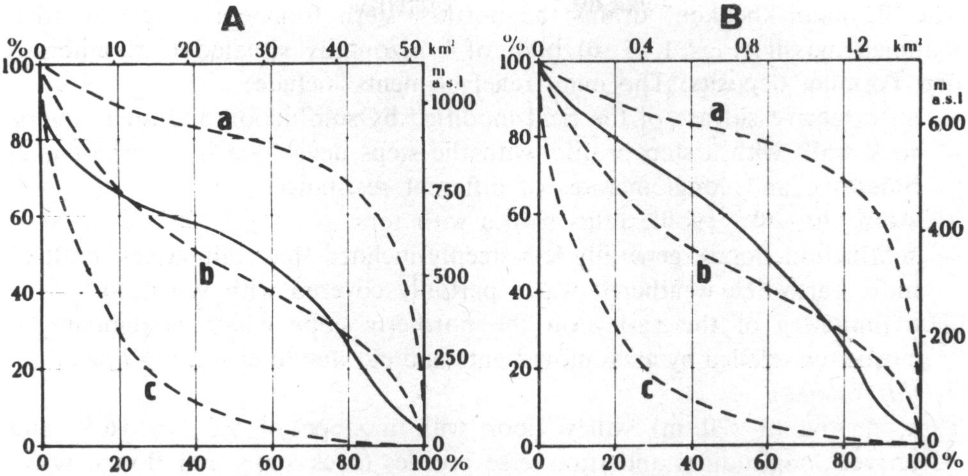


Fig. 5. Hypsographic curves of the Ebbaelva (A) and *Dynamiskbekken* (B) drainage basins against Strahler's curves

Fig. 6. The *Dynamiskbekken* valley. A patch of years-old snow in the upper part of the valley

The "Dynamiskbekken" drains the north-western fragment of the Wordiekammen massif (Figs 1, 5, 6) built of horizontally situated Carboniferous and Permian deposits. The main relief elements include:

- an extensive surface of the fjeld modified by solifluction and melt waters,
- rock walls with a step profile, with the steps developed in layers of gray limestone and conglomerates of different resistance,
- steep (30—40°) rubble talus slopes with tors,
- solifluction slopes, generally less steeply inclined than talus ones, built of more earth-like weathered waste partially covered with vegetation,
- a flattening of the valley on the northern slope which is remnant of cirque remodelled by mass movements and cut due to erosion (Kłysz *et al.*, *this volume*),
- a narrow (3—20 m) valley floor with a slope of 9.3° to 16.5° and uneven longitudinal and transverse profiles (rock steps and floors, widenings and narrowings),
- an alluvial fan with a system of braided channels and slopes varying from 3° to 8°; the morphology of fan indicates that there was at least a temporary flow towards the Ebbaelva.

The maximum altitude of the drainage basin reaches 725 m above sea-level and the mean one 430 m, with a mean slope of some 18° (Fig. 5). The stream draining the basin is about 1600 m long, of which 950 m are taken by the alluvial fan.

Meteorological conditions

The climate of the central part of West Spitsbergen, the "inner fjords" region, is markedly more continental than that of the western coast of the island. This is evident both in the annual pattern of temperatures and precipitation as well as of other meteorological parameters (Table 1). A comparison of data from the Løngyearbyen and Hornsund stations presented below offers an insight into the climatic conditions of the "inner fjords" region and the western coast.

Since Petuniabukta (an arm of Billefjorden) is situated some 60 km up Isfjorden in relation to the location of Longyearbyen, the climatic contrast with Hornsund should be even more pronounced. Koriakin *et al.* (1985) state that in summer the warmest region of West Spitsbergen is that between Billefjorden and Dicksonfjorden, where the mean temperature of the season is about 5°, and July 7°C.

A comparison of temperatures from Skottehytta and Hornsund measured over the observation period confirms the differences in their thermal regimes, with generally the same tendencies (Fig. 7, the correlation coefficient for diurnal means is 0.638 and for pentade means 0.837). On all days the average air temperature registered was higher in Skottehytta than in Hornsund

(Rocznik Meterologiczny, Hornsund 1984/1985). The minimum temperature measured at 2 m altitude in Skottehytta was higher with the exception of 3 days, than the mean diurnal temperature in Hornsund. The difference between the mean diurnal temperature in Skottehytta and Hornsund was even greater and amounted to 6.5°C (14 July), whereas that between the means for the whole period studied was 3.3°C (Skottehytta 8.4°, Hornsund 5.1°). July 4 was in Skottehytta the day that most closely resembled the thermal conditions of Hornsund. The mean temperatures in Skottehytta and Hornsund were 4.8° and 4.6°C, respectively (Fig. 7).

Table 1

Many-year means of selected climatological elements for the Longyearbyen station (1965—1974 after Pereyma 1983) and the Hornsund station (1978—1983 after Rodzik, Stepko 1985 and 1978—1986 after Ustrnul 1987)

Parameter	Longyearbyen	Hornsund
Mean annual air temperature (°C)	−6.2	−5.0
Mean monthly air temperature of warmest month	6.6 (July)	4.4 (July)
Mean monthly air temperature of coldest month	−15.5 (March)	−12.1 (Jan)
Mean annual air humidity (%)	71	78
Mean annual wind velocity (m s^{-1})	2.7	5.3
Cloud cover 0—10	6.5	7.1
Annual precipitation (mm)	187.3	406.2

The diurnal means of selected meteorological parameters for the Skottehytta station can be seen plotted in Fig. 7 and collected in Tables 2, 3 and 4.

Vapour pressure, in corespondence to the temperatures, was not very high. The average for the period studied was 7.8 hPa. Daily changes in vapour pressure are considerable and connected with changes in air temperature. The highest values occur with warm air advection, when diurnal means exceed 9 hPa (23 to 25 July). Humidity deficit on the days of warm air advection can exceed 6 hPa. It was the highest on 12 July during the foehn wind. Relative air humidity dropped then to 43% and was the lowest diurnal average over the whole period under investigation. The total of water evaporation from the Lambrecht evaporograph amounted to 76.3 mm H_2O, which yields an average diurnal evaporation of 2.6 mm.

Of the four chosen days with a continuous registration of some meteorological elements, the greatest number of hours of sunshine was recorded on

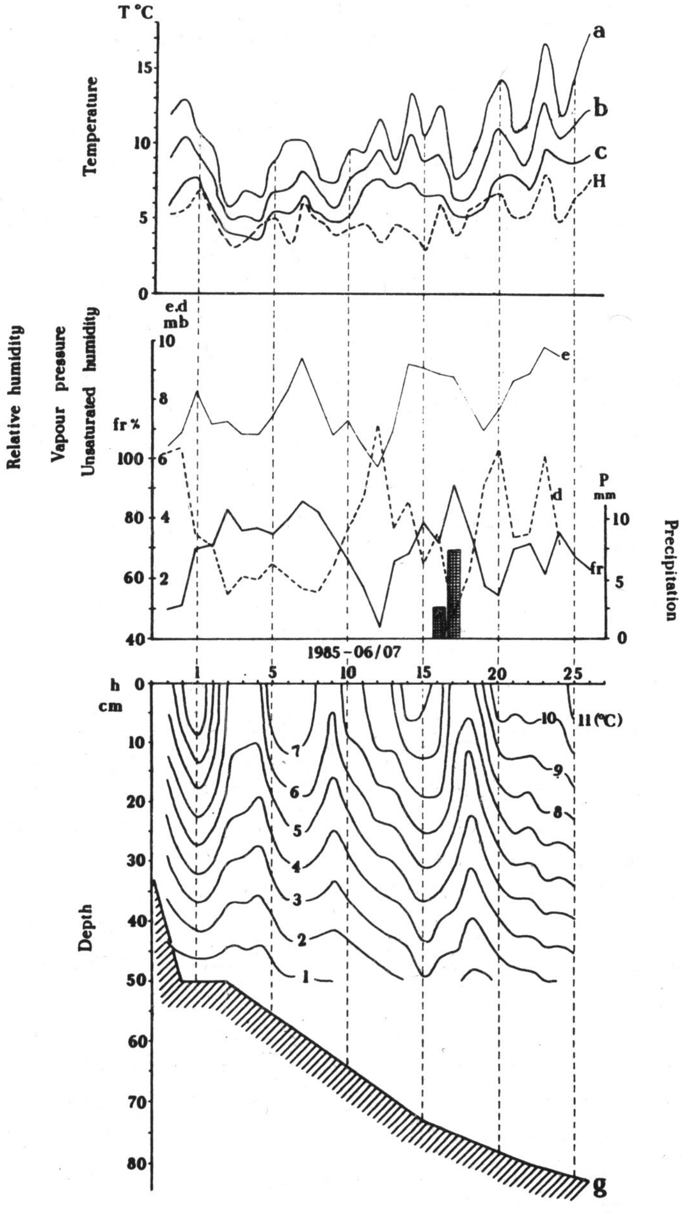


Fig. 7. Course of selected meteorological elements (diurnal means) at Skottehytta from 28 June to 26 July 1985:

air temperature: a — maximum, b — mean, c — minimum, H — mean diurnal air temperature in Hornsund, e — vapour pressure, d — humidity daficit, fr — relative humidity, P — precipitation, thermoisoplethes of ground temperature (tundra) and depth of permafrost top — g

Table 2

Results of meteorological observations from 28 June to 26 July 1985, Skottehytta, Spitsbergen

Date	Air temperature Max.	 Min.	 Amplitude °C	Diurnal mean	Vapour pressure hPa	Relative humidity %	Humidity deficit hPa	Wind direction and velocity I	 II m s^{-1}	 III	 mean	Cloud cover Diurnal mean 0—10	Precipitation mm
06—28	11.9	5.8	6.1	9.0	5.9	50	6.2	S 2.5	ESE 4.5	E 4.0	3.7	9	—
29	12.9	7.3	5.6	10.3	6.5	51	6.4	C 0	S 2.0	E 3.0	1.7	4	—
30	10.5	7.6	2.9	9.0	8.2	70	3.5	C 0	S 4.2	S 6.3	3.5	2	—
07—01	9.2	4.7	4.5	7.3	7.2	71	3.1	S 3.8	S 9.0	S 6.1	6.3	8	—
02	5.8	4.0	1.8	4.9	7.3	83	1.5	SSW 6.5	S 7.0	SSW 5.8	6.4	10	—
03	6.9	3.8	3.1	5.0	6.8	76	2.1	S 4.0	S 6.5	S 6.5	5.7	9	0.0
04	6.4	3.5	2.9	4.8	6.8	77	2.0	S 2.8	SSW 4.0	S 5.5	4.1	10	—
05	9.6	5.5	4.1	6.6	7.4	75	2.5	SSW 2.8	SSW 4.5	SSW 4.5	2.8	6	—
06	10.2	5.3	4.9	7.0	8.3	80	2.1	SSW 0.5	C 0	C 0	0.2	9	0.0
07	10.7	6.5	4.2	8.1	9.4	86	1.7	C 0	C 0	SSW 3.8	3.8	10	—
08	7.7	5.1	2.6	6.7	8.1	83	1.6	SSE 5.0	S 6.2	S 6.5	5.9	10	—
09	7.3	4.7	2.6	5.6	6.8	74	2.4	SSW 4.7	SSW 4.2	S 4.8	4.6	9	—
10	9.6	5.2	4.4	7.6	7.3	66	3.8	C 0	C 0	SSE 2.4	2.4	10	—
11	9.3	7.3	2.0	8.2	6.4	57	4.7	S 2.2	ESE 1.8	ESE 1.0	1.7	10	—
12	11.7	7.7	4.0	9.6	5.8	43	7.2	S 0.5	SE 6.0	S 9.0	5.2	7	—
13	8.9	7.1	1.8	7.9	7.0	66	3.7	SSW 3.5	S 2.5	S 2.0	2.7	7	—
14	13.5	7.5	6.0	10.6	9.2	68	4.6	C 0	S 2.5	S 2.0	2.2	2	—
15	10.6	6.5	4.1	8.8	9.1	79	2.5	SSW 2.5	SSW 2.0	SSW 1.0	1.8	9	—
16	12.6	6.7	5.9	9.3	7.0	72	3.6	SSW 0.8	E 6.5	E 0.5	2.6	8	0.0
17	8.1	5.2	2.9	6.4	8.8	92	0.7	SSW 1.2	SSW 6.0	S 8.5	5.2	10	0.0
18	8.6	5.2	3.4	6.6	7.8	78	2.2	SSE 6.0	S 0.0	E 5.0	5.5	10	—
19	12.0	6.0	6.0	8.8	7.0	58	5.1	E 4.0	SE 3.5	E 1.0	2.8	6	—
20	14.4	7.8	6.6	11.0	7.7	55	6.4	C 0	S 2.0	S 3.0	2.5	1	—
21	10.9	7.9	3.0	9.5	8.7	70	3.4	C 0	S 3.7	S 1.0	2.4	4	2.6
22	12.0	7.1	4.9	9.3	8.8	72	3.5	C 0	S 2.0	C 0	2.0	5	7.5
23	16.8	9.8	7.0	12.9	9.8	62	6.2	C 0	C 0	E 1.0	1.0	6	—
24	12.0	9.0	3.0	10.5	9.5	76	3.1	C 0	C 0	C 0	—	5	0.0
25	14.7	7.8	6.9	11.5	9.9	68	4.8	C 0	C 0	C 0	—	6	0.0
26	17.5	9.4	8.1	12.3	8.5	57	6.8	C 0	C 0	C 0	—	3	0.0
Mean Total	10.8	6.4	4.4	8.4	7.8	69	3.7				3.1	7.1	10.1

Table 3

Ground temperature at Skottehytta from 28 June to 25 July 1985 (°C)

Date	Ground temperature							
	Tundra				Uncovered ground			
	5	10	20	50	5	10	20	50
	Depth in cm							
06—28	6.8	6.1	4.3	0.0	7.6	5.9	3.6	0.1
29	8.7	7.7	5.6	0.1	9.9	7.4	5.2	0.1
30	9.9	8.8	6.6	0.2	10.6	8.5	6.0	0.4
07—01	7.9	7.4	5.9	0.3	7.9	6.3	4.9	0.6
02	5.7	5.4	4.5	0.2	5.3	4.5	3.5	0.6
03	5.4	5.1	4.3	0.3	5.7	4.5	3.4	0.5
04	5.3	5.0	3.9	0.3	5.4	4.4	3.4	0.5
05	7.5	6.8	4.9	0.5	8.7	6.8	4.7	0.8
06	8.0	7.4	5.6	0.9	8.9	7.2	5.5	1.2
07	7.6	7.1	5.9	0.9	8.2	7.0	5.6	1.3
08	6.8	6.6	5.3	1.0	7.1	6.3	5.3	1.4
09	5.9	5.6	4.6	1.0	6.4	5.2	4.3	1.3
10	7.5	6.8	5.2	1.1	8.5	6.8	5.3	1.5
11	7.7	7.2	5.8	1.3	8.1	7.0	5.8	1.8
12	8.8	8.2	6.5	1.5	9.6	8.0	6.4	2.0
13	8.7	8.2	6.7	1.8	9.6	8.1	6.8	2.2
14	10.3	9.4	7.3	2.0	12.0	9.7	7.6	2.4
15	10.0	9.4	7.9	2.9	11.1	9.6	8.0	3.1
16	9.8	9.3	7.9	2.3	10.6	9.2	7.9	3.1
17	7.4	7.3	6.7	2.3	7.0	6.7	6.4	2.9
18	7.2	6.1	5.3	1.8	6.7	6.2	5.2	2.1
19	8.1	7.6	6.1	1.8	9.6	7.7	6.2	2.1
20	10.2	9.3	7.3	2.2	11.2	9.8	7.7	2.7
21	10.0	9.4	7.9	2.6	11.2	9.5	8.1	3.2
22	10.3	9.4	7.7	2.7	11.5	9.3	8.1	3.2
23	10.1	9.5	8.3	3.0	11.2	9.7	8.5	3.5
24	10.1	9.6	8.2	3.0	11.1	9.7	8.3	3.5
25	11.2	10.3	8.5	3.2	13.2	10.9	9.0	3.7
Mean	8.2	7.6	6.2	1.5	9.1	7.4	5.8	2.4

Total (R_T) and dispersed (R_D) radiation at Skottehytta

Date R_T R_D	1:00	Hour 7:00	 13:00	19:00
06—28	117.81	119.90	473.70	262.08
	117.81	119.90	307.58	182.70
29	100.50	421.78	676.15	304.98
	58.89	231.01	205.05	136.27
30	201.09	423.08	556.76	200.34
	56.02	84.75	97.67	144.90
07—01	123.53	426.97	635.92	120.58
	123.53	93.37	246.96	120.58
02	71.82	117.78	171.36	97.67
	71.82	117.78	171.36	97.67
03	58.90	126.13	311.47	177.66
	58.90	126.13	311.47	177.66
04	24.42	220.50	175.14	121.96
	24.42	220.50	175.14	121.96
05	68.94	167.58	548.96	145.35
	68.94	167.58	116.35	145.35
06	61.76	117.81	362.08	rain
	61.76	117.81	191.52	—
07	15.80	41.65	133.62	15.80
	15.80	41.65	133.62	15.80
08	14.36	145.35	189.00	66.07
	14.36	145.35	189.00	66.07
09	20.10	89.06	275.13	89.06
	20.10	89.06	275.13	89.06
10	33.03	236.88	272.16	120.69
	33.03	236.88	272.16	120.69

1 July — 16 hours. Total radiation (R_T) reached a maximum of 636 W m ^{2} at 13.00. This was also a day of the greatest thermal differences. The diurnal amplitude of air temperature reached 4.5°C (Fig. 8). Correspondingly, a relatively great variation in relative air humidity was observed (from 56% to 88%). When analysing the two figures (8 and 9) it should be noted that on 13 and 15 July the maximum air temperature was in the afternoon hours, while on 1 and 8 July it was in the morning. This was connected with the occurrence of total sky cover and a considerable drop in total radiation to below 100 W m ^{2}.

Table 4

from 28 June to 26 July 1985 (W m^{-2})

Date R_T R_D	1:00	Hour		19:00
		7:00	13:00	
07—11	64.64	163.80	173.88	149.94
	64.64	163.80	173.88	149.94
12	118.00	490.57	329.64	274.68
	118.00	194.04	231.00	74.69
13	163.80	413.99	317.96	103.42
	86.18	83.31	268.38	103.42
14	56.02	148.68	498.35	245.70
	56.02	148.68	116.35	87.62
15	127.51	68.94	529.50	233.10
	71.82	68.94	224.28	157.50
16	47.40	399.34	116.34	rain
	47.40	97.67	116.34	—
17	74.69	rain	rain	28.7
	74.69	—	—	28.7
18	21.55	126.13	151.20	80.44
	21.55	126.13	151.20	80.44
19	68.94	460.72	599.58	134.44
	68.94	121.97	170.10	124.74
20	30.16	310.17	503.55	239.40
	30.16	89.06	133.06	66.07
21	53.15	217.98	404.91	99.11
	53.15	206.64	141.37	83.31
22	45.96	402.32	542.48	81.87
	45.96	113.65	145.35	81.87
23	44.52	327.04	519.12	rain
	44.52	97.67	519.12	—
24	27.29	389.34	189.00	93.37
	27.29	33.37	189.00	93.37
25	53.15	364.68	417.89	295.90
	53.15	73.26	146.85	191.52
26	—	—	495.76	—
	—	—	87.62	—

When analysing the measurement period against a long-term scale it was found that July of 1985 was the warmest in Hornsund since the setting up of the Polish Academy of Sciences Station, viz. 1978. The mean air temperature of the whole of the measurement period was 8.4°C in Skottehytta, and for 26 days of July 8.3°C. The extrapolation of the temperature data for the last July pentade from Hornsund shows that the monthly mean could be lower by only 0.1 to 0.3°C. The maximum mean temperature of July in Longyearbyen over the 1965—1974 decade was 7.4°C (after Pereyma 1983). Hence, there is reason to suppose that the probability of occurrence of such

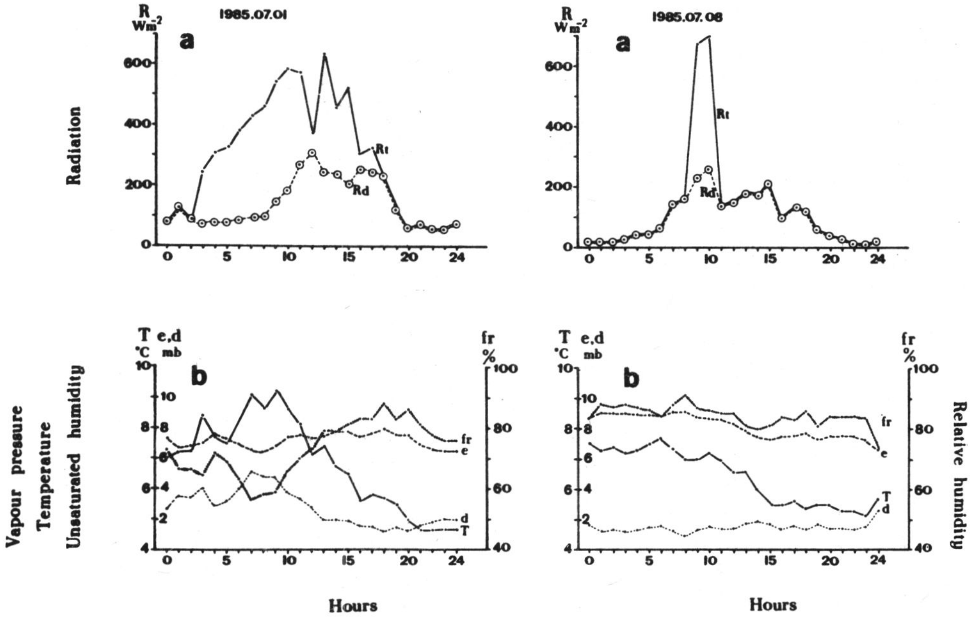


Fig. 8. Diurnal course of total radiation (R_T), dispersed radiation (R_D), air temperature (T), vapour pressure (e), humidity deficit (d) and relative humidity (fr) at Skottehytta, 1 and 8 July

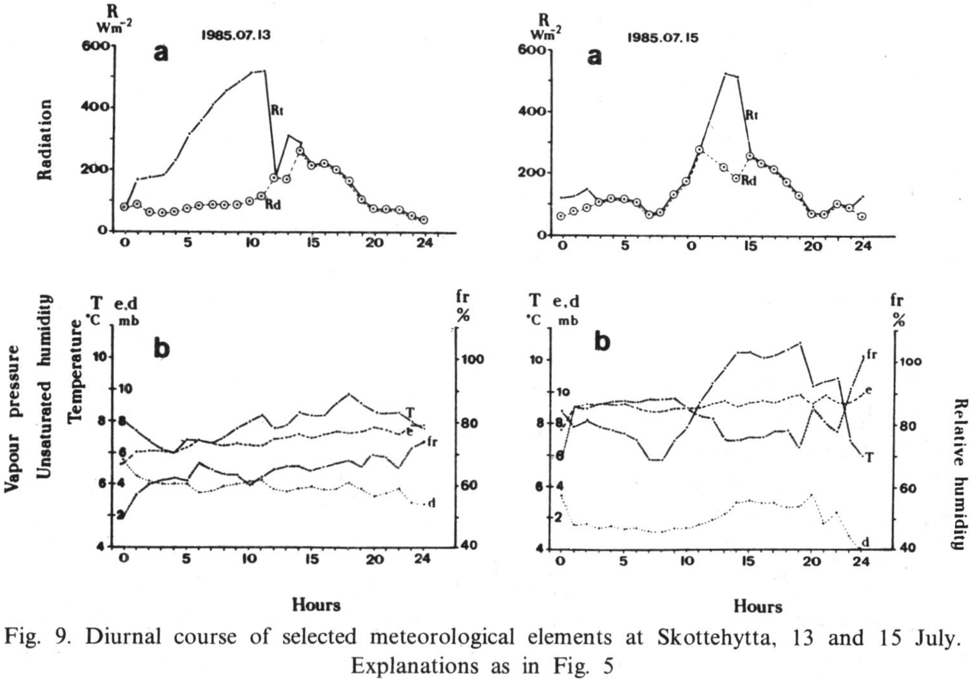


Fig. 9. Diurnal course of selected meteorological elements at Skottehytta, 13 and 15 July. Explanations as in Fig. 5

warm observation period is less than once in 10 years. The precipitation total, allowing also rainfall at the end of July that was not registered, approximated to the Longyearbyen average, though in Hornsund less than half of mean many-year precipitation was recorded in July of that year (Rocznik Meteorologiczny Hornsund 1984/1985).

Hydrological conditions

The Ebbaelva is a result of the combination of two streams draining the Ebbabreen and Bertrambreen below the zone of Ebbabreen end moraines. Between this zone and the mouth the river is supplied with melt waters coming from the snow covering the slopes of the valley, and from permafrost. When the research began there was no snow on the valley floor any more. Small patches of snow could be found at the bottoms of gullies and on shaded parts of the slopes. The north-facing slope was mostly snow-capped. Also the snow cover on the surface of glaciers was still fairly thick.

The study of the variation in the water stage and discharge of the Ebbaelva started on 27 June at 18.00, at a stage $H = 14$ cm, and ended on 23 July at 8.00, at a stage $H = 51$ cm. On that day a flood occurred that destroyed the gauging station. The stage variation in a durinal cycle is connected with that of air temperature and sunshine (Figs 16, 17 and 18). The discharge retardation at the gauging point was 6 to 10 hours. The minimum stage took place early in the day (from 5.00 to 9.00). Then the stage increased to reach a peak between 18.00 and 22.00. It was only on sunny days with high air temperature that the peak time shifted between 22.00 and 24.00. The daily amplitude of the Ebbaelva water stage depended on the type of weather. The largest amplitudes, reaching 20 cm (22 July) were noted on days of the greatest radiation and high air temperature. A decrease in the ice ablation rate on cloudy and cool days resulted in the lowering of the stage, and the amplitudes dropped even to 1 cm. A shower of rain increased the stage while the diurnal amplitude remained small (7 July, 3 cm). The smallest diurnal discharge amplitude measured amounted to 0.2 (9 July) and the largest to over 13 $m^3 s^{\ 1}$ (7 July). Over the observation period the Ebbaelva discharge measured directly ranged from 2.5 to 16.8 $m^3 s^{\ 1}$, which corresponds to unit runoff of from 50 to 338 $dm^3 s^{\ 1} km^{\ 2}$. The largest discharge, estimated from the discharge curve, amounted to 21.4 $m^3 s^{\ 1}$ (415 $dm^3 s^{\ 1} km^{\ 2}$).

Differences were determined in the magnitude of supply of the Ebbaelva runoff from the glaciated and non-glaciated parts of the catchment. The values assumed for the non-glaciated catchment were those of unit runoff measured on particular days in the *Dynamiskbekken* catchment. The difference between the total runoff of the Ebbaelva and the runoff from the non-glaciated part of the drainage basin calculated in this way defined the volume of runoff from the glaciated basin. For the period of 17 to 22 July, when observations on the *Dynamiskbekken* were carried out no longer, a value of 1.12 $m^3 s^{-1}$ was adopted for the non-glaciated part of the basin, which corresponded to the value recorded on the last day of observation. The above values are presented in Table 5 and in Fig. 10. The conclusion that follows from these data is that the Ebbaelva runoff is dominated by ablation water from glaciers. Over the whole period studied (29 June — 22 July), the runoff from the glacier-coverd part of the drainage basin amounted to 452 mm, whereas for the whole drainage basin of the Ebbaelva is totalled 286 mm. The mean ablation runoff in relation to the glacier area was 20 mm per day, which approximates to the quantity obtained by other authors (*cf.* Leszkiewicz 1987, p. 87).

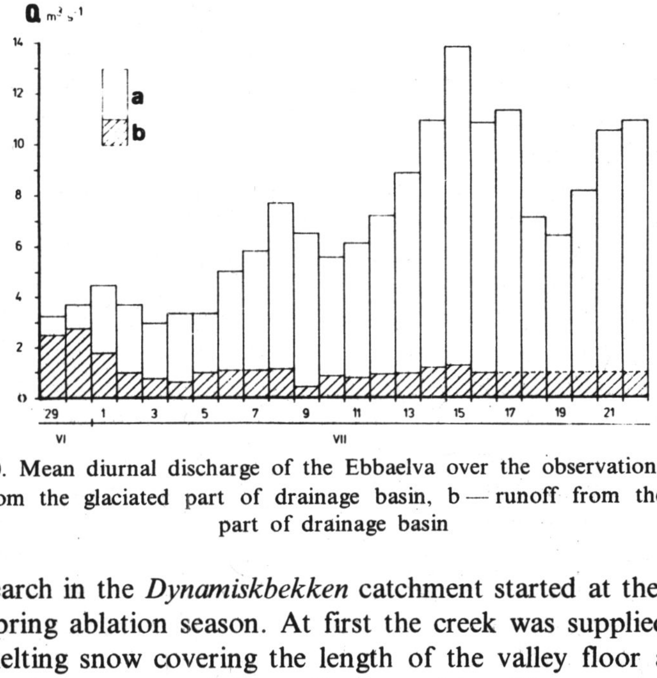


Fig. 10. Mean diurnal discharge of the Ebbaelva over the observation period: a — runoff from the glaciated part of drainage basin, b — runoff from the non-glaciated part of drainage basin

The research in the *Dynamiskbekken* catchment started at the close of the principal, spring ablation season. At first the creek was supplied with water from the melting snow covering the length of the valley floor and parts of north-facing slopes protected from direct sunshine. There was also a much snow on the surface of the fjeld. From the mouth of the valley to an altitude of some 200 m above sea-level the beck flowed on rocky-alluvial ground in a channel cut in snow. Farther on, along a length of some 50 m, the channel had the shape of an ice-snow trough, to disappear finally under snow. By the end of the observation period snow had melted away to an altitude of 200 m above sea-level. Above was a snow-firn cover of many meters which, considering the shading of the deeply cut, narrow valley floor, was likely to last thorough the summer season.

Table 5

Runoff from the Ebbaelva drainage basin from 29 June to 22 July 1985 (diurnal means)

Date	Total runoff $A = 51.5\ km^2$			Runoff from unglaciated part of basin $A = 24.6\ km^2$			Runoff from glaciated part of drainage basin $A = 26.9\ km^2$		
	Q $m^3\ s^{-1}$	q $dm^3 s^{-1} km^{-2}$	mm	Q $m^3\ s^{-1}$	q $dm^3 s^{-1} km^{-2}$	mm	Q $m^3\ s^{-1}$	q $dm^{-3} s^{-1} km^{-2}$	mm
06—29	3.33	64.7	5.6	2.77	112.7	9.7	0.56	20.8	2.5
30	3.75	72.8	6.3	2.17	88.4	7.6	1.58	58.7	6.1
07—01	4.50	87.4	7.6	1.96	79.8	6.9	2.54	94.3	8.2
02	3.75	72.8	6.3	1.13	46.1	4.0	2.62	97.3	8.4
03	3.03	58.8	5.1	0.84	34.3	2.9	2.19	81.3	7.0
04	3.42	66.4	5.7	0.71	29.1	2.5	2.71	100.1	8.7
05	3.42	66.4	5.7	1.09	44.3	3.8	2.33	86.5	7.5
06	5.08	98.6	8.5	1.20	49.0	4.2	3.88	144.1	12.4
07	5.92	115.0	9.9	1.23	50.2	4.3	4.69	174.2	15.0
08	7.83	152.0	13.1	1.28	52.2	4.5	6.55	243.2	21.0
09	6.58	127.8	11.0	0.53	21.7	1.9	6.05	224.7	19.4
10	5.67	110.1	9.5	0.92	37.6	3.2	4.75	176.4	15.2
11	6.17	119.8	10.3	0.86	34.9	3.0	5.31	197.2	17.0
12	7.33	142.3	12.3	1.02	41.7	3.6	6.31	234.3	20.2
13	9.00	174.8	15.1	1.06	43.2	3.7	7.94	294.8	25.5
14	11.08	215.1	18.6	1.34	54.6	4.7	9.74	361.7	31.2
15	14.00	271.8	23.5	1.41	57.3	5.0	12.59	467.5	40.4
16	11.00	213.6	18.5	1.12	45.6	3.9	9.88	366.9	31.7
17	11.50	223.3	19.3	1.12	45.6	3.9	10.38	385.4	33.3
18	7.25	140.8	12.2	1.12	45.6	3.9	6.13	227.6	19.7
19	6.50	126.2	10.9	1.12	45.6	3.9	5.38	199.8	17.3
20	8.33	161.7	14.0	1.12	45.6	3.9	7.21	267.7	23.1
21	10.67	207.2	17.9	1.12	45.6	3.9	9.55	354.6	30.6
22	11.08	215.1	18.6	1.12	45.6	3.9	9.96	369.8	32.0
Mean	7.09	137.7		1.22	49.8		5.87	217.9	
Total			285.5			102.8			452.4

On the alluvial fan the stream pattern was diversified. In the upper part fan, there was a short single channel, while lower the channel was braided and unstable. In the lower part, two channels had developed which maintained a relatively stable location and flowed into the fjord. From 27 to 30 June the northern channel was the principal one, and later the southern one. On 17 July whole drainage system of the alluvial fan changed as a result of considerable increase in discharge following a fall of rain. Till 1 July there was also a small stream in the northern part of the fan supplied with snowmelt water from the mouth of the valley.

There was a clear falling tendency in the stage variability which was mostly connected with the dominance of vertical erosion in the stream channel. Hence the relation between the water stage and the discharge was not linear. Daily amplitudes of the stream water stage oscillated between 1 and 11 cm at station N, 1.5 and 6 cm at station S, and 1.5 and 4.5 at station E (Fig. 11).

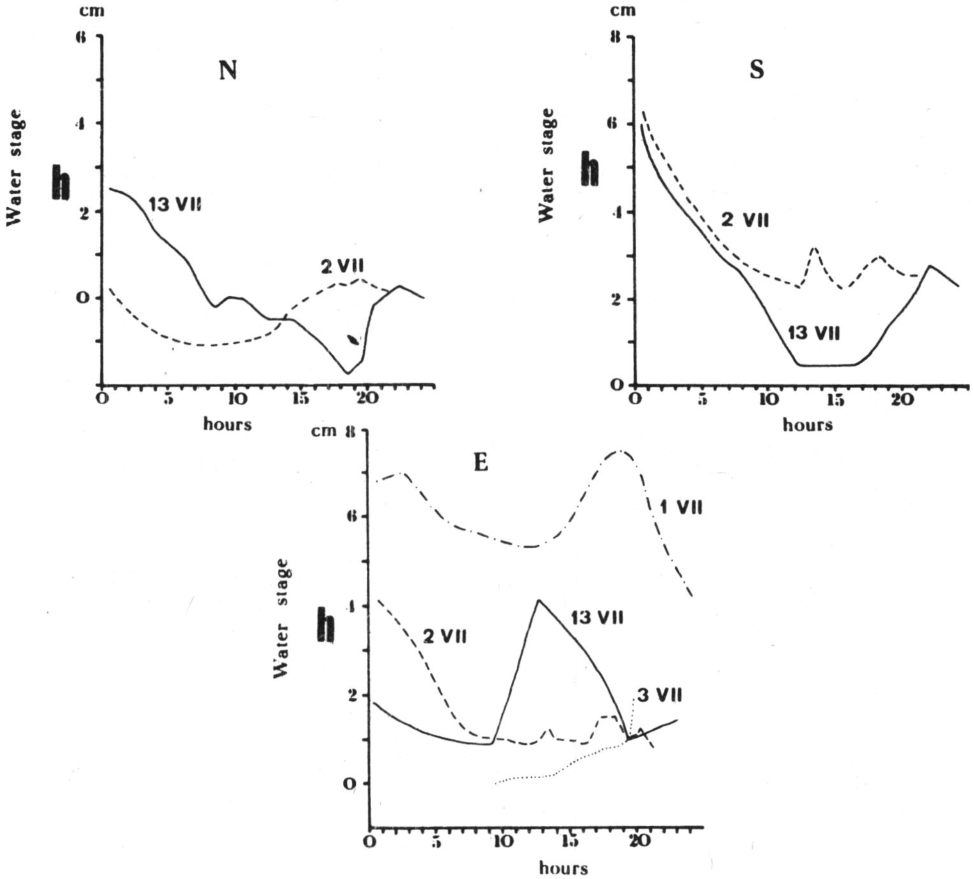


Fig. 11. Diurnal variation in the water stage at the water-gauging stations in the *Dynamiskbekken* catchment

Maximum amplitudes amounted to 13, 12 and 14 cm respectively. There was a distinct daily rhythm in the stage variability dependent on weather conditions, especially on air temperature and sunshine. This rhythm was also greatly affected by the north-western aspect of the *Dynamiskbekken* valley, which meant that it received sunshine only in the afternoon hours. Hence the highest stage in the day occurred usually between 16.00 and 20.00. It was particulary marked on sunny days (29—30 June, 12—14 July). On cloudy and cold days daily amplitudes amounted usually to 1—2 cm (Fig. 11). The lowest stage generally took place in the morning hours (5.00—9.00) or in the evening (22.00—24.00).

The measurements of the discharge volume taken during hydrochemical mapping (3 and 10 July) yielded, on 3 July, the same results at the outlet of the ice channel and in the lower part of the valley (29 dm^3 s ^{1}). The lack of increament in the discharge volume indicates that the supply with the debris flow coming from melting of the remnants of snow from the valley slopes was balanced by the infiltration of water from the stream channel into alluvial deposits of the widening valley floor. On 10 July, when the supply with the debris flow was insignificant, the discharge in the ice channel was markedly bigger than in the lower part of the valley (52 and 39 dm^3 s ^{1}, respectively).

In the period to 2 July, in the area of the alluvial fan, a marked increase in the discharge was recorded downstream connected with the supply by melt water from isolated snow patches. The increase amounted up to 30‰. After the snow patches had disappeared, similar discharge values were recorded in the upper and lower part of the alluvial fan.

The total discharge in the two outlet channels ranged from 30 to 125 dm^3 s ^{1}. The mean diurnal unit runoff in the upper part of the fan oscillated between 30 and 101 dm^3 s ^{1} km ^{2}, and in the lower part, from 22 to 88 dm^3 s ^{1} km ^{2} (Table 6). In the period from 1 to 16 July, 79 030 m^3 flowed past station E controlling the runoff from a drainage basin of 1.18 km^2, which gives a runoff of 67 mm. In the same period the total runoff at stations N and S was 88 513 m^3, which, with the drainage basin of 1.42 km^2, gives a runoff of 62 mm.

The *Dynamiskbekken* was fed predominantly by melt water from snow lying in the upper part of the valley. Of much lesser importance was the supply by melt water from permafrost, but there were no studies of this process carried out in 1985. In 1987 the supply by permafrost melt water was measured in the Skottehytta region by Choiński (*this volume*). Between 6 and 24 July it kept diminishing from 90 to 0 dm^3 s ^{1} km ^{2}, with a similar depth of thawing of the ground (68 cm). Thus, it can be assumed that permafrost melt water plays an insignificant role in the supplying of the *Dynamiskbekken*.

The hydrometric investigations of the *Dynamiskbekken* were started in the

Table 6

Mean diurnal discharge and unit runoff in the *Dynamiskbekken*

Date	Station E A = 1.18 km²		Stations N and S A = 1.42 km²	
	Q $dm^3\ s^{-1}$	q $dm^3\ s^{-1}\ km^{-2}$	Q $dm^3\ s^{-1}$	q $dm^3\ s^{-1}\ km^{-2}$
06—29	108.3	91.8	—	—
30	119.2	101.0	125.5	88.4
07—01	84.2	71.3	113.3	79.8
02	62.5	53.0	65.4	46.1
03	48.3	41.0	48.8	34.3
04	41.7	35.3	41.2	29.1
05	54.2	45.9	62.9	44.3
06	64.2	54.4	69.6	49.0
07	64.2	54.4	71.9	50.2
08	72.5	61.4	74.2	52.2
09	35.0	29.7	30.8	21.7
10	50.0	42.4	53.3	37.6
11	48.3	41.0	49.6	34.9
12	49.2	41.7	59.2	41.7
13	50.0	42.4	61.4	43.2
14	65.8	55.8	77.5	54.6
15	60.4	51.2	81.4	57.3
16	64.1	54.3	64.6	45.5
17	76.7	65.0	—	—
Mean	63.5	53.8	67.7	47.7

final stage of the main, spring ablation season, in the period of the maximum discharges of the stream. In July the runoff steadied down to a relatively low level, being mainly supplied by a slowly melting patch of perennial snow in the upper part of the valley. The regime of the *Dynamiskbekken* as a stream with a predominantly nival supply depends on the reserve of water in the snow cover and on the rate of melting of this cover or snow patches.

Mineralogical composition and grain-size distribution of suspended material

The thermal analysis of suspended material revealed considerable quatities of carbonates—endothermal effects occurred between 700 and 1 000°C (Fig. 12, Langier-Kuzniarowa 1967). For the suspended material from the Ebbaelva the loss in weight for this range of temperature (TG) was from 14.1 to 16.9‰, while for that from the *Dynamiskbekken*, from 23.0 to 44.3‰. Clearly distinct peaks of the decomposition of $MgCO_3$ and $CaCO_3$ made it possible to calculate the percentage of each compound in the sampled mass. For the

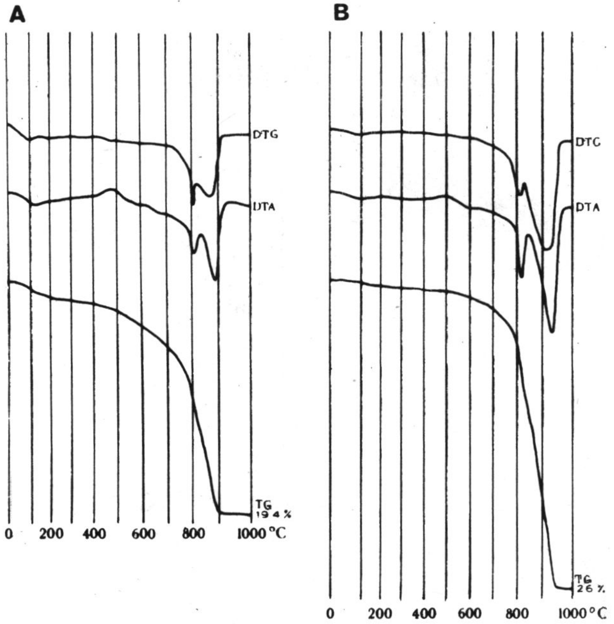


Fig. 12. Thermal analysis of chosen suspended sediment samples from the Ebbaelva (A) and *"Dynamiskbekken"* (B) drainage basins

suspended sediment transported by the Ebbaelva waters the content of $MgCO_3$ ranged from 10.0 to 11.7%, while that of $CaCO_3$, from 20.2 to 25.7%. The respective figures fr the *"Dynamiskbekken"* were: 9.2—16.5% and 38.8—81.0%. In the 300—500°C interval there occurred clear dehydration effects in silicate minerals (for the Ebbaelva TG= 0.5—0.9%, for the *Dynamiskbekken*, TG= 0.3—1.0%). In some of the samples an exothermal effect appeared at 470—480 C, probably connected with the occurence of $CaSO_4$.

An analysis of the grain-size distribution of selected samples of the suspended material from the Ebbaelva and *Dynamiskbekken* revealed the dominance of the silt fraction (62.5—2 µm, Fig. 13). In both streams there was a relatively large share of material over 62.5 µm in diameter exceeding 10% of the mass of each sample. The mean grain diameter was 20.3 µm for the Ebbaelva and 14.6 µm for the *Dynamiskbekken*. The differences among particular samples were not big. The maximum deviation from the mean did not exceed 85%. In both streams the transported material was poorly sorted, highly skewed positively, and leptokurtic, which well reflects the dynamics of the sedimentary environment.

An attempt at the correlation of several grain-size parameters and discharge, mean flow velocity, and suspended material concentration, revealed a number of significant dependences, usually hyperbolic or power (Fig. 14).

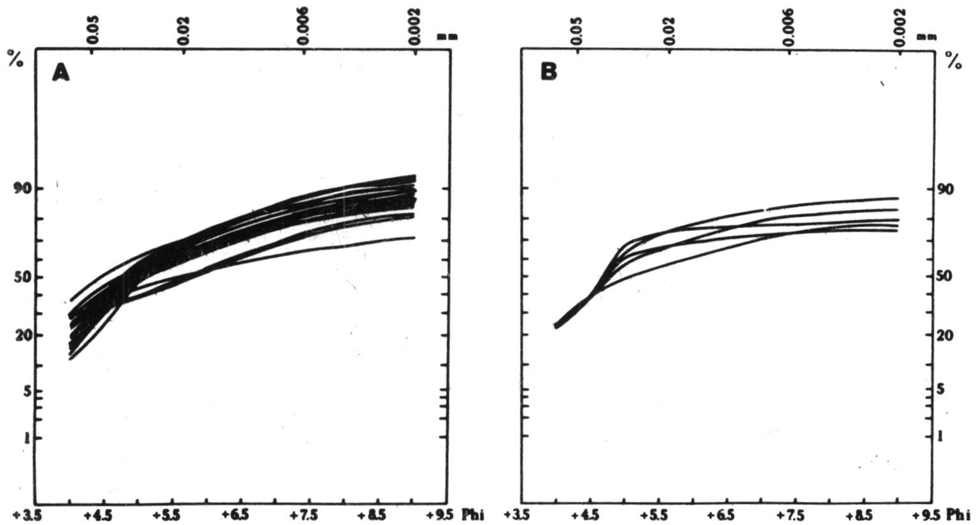


Fig. 13. Grain size distribution curves of suspended sediment samples from the Ebbaelva (A) and the *Dynamiskbekken* (B)

With the increase in discharge the mean grain diameter and the median grow, the clay fraction decreases, and sediment sorting improves. As the suspended material concentration increases, the share of the sand fraction diminishes, and kurtosis and skewness grow. Similar dependences have been observed in other streams (Walling and Moorehead 1987). Below are presented selected regression equations significant at < 0.05 level; the symbols and units are as in Table 7.

$$d50 = 2.78/Q + 4.63 \qquad r = -0.576 \tag{2}$$
$$M_z = 6.6Q^{0.08} \qquad r = -0.523 \tag{3}$$
$$\delta = 6.06/Q + 1.77 \qquad r = -0.698 \tag{4}$$
$$\delta_I = 13.43/Q + 4.53 \qquad r = -0.658 \tag{5}$$
$$C = 7.75/V + 3.62 \qquad r = -0.674 \tag{6}$$
$$K_G = 0.001Cs + 0.86 \qquad r = 0.535 \tag{7}$$
$$Sk_I = 0.0002Cs + 0.31 \qquad r = 0.506 \tag{8}$$

The suspended sediment samples from the Ebbaelva analysed for the grain-size distribution were taken on the three days of round-the-clock observations, *viz.* 1, 8 and 15 July. Due to this certain temporal effects could be noticed, probably related to the exhaustion of transportable weathered material and to the phenomenon of hysteresis during floods (Richards 1984, *cf.* also next section). In the samples taken on 1 July ($n = 8$) the correlations between discharge volume and the textural parameters were better than in the whole of the population. In the samples taken on 15 July ($n = 7$) these

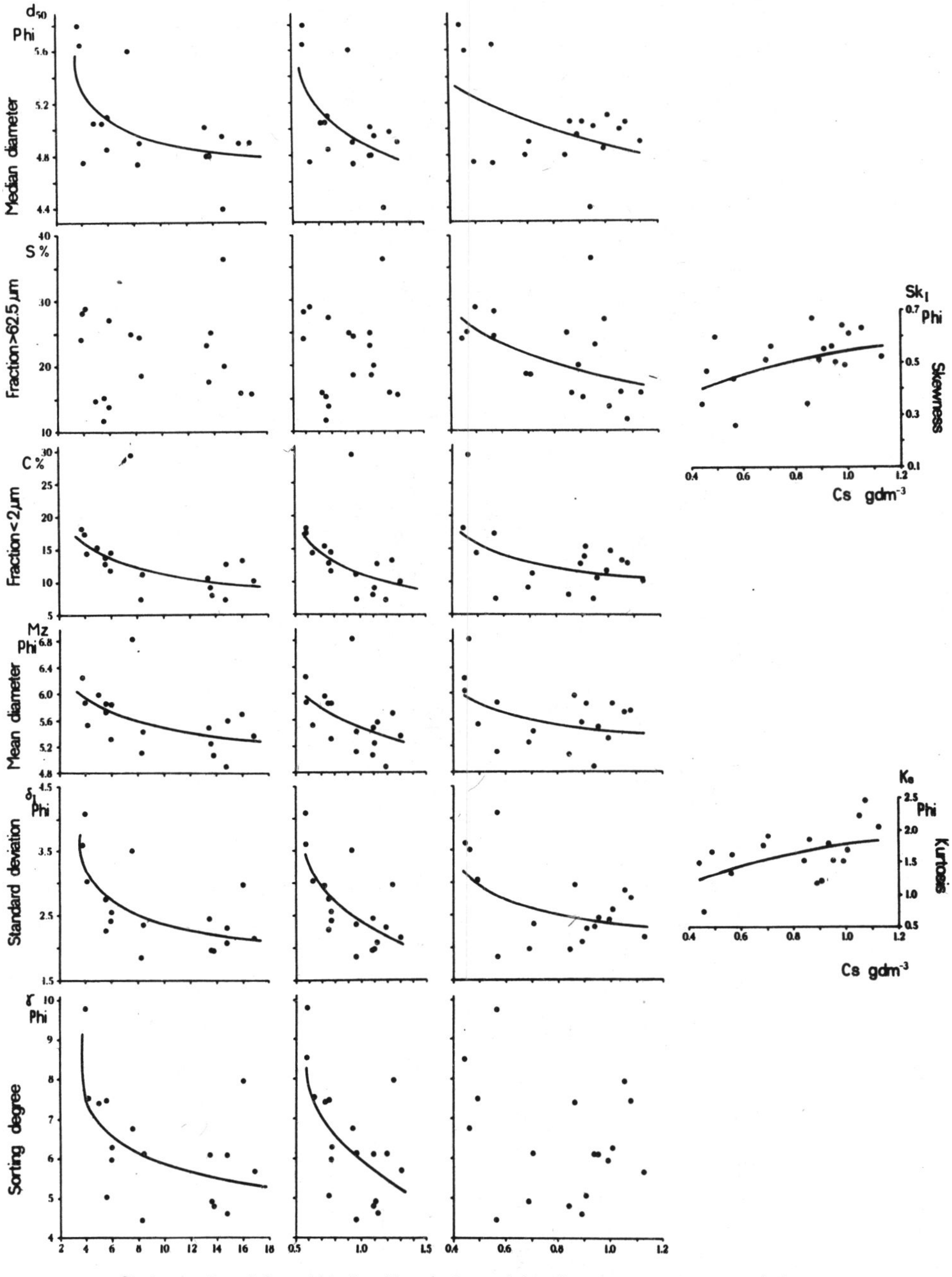


Fig. 14. Relationships between discharge ($\dot{Q}$), velocity (V), and suspended sediment concentration (Cs), and median grain diameter (d50), per cent of fraction larger than 62.5 μm (S) and smaller than 2 μm (C), mean diameter (M_z), standard deviation (δ_I), sorting degree (γ), kurtosis (K_G) and skewness (Sk_I), in suspended sediment samples from the Ebbaelva

Table 7

Statystics of hydrological parameters and grain size distribution of suspended sediment material from Ebbaelva and the *Dynamiskbekken*

	Q $m^3\ s^{-1}$	V $m\ s^{-1}$	Cs $mg\ dm^{-3}$	S $>62.5\mu m$	C $<2.0\mu m$ %	d50	M_z	δ_I ϕ	Kg	Sk_I	γ
					EBBAELVA n = 18						
mean	9.23	0.92	809.7	21.5	13.2	5.02	5.62	2.63	1.64	0.51	6.42
99% confidence interval for the mean				4.4	3.5	0.24	0.32	0.43	0.27	0.08	1.00
standard deviation	4.57	0.23	219.0	6.3	5.0	0.34	0.45	0.61	0.39	0.11	1.42
maximum	16.78	1.3	1129.2	36.3	29.3	5.8	6.84	4.09	2.46	0.67	9.81
minimum	3.7	0.6	441.4	11.7	7.3	4.4	4.89	1.86	0.73	0.26	4.47
					DYNAMISKBEKKEN n = 6						
mean				21.7	18.3	4.85	6.10	3.26	2.21	0.60	7.49
99% confidence interval for the mean				7.5	7.8	0.26	1.12	1.33	1.27	0.15	2.02
standard deviation				4.2	4.3	0.14	0.62	0.74	0.70	0.09	1.12
maximum				24.5	24.5	5.05	6.95	4.24	3.47	0.69	9.34
minimum				12.5	12.5	4.7	5.20	2.40	1.26	0.43	6.32

Denotation: Q — discharge, V — mean flow velocity, Cs — suspended sediment concentration, S — per cent of fraction larger than 62.5μm, C — per cent of fractions smaller than 2μm, d50 — median of grain diameter, M_z — mean grain diameter, δ_I — standard deviation, Kg — kurtosis, Sk_I — skewness, γ — sorting degree dependences were weak and had reverse tendency than in whole of the population, as exemplified below:

1 July

$$M_z = 3.2/Q + 5.13 \qquad r = -0.471 \tag{9}$$
$$C = 43.8/Q + 5.53 \qquad r = -0.836 \tag{10}$$
$$\delta_I = 12.3Q^{-0.91} \qquad r = -0.887 \tag{11}$$

15 July

$$M_z = -15.22/Q + 6.38 \qquad r = 0.308 \tag{12}$$
$$C = -149.3/Q + 20.4 \qquad r = 0.386 \tag{13}$$
$$\delta_I = -23.75/Q + 3.9 \qquad r = 0.389 \tag{14}$$

The explanation of the greater mineralogical diversity and of some parameters of the grain size distribution of the suspended sediment from the *Dynamiskbekken* should be looked for first of all in the location of the principal sources supplying this sediment to the channel. In the case of the Ebbaelva this is undoubtedly the channel bed and banks in a 4 km length of the valley. The gape reach directly above the measurement cross-section may play an important role here. After high discharges, on the lateral bars of the lower Ebbaelva reach, one can often find perfectly preserved (with no traces of reworking) fossil shells of marine molluscs. This may indicate scoured glacio-marine deposits as one of the main sources of suspended sediment. In many filtered samples of the Ebbaelva water high turbidity was observed (the Tyndall effect), which suggests the occurence of unfilterable actual colloids. However, the contemporary glacio-marine deposits studied in other regions of Spitsbergen have a much lower content of carbonates (Stankowska 1987) with the dominance of calcite and dolomite in the Wijdefjorden area (Rudziński and Kowalewski 1988).

In the *Dynamisbekken* catchment the valley cuts through horizontally stratified rocks with mineralogically and granulometrically diversified weathered material, which, together with advancing snow cover ablation, contributes to the temporal variation in the properties of the suspended sediment transported by the stream.

Physico-chemical properties of water

The Ebbaelva waters examined in the water-gauging crossection are, from the phisico-chemical point of view, a mixture of various genetic types of water (Pulina 1982, 1983, 1984, Stankowska 1988a, b, *this volume*). The physico-chemical properties of water (temperature, conductivity, reaction and the redox potential), measured twice a day, changed significantly over the

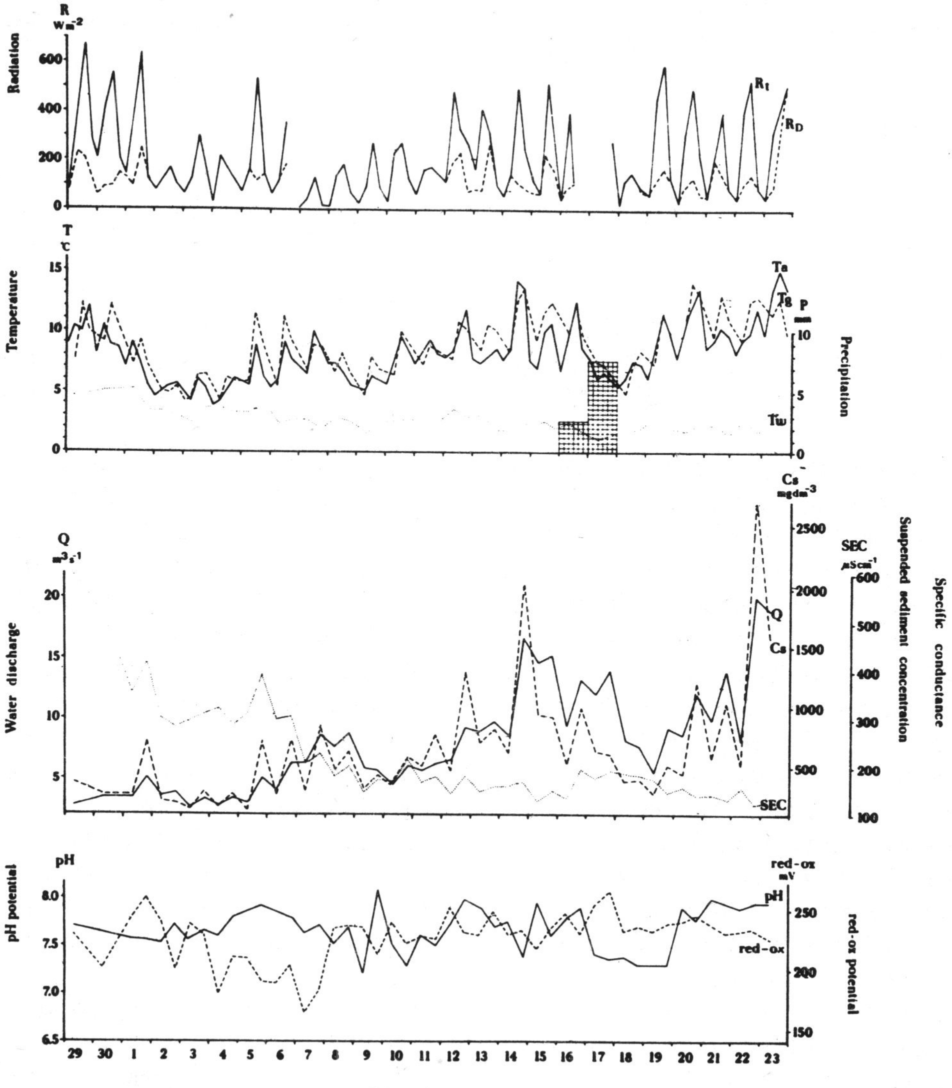


Fig. 15. Course of runoff, suspended sediment concentration as well as physico-chemical properties of water in the Ebbaelva drainage basin from 29 June to 23 July 1985 in relation to selected meteorological elements:
R_T — total radiation, R_D — dispersed radiation, Ta — air temperature, Tg — uncovered ground temperature at depth of 5 cm, Tw — water temperature at a gauge, P — precipitation, Q — water discharge, Cs — suspended sediment concentration, SEC — specific conductance, pH — reaction, red-ox — redox potential

observation period (Table 8, Fig. 15), which means that the share of particular genetic types in the total runoff was not constant.

The first period (29 June—2 July) was characterised by relatively high mean air temperature (7.3—10.3°C and low discharge (diurnal means

Table 8

Physico-chemical properties of Ebbaelva water

	Temperature °C	Conductivity µS cm^{-1}	Reaction pH	Redox mV
Whole observation period n = 47				
1 Mean	2.6	222	7.7	227
2 95% confidence interval for the mean (+/−)	0.27	30.4	0.07	6.1
3 Standard deviation	0.89	102.2	0.22	20.6
4 Minimum	1.1	122	7.2	165
5 Maximum	5.2	597	8.1	265
Period I, 29 June — 2 July, n = 5				
1	4.6	437	7.6	238
2	0.92	150.3	0.09	20.6
3	0.67	108.3	0.07	14.9
4	3.4	300	7.5	215
5	5.2	597	7.7	260
Period II, 2—6 July, n = 9				
1	3.2	309	7.8	205
2	0.43	22.8	0.09	14.6
3	0.54	27.9	0.12	17.9
4	2.4	282	7.6	180
5	4.0	382	7.9	238
Period III, 7—16 July, n = 19				
1	2.4	170	7.7	227
2	0.25	13.2	0.11	10.3
3	0.5	26.6	0.23	14.2
4	1.5	127	7.2	165
5	3.6	226	8.1	252
Period IV, 16—19 July, n = 6				
1	1.9	185	7.3	243
2	0.71	9.0	0.05	14.4
3	0.62	7.8	0.05	12.5
4	1.1	175	7.3	230
5	3.1	196	7.4	265
Period V, 20—23 July, n = 8				
1	2.1	141	7.9	236
2	0.32	11.3	0.07	5.0
3	0.36	12.6	0.07	5.6
4	1.5	122	7.8	226
5	2.7	158	8.0	245

3.33—4.5 $\mathrm{m^3s^{-1}}$). At the same time a systematic decrease in water mineralisation was noticed (conductivity dropped from 600 to 300 µS cm^{-1}) as well as the highest water temperatures in the whole observation period (with a maximum on 1 July — 6.9°C). pH was relatively low and the redox potential high. Analyses made on 1 July showed that the ion composition of the water was dominated by sulphates, calcium and bicarbonates. In the preliminary interpretation of the research results (Kostrzewski *et al.* 1988) a supposition was expressed that it was highly mineralised water of internal, "winter" circulation in the glacier (Pulina 1984, Pulina *et al.* 1984b). It follows from the analysis of hydrological data (Table 5) that in the first days of observation the runoff from the non-glaciated drainage basin predominated. The high mineralisation should therefore be attributed to the spring flow of permafrost water due to the cryochemical effect in the tundra (Pulina 1984, Pulina *et al.* 1984a), and the high temperature to the long water flow duration.

In the second period (2—6 July) there was a considerable drop in air temperature (diurnal means 4.9 to 6.6°C) and in the discharge (3.03—3.42 $m^3 s^{-1}$). Conductivity remained constant at the 300 μS level and the water temperature at roughly 3°C. This was undoubtedly the effect of the constant and still relatively high share (21—32%) of water from the non-glaciated basin (including permafrost water).

The third period (7—16 July) was marked by significant rise in air temperature, especially towards the end (diurnal means from 5.6 to 10.6°C), and decided increase in discharge (5.1—14.0 $m^3 s^{-1}$). There was a systematic, though slower and slower, drop in the mineralisation (226—127 μS). The reaction and redox potential were unstable. This was a period of a decided dominance of glacial ablation runoff and a systematic decrease in the share of water from non-glaciated drainage basin in the total runoff. A change in the ion composition of water was also registered. Analyses made on 8 and 15 July showed the beginning of the dominance of bicarbonates.

The fourth period lasting from 16 to 20 July was characterised by rapid increase in mineralisation followed by its slow decline and by a depresion of the pH curve. The redox potential increased steeply at the beginning of the period, to fall back to its previous level later on. All these changes were connected with the falls of rain that took place on 16 and 17 July (10.1 mm). They brought about a drop in air temperature and a significant increase in the discharge, which then decreased gradually. The measurements of the physico-chemical properties of the rainwater taken four times in various phases of the rainfall revealed a drop in mineralisation (from 18.8 to 9 μS) and in pH (from 6.3 to 5.7) as well as an increase in the redox potential from 300 to 345 mV.

From the first to the third period inclusive, a increase of conductivity during floods induced by an increase in temperature was observed on several occasions, despite a continual drop in mineralization (Figs 16, 17 and 18). The maximum of the dissolved material concentration was somewhat retarded in relation to the discharge peak, and there was a slight drop in conductivity in the first stage of the flood. This dependence should be

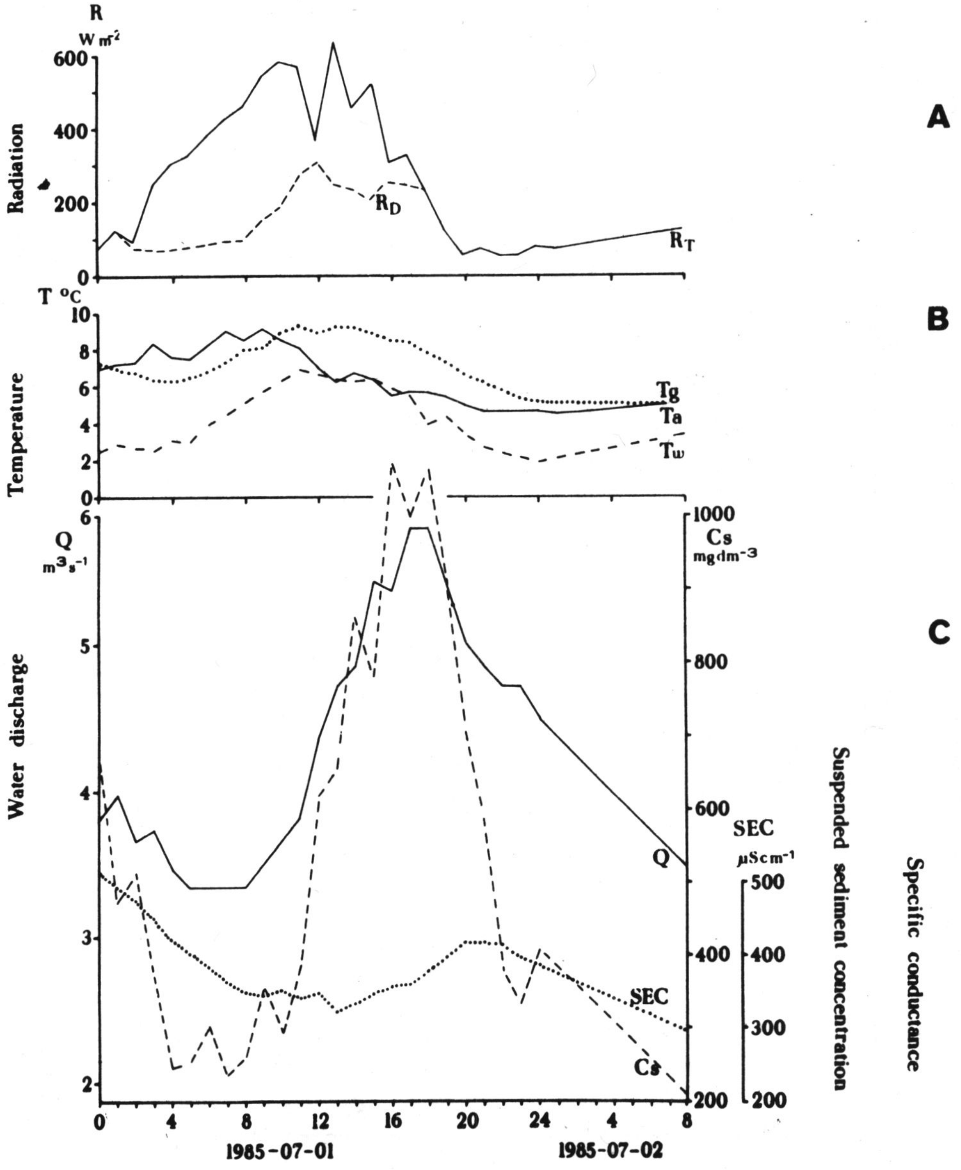
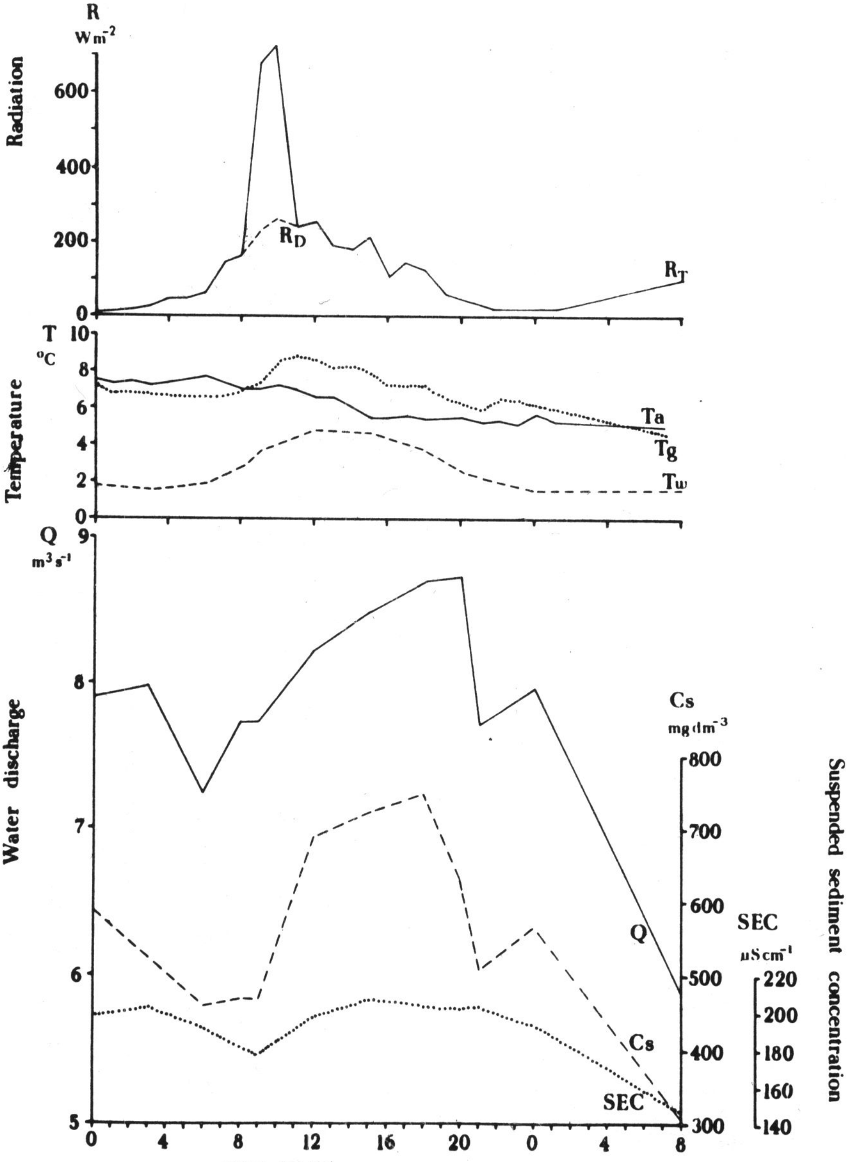


Fig. 16, 17 and 18. Diurnal course of runoff, suspended sediment concentration and water conductivity in relation to selected meteorological elements in the Ebba drainage basin on 1, 8 and 15 July 1985. Explanations as in Fig. 15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500
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Suspended sediment concentration
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Fig. 17

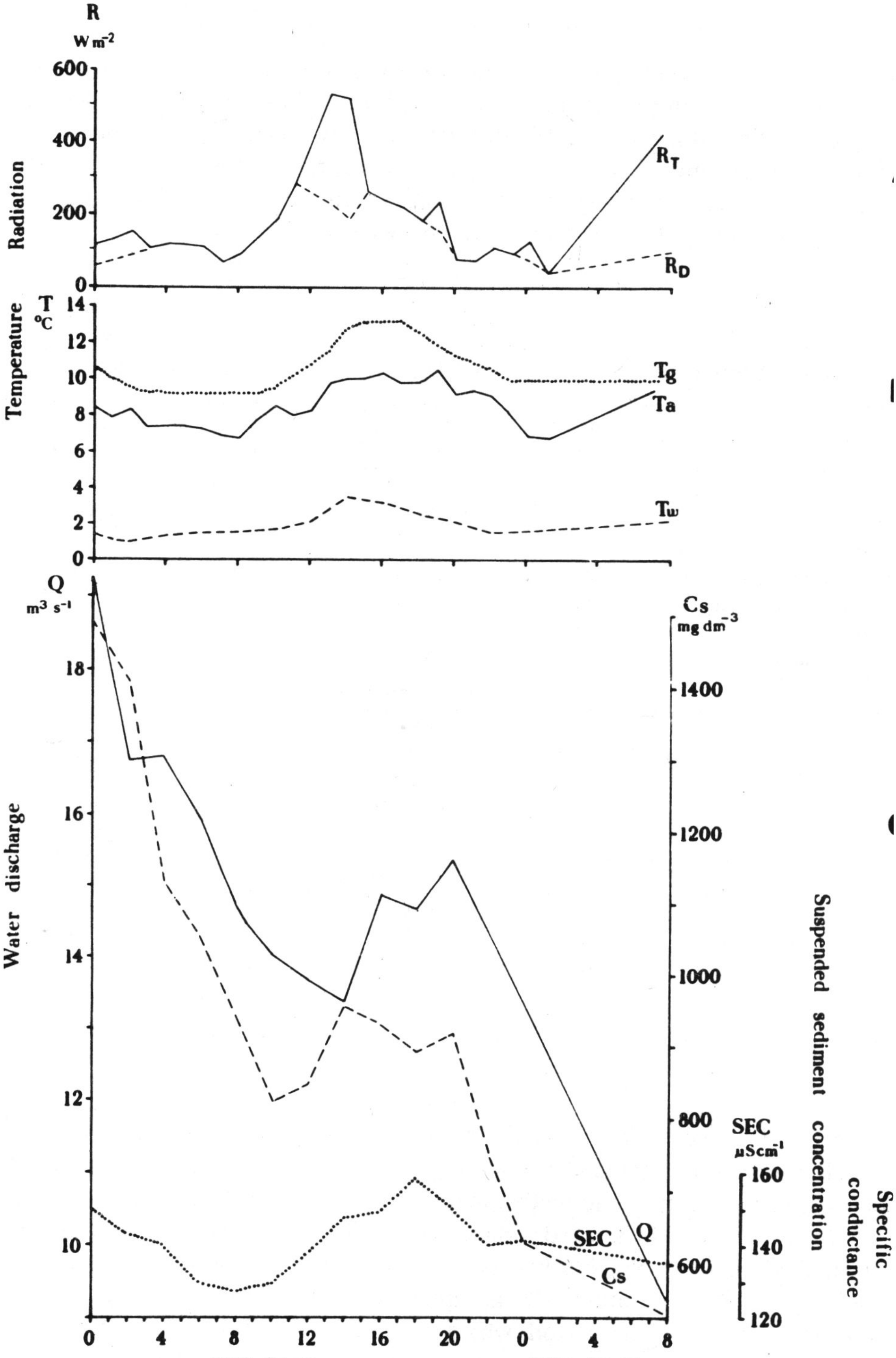
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Fig. 18

attributed to differences in the duration of water flow from snow and glacier ice ablation, and from the melting of snow and permafrost in the non-glaciated area. In the first stage of the flood water from the glaciers was dominant, while in the second there was an increase in the share of water from non-glaciated areas, carrying dissolved salts accumulated in winter due to physical and chemical weathering and the cryochemical effect.

Table 9

Physico-chemical properties of *Dynamisbekken* water from 30 June to 17 July

	Temperature °C	Conductivity $\mu S\ cm^{-1}$	Reaction pH	Redox mV
		Station S, n = 39		
1 Mean	4.4	161	8.0	217
2 95% confidence interval for the mean (+/−)	0.27	3.3	0.05	6.1
3 Standard deviation	1.00	12.1	0.18	22.2
4 Minimum	2.0	141	7.5	170
5 Maximum	6.3	200	8.4	260
		Station N, n = 37		
1	5.5	170	8.0	216
2	0.32	3.1	0.06	5.5
3	1.12	8.7	0.21	19.7
4	3.7	147	7.4	175
5	8.8	200	8.5	260
		Station E, n = 38		
1	2.1	153	7.9	217
2	0.22	3.7	0.05	7.1
3	0.78	13.3	0.17	25.5
4	0.5	129	7.5	150
5	3.4	185	8.2	265

Precipitation caused not only the acceleration of glacial ablation, but also the melting of the remnants of the snow cover on the slopes of the Ebbadalen, and, as a result, an increase in the share of the runoff of highly mineralised water from the non-glaciated drainage basin. The lasting rise in the mineralisation level of the Ebbaelva waters must also have followed from a considerable drop in temperature and a rapid recession of the discharge.

During the last, fifth period which started on 20 July, the runoff was dominated by glacial ablation water. The mean mineralisation was at its lowest, water temperature was also low. An increase in the discharge in the daily cycle made the dissolved material concentration decrease. The share

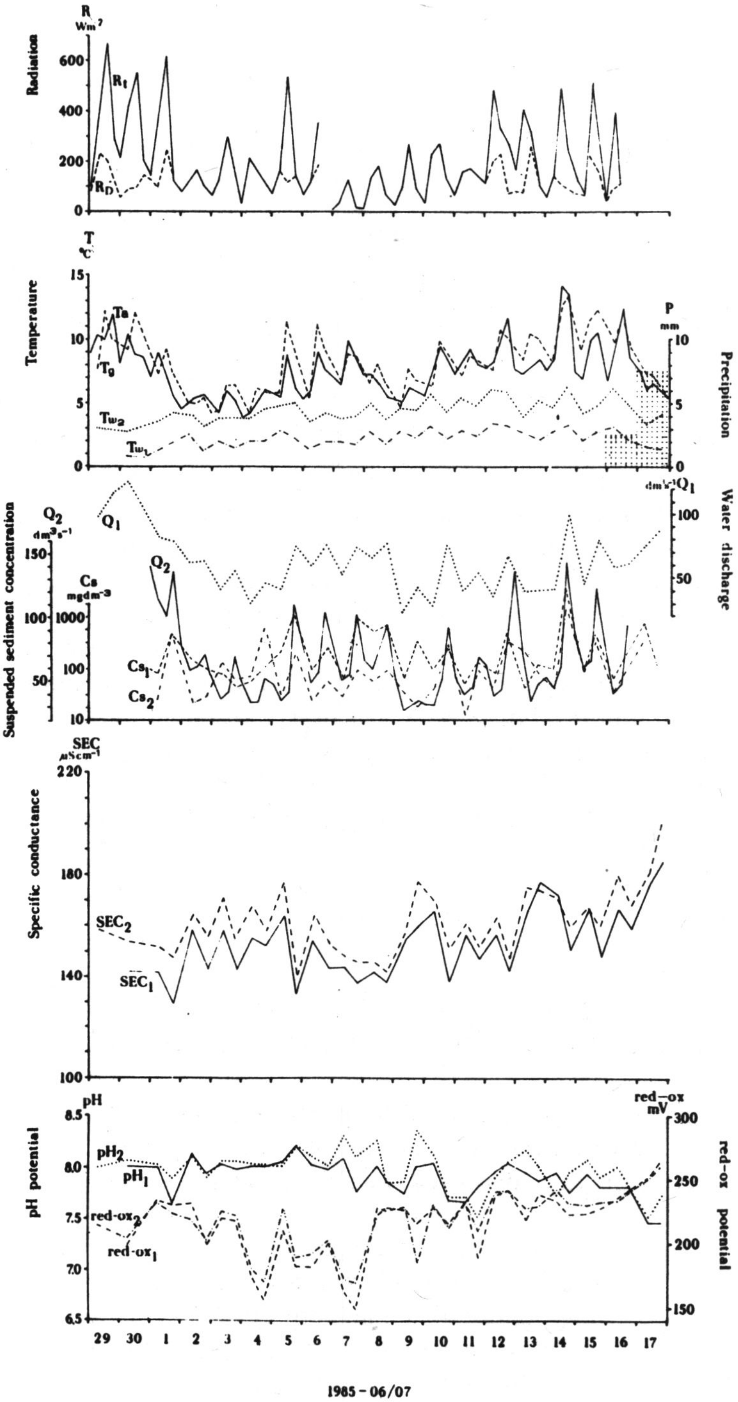

Fig. 19. Course of the runoff, suspended sediment concentration as well as physico-chemical properties of water in the *Dynamiskbekken* catchment from 29 June to 17 July 1985. Indices 1 and 2 denote data from station E and stations N and S respectively. Otherwise explanations as in Fig. 12

Table 10

Ion composition (mval dm^{-3}) of the *Dynamiskbekken* water (stations) N and S, n = 14

	HCO_3^-	SO_4^{--}	Cl^-	Ca^{++}	Mg^{++}	$Na^{+}+K^{+}$
1 Mean	1.54	0.28	0.12	1.37	0.30	0.28
2 95% confidence interval for the mean (+/−)	0.07	0.09	0.01	0.05	0.03	0.08
3 Standard deviation	0.10	0.15	0.01	0.09	0.05	0.13
4 Minimum	1.25	0.10	0.10	1.12	0.20	0.08
5 Maximum	1.75	0.72	0.14	0.46	0.38	0.61

of nival water was very slight, and a drop in the rate of permafrost melting resulted in the systematic decline in permafrost water runoff.

In the *Dynamisckbekken* drainage basin temporal differences in the physico-chemical properties of water over the observation period were insubstantial (Table 9, Fig. 19). However, there were marked differences between particular stations. The water flowing in the upper part of the alluvial fan (station E) was less mineralized and colder then in the lower part (stations N and S). In cross-section N, where the discharge was sometimes even more than ten times smaller than in cross-section S over nearly the whole observation period, the conductivity of water was higher by 9 μS on average and the temperature by 1.1°C. A fall of rain brought about an increase in water conductivity by 15, 30 and 25 μS cm^{-1} at stations N, S and E, respectively.

The ion composition of water was stable over the observation period (Table 10): $HCO_3 - > Ca^{+\,+} > Mg^{+\,+} > SO_4 \quad = Na^2 + K^2 > Cl^-$.

Source supplying dissolved and suspended material to the channel in the *Dynamiskbekken* catchment

The hydrological-hydrochemical mapping that was carried out on 3 and 10 July in the *Dynamiskbekken* catchment made it possible to identify the main sources supplying dissolved and suspended material to the stream channel.

Pure snow in the upper part of catchment had a conductivity of 3.6 to 11.5 μS cm ^{1} (Fig. 20). Snow contaminated with weathered material and verging on the melting-point had a conductivity of 39.5 μS cm ^{1}. The water flowing from under the snow had 87 (3 July) and 123 (10 July) μS cm ^{1} and it gained from 10 (10 July) to 20 (3 July) μS cm ^{1} along a distance of some tens of metres. Up to an altitude of roughly 150 m above sea-level mineralisation were similar in both cases, to be followed by a substantial drop which was especially sharp on 3 July. It was in the supply zone of poorly mineralised water from snow patches melting on the north-facing slope. On 10 July this source of water and solutes supply was already

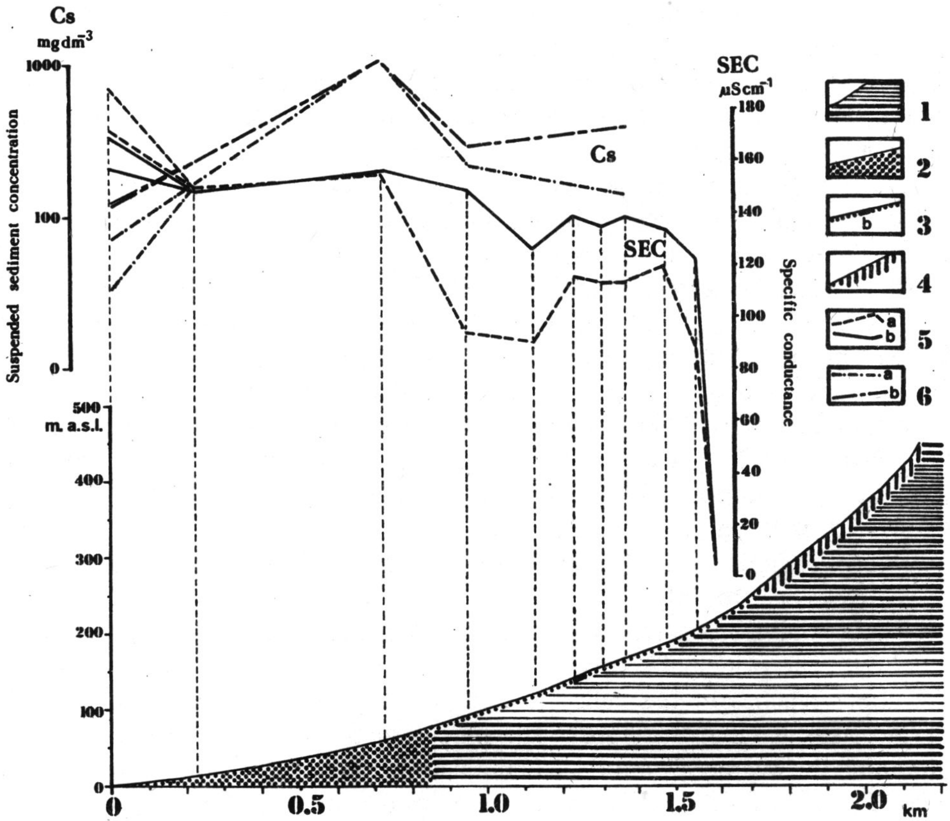

Fig. 20. Patterns of water conductivity and suspended sediment concentration along the course of *Dynamiskbekken* on 3 and 10 July 1985:
1 — rock substrate, 2 — aluvial fan, 3 — alluvial deposits in valley floor, b — rock gate, 4 — years-old snow on valley floor, 5 — specific conductance, a — on 3 July, b — on 10 July, 6 — suspended sediment concentration, a — on 3 July, b — on 10 July

exhausted to large extent, hence the drop in the concentration of dissolved material was less marked. This confirms the observations of changes in the discharge in the valley.

Another section of an intensive supply of soluble salts was the areas where the stream leaves the valley to flow in the upper part of the alluvial fan. On 3 July an increase in the mineralisation level of over 60% was registered here (as against 5% on 10 July). A drop in the flow velocity of water and a greater amount of fine-grained weathered material might be the causes of more intensive leaching. In the middle part of the a alluvial fan a slight decrease in the concentration of dissolved material was noticed (within the limits of the measuring error). In the lower part of the alluvial fan, after the stream divides into two outlet channels, a significant increase in the mineralisation level was registered connected with a drop in flow velocity and larger amount of fine-grained material.

The analysis conducted shows that the principal supply sources of dissolved material are areas under and immediately below melting snow patches, as well as the upper and lower parts of the alluvial fan, where a change in the character of the flow and in the kind of alluvial deposits facilitates more intensive leaching.

During the mapping samples were also taken at 5 sites to determine suspended material concentration. Twice a similar pattern of concentration along the course of the *Dynamiskbekken* was obtained (Fig. 20). In the snow-ice channel, water contained 140 (3 July) and 391 (10 July) mg dm ^{3} of suspended material. Along the valley, down to the alluvial fan, a slight increase in concentration (216 mg dm ^{3}, 3 July) or a slight drop (291 mg dm ^{3}, 10 July) was recorded. A steep increase (490% and 350% respectively) up to values exceeding 1000 mg dm ^{3} was observed in the upper part of the fan. Along a 720-metre section between the hydrometric cross-section E and the cross-sections on the channels coming into the fjord, a drop in suspended material concentration by 93% (main channel, S) and 96.9% (northern channel) was registered on 3 July, and by 88.4% and 87.9%, respectively, on 10 July.

The mapping was carried cut during a low (3 July) and a medium discharge (10 July). The principal source of water was long-term snow on the floor in the upper reaches of the valley and, to lesser extent, snowmelt water from the fjeld surface and the slopes. The main source of suspended material was undoubtedly weathered material contained in snow (slope, niveo-eolian and niveo-fluvial) as well as the valley floor under melting snow, especially in the transition zone from unconcentrated to linear flow. This is evidenced both by the relatively high concentration of suspended material in water from long-term snow and by the slight variation in this concentration downstream. After the rapid runoff of the initial phase of ablation, most of the fine-grained weathered material that could have been transported in suspension with a discharge of this size was cleared out from the channel. In turn, the change in flow velocity at the outlet from the valley and in the upper part of the fan was relatively slight in realation to the amount of weathered material available, which brought about a steep increase in the concentration in this reach. Before flowing into the fjord, water deposited most of the suspended material within the lower part of the fan. This fact was corroborated by the results of daily measurements.

Another mechanism of supplying weathered material to be transported in suspension can be expected during a flood discharges (especially one induced by precipitation). A variety of potential sources were identified while mapping:

— an active undercutting of a solifluction slope, of more than ten metres, below a structural narrowing in the valley (Fig. 20).

— debris flows coming to the valley floor,

— some 20 flow lines (gullies) coming down to the valley floor, dry at the moment or carrying insignificant amounts of water, but capable of becoming the paths for concentrated water flow and sediment supply.

Also in the processes of chemical denudation precipitation caused a shift in the source zones supplying solutes. Both in the *Dynamiskbekken* and the Ebbaelva catchments the response to a supply of water after a longer dry period was similar to that in the semi arid climates: an increase in solution concentration (figs 15 and 19 as well as Walling and Webb 1983). Precipitation in the catchments speeding-up the rate of ablation of the snow cover, and after wetting the surface of rocks and weathered material caused a rapid downflow of water from slopes of poor retentive capacity. The source of solutes contributing to the increase in their concentration in water flowing from the catchments could not be the permanently leached channel and the areas under and below snow patches. These solutes could have come only from the slopes and the valley floor outside the channel, where, during a long dry period, enough soluble substances had accumulated as a result of physical and chemical weathering to become even in excess the dilution effect brought about by activated snow ablation and precipitation right into the channel. What may crucially influence the creation of this phenomenon is “old water”, that is, water retained in the drainage basin before rainfall and pushed out by “new”, precipitation water. That this process plays a role in non-glaciated drainage basins in areas with permafrost has been demonstrated by isotopic studies of Obradovic and Sklash (1986). The only way to get an unambiguous answer to the question of the sources of the matter leaving the drainage basin would be through precise hydrometric measurements which, together with measurements of the concentration of dissolved and suspended material, would make it possible to estimate the amount of water and its material load supplied to (and leaving) the channel.

The zone of the most intensive denudation shifts with melting of the snow cover, while denudation is most intensive in areas with the greatest snow accumulation. One such areas is the valley floor below and under the lower part of a longterm snow patch. The morphological effects of these processes are visible as valley widenings and a change of slope in this zone.

Magnitude and dynamics of fluvial transport in the observation period

The concentration of suspended material transported by the Ebbaelva ranged from 125 to 2717 mg dm^{-3} (Fig. 15). The mean for the whole of the observation period was 639 mg dm^{-3} (SD = 487). The suspended material concentration and load were significantly correlated with the discharge (Figs 15, 21 and 25). What makes our findings different from those presented in the literature (Walling and Webb 1981b) is a low exponent for the discharge-suspended material concentration relation as well as the fact that a better approximation to the observation data is obtained by means of a linear equation. The average range of variation of the exponent is from 1 to 2 (from 0.1 to 3.2 by global data). Richards (1984) and Szczepanik (1982) give equally untypical dependences for proglacial rivers. When studying suspended material transport in the Ebbaelva in July 1987, Choiński (*this volume*) also obtained the best approximation to the observation data using a linear equation. Due to a lower discharge and greater dynamics of its variation, the slope of the regression curve is greater, but also in this case the rate of discharge variation exceeded the rate of variation of suspended material concentration (exponent smaller then unity).

This phenomenon has its source in the exhaustion of transportable weathered material over time (Fenn *et al.* 1985). This fact is well illustrated by a comparison of discharge on successive days on which concentration exceeded 1000 mg dm ^{3}:

1 July	about 5.5 m^{3}s ^{1}
12 July	9.3
14 July	10.0
16 July	13.3
20 July	12.0
21 July	14.0

For diurnal observation cycles the highest correlations between the discharge and suspended material concentration were obtained for power functions with exponents contained in the interval from 1.4 to 2.8. The hysteresis loops registered for diurnal ablation rises (Fig. 23) have a clockwise direction typical for a proglacial streams (Richards 1984, Fenn *et al.* 1985), with the peak of suspended material concentration preceding the discharge peak by 1 to 4 hours.

The magnitude of suspended sediment load (Ls, kg s ^{1}) as an effect of concentration and discharge during observation was more closely dependent on discharge variation (Q, m^{3}s ^{1}):

$$Ls \quad 0.109\ Q^{1.878} \qquad R = 71_{0} \tag{15}$$

The concentration variation of dissolved material transported in the Ebbaelva channel is to a large extent conditioned by the origin of water flowing at a given time moment. In the diagram of the discharge-conductivity relationship (Fig. 22) points can be distinguished connected with the dominance of water from permafrost melting and water from glacial ice ablation. A intermediate position represents measurements taken during a rainfall-induced flood. They correlate positively with the discharge.

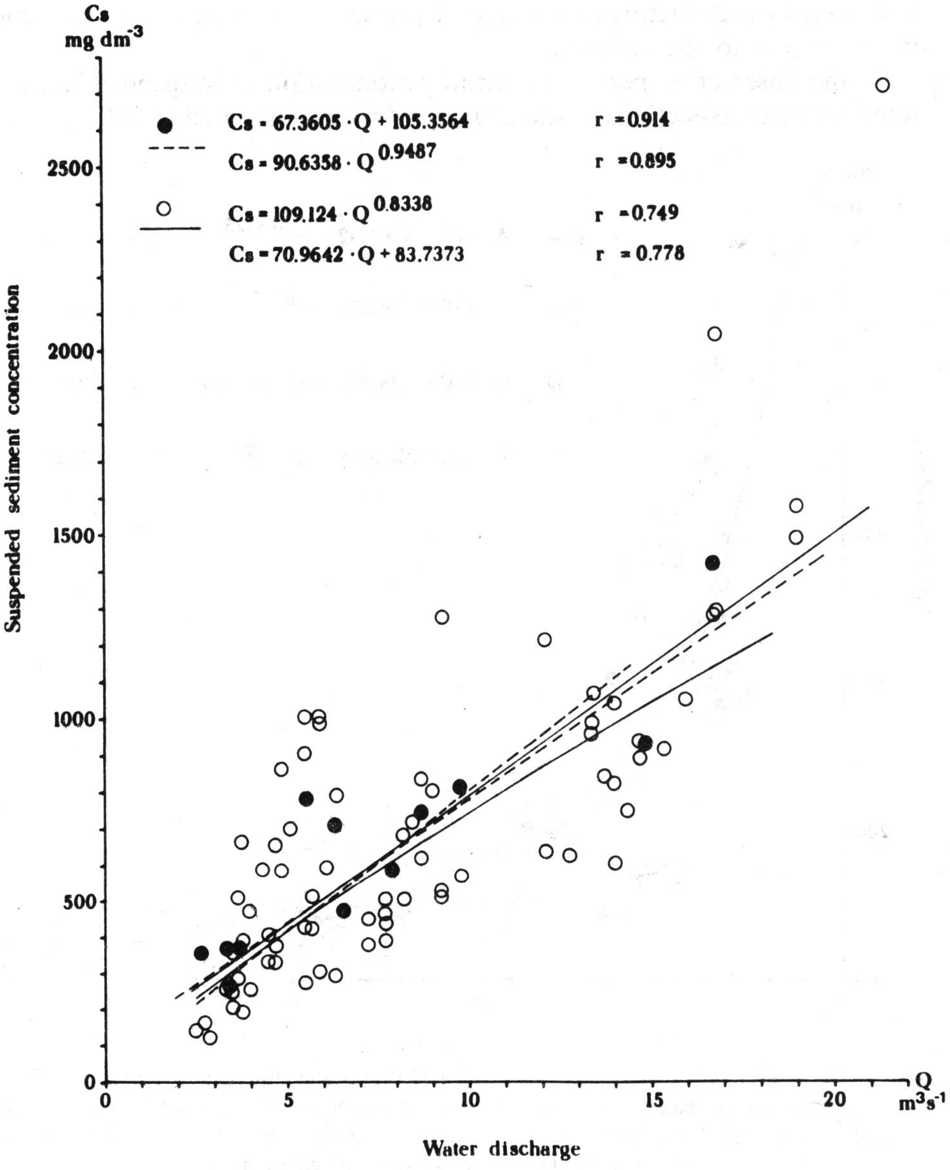

Fig. 21. Relationships of suspended sediment concentration (Cs) on discharge for Ebbaelva. Solid circles — data from direct discharge measurements, empty circles — all data

A relatively week and untypical (linear) relationship between the discharge and the dissolved load (Fig. 25) also resulted from the variability of sources supplying water to the channel. Heavily dependent on the discharge are loads during ablation water dominance and rainfall-induced flood. In the runoff in which permafrost supply from the unglaciated drainage basin dominated or crucially affected the mineralisation, the magnitude of load was also controlled by such factors as the rate of permafrost melting and the duration of water flow to the channel.

In the observation period the mean concentration of suspended sediment in the outlet cross-sections of the *Dynamiskbekken* amounted to 180 mg dm^{-3} (4.2—4241, SD = 760), while in cross-section E, 373 mg dm^{-3} (41.1—3615, SD = 605). In 86% of measurements concentration in the upper part of the alluvial fan exceeded those registered in the outlet channels. No definite rule was observed, but it can be presumed that higher concentration in the outlet cross-sections occur more often with a higher discharge, when the transport process is continuous and the erosion of previously deposited sediments which are easy to initiation can take place. The low correlation coefficients of the dependence between the discharge and suspended material concentration

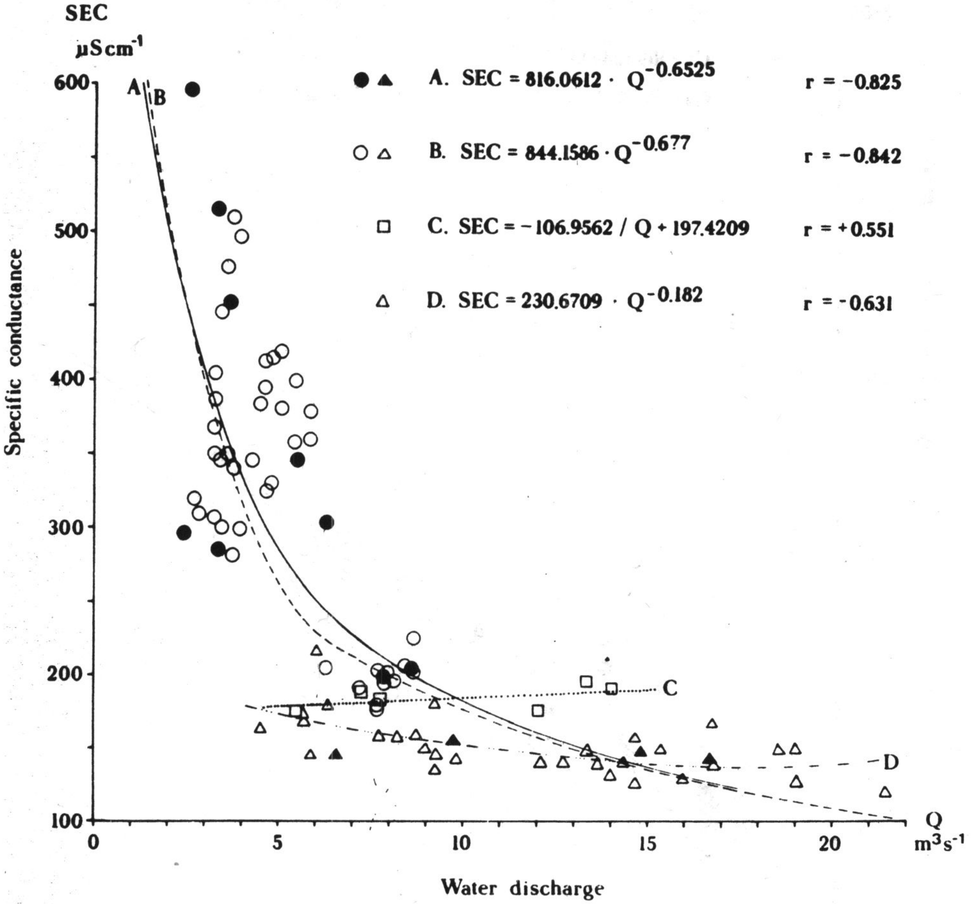

Fig. 22. Relationships between specific conductance (SEC) and discharge (Q) in the Ebbaelva: A — curve plotted for data from direct discharge measurements, B — curve plotted for all data (discharge calculated from the discharge curve), C — curve plotted for the rain-induced flood of 17—20 July, D — curve plotted for ablation water

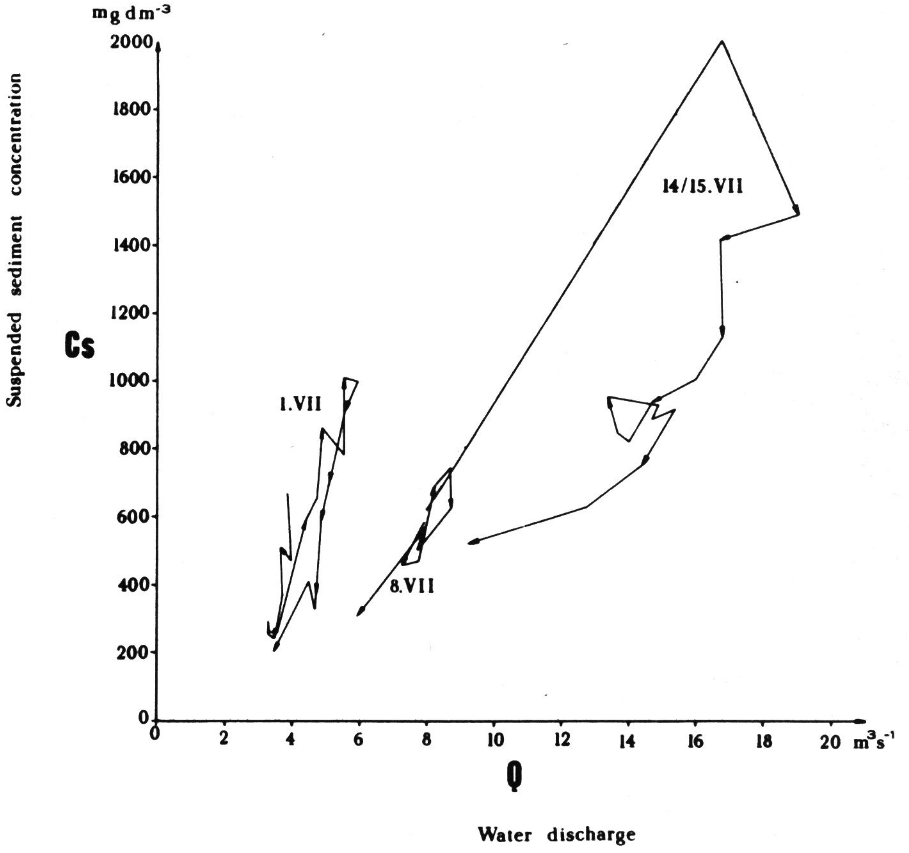

Fig. 23. Histeresis loops of suspended sediment concentration during round-the-clock measurements in the Ebbaelva on 1, 8 and 14/15 July

(Fig. 24) and exponents smaller than unity should be attributed to both, big errors in the measurement of the discharge using the float method and the exhaustion of transportable weathered material after it was "clered out" by the rapid ablation runoff of early spring. A major role may also played by accidental factors connected with sudden release of local supplies of weathered material, for example as a result of mass movements.

A low variability in the mineralisation of the ablation runoff from *Dynamiskbekken* catchment made the discharge the decisive factor of the load magnitude (Figs 24 and 25).

In the preliminary raport of the expedition's results (Kostrzewski *et al.* 1988) the magnitude of fluvial load in a water-gauging station of the Ebbaelva over a 25-day observation period was estimated at 269 t km^{-2} ±40% (with a 99% confidence interval for prediction) of suspended material, and at

43.5 t km $^{-2}$ ±33% of dissolved material. The calculations were performed using the "extrapolation" method (Walling and Webb 1981a) and choosing regression equations that gave the best fit to the observation data. According to Walling and Webb (1981a), extrapolation methods are characterised by great precision but low accuracy and by a considerable underestimation of the actual load magnitude.

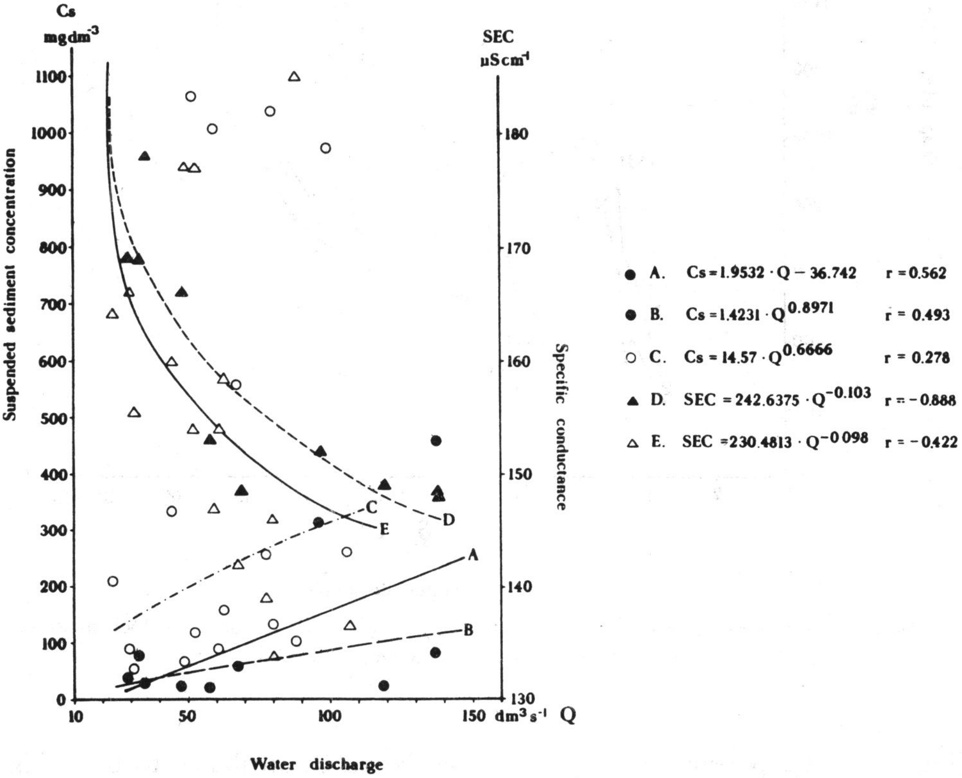

Fig. 24. Relationships of suspended sediment concentration and specific conductance on discharge in the *Dynamiskbekken* catchment:
A and B — suspended sediment concentration in cross-sections N and S, respectively, C — suspended sediment concentration in cross-section E, D — specific conductance in cross-sections N and S, E — specific conductance in cross-section E

In the present work use made of an "interpolation" procedure following the formula for two measurements per day:

$$\mathrm{TsL} = Q_i C_i / 1192.13 \tag{16}$$

where:

TsL — the total unit load (t km $^{-2}$),
C_i — material concentration in water (mg dm $^{-3}$),

Q_i — discharge calculated from the discharge curve (m^3s^{-1}), for the moment of water sampling,
1192.13 — a constant resulting from the conversion of the units of time, weight and area.

The results obtained exceed those published previously (Kostrzewski *et al.* 1988) by 12.6% for suspended load and by 16.7% for dissolved load. The bigger estimation error in the case of the dissolved load follows from the adaptation in the earlier work of constant of 0.688 for the conversion of water conductivity to mineralisation.

In order to evaluate the error of the fluvial load estimates given below, one should consider the inaccuracies following from both, the measurement methods (measurement of discharge and concentration) and the assumption of observation frequency. With the concentration levels recorded in the Ebbaelva, the error of the filtration method of determining the amount of suspended material did not exceed 1% and is practically negligible. The conductometric method with automatic temperature compensation and the use of standards can yield results deviating from the real quantity by up to 2%. Hence, in order to determine the range of errors following from the measurement methods, a 95% confidence interval was adopted for the discharge curve and the regression equation: the total of dissolved material (TDS) — conductivity (SEC). The extent of errors following from the assumption of observation frequency of measurements can be estimated by comparing the totals of daily load calculated from measurements taken every 1—3 hours (1, 8 and 15 July) with those obtained at 8.00 and 20.00. These differences for the data from 1, 8 and 15 July amounted respectively to +16.8, +3.5 and +13.8% for suspended load, and +2.7, −1.1 and +4.9% for dissolved load.

Thus, the amount of suspended material yield from the Ebba catchment from 29 June to 23 July 1985 can be estimated at 303 t km^{-2} (from 280 to 370 t km^{-2}), while that of dissolved material at 51 t km^{-2} (from 43 to 60 t km^{-2}), or 12.1 and 2.0 t $km^{-2}day^{-1}$ on average, respectively. The share of dissolved material was from 3.2 to 67.2% of the total transport (with an average for the whole period of 14.4%).

The estimate of the denudation rate for the *Dynamiskbekken* catchment was arrived at using the extrapolation method with a 95% confidence interval for prediction. In relation to the earlier paper (Kostrzewski *et al.* 1988), there is a slight change in the rate of chemical denudation resulting from a different basis of conversion of conductivity to the total dissolved material. Over the observation period (1—17 July), 27.9 t km^{-2} (22—35) of suspended material and 10 t km^{-2} (8.8 to 11.5) of dissolved material left the upper part of the *Dynamiskbekken* catchment. The respective indicies for the whole of the catchment are 9.4 t km^{-2} (7.9 to 11.2) and 9.9 t km^{-2}

(9.6 to 10.3). On the alluvial fan about 19.6 t of suspended material were accumulated, which amounts to 60% of the load transported from the upper part of the *Dynamiskbekken* catchment.

Concluding remarks

The diagrams of the unit runoff — unit load relationship (Fig. 25) plotted for the Ebbaelva and *Dynamiskbekken* catchments display a similar mechanics of processes with a strongly marked hydrological dissimilarity of the catchments. The ample supply from glacier ablation affects the rate of denudation processes, while their dynamics as expressed by the slope of regression curves is similar. The dissimilarity of the unit curve of chemical denudation for the Ebbaelva drainage basin follows from the clearly marked influence of the chemistry of different genetic types of water. However, the dependence calculated for ablation water only is close to those obtained for the *Dynamiskbekken* catchment. The diagrams also illustrate the substantial role of the alluvial fan as the site of deposition of fine-grained material transported in suspension. While in the upper part of the *Dynamiskbekken* catchment suspended material transport is dominant, in the whole of the catchment dissolved material transport may be of greater significance.

Taking into consideration the short time of observation (1/4 to 1/5 of the runoff season) and comparing data at a global scale provided by Walling and Webb (1983, 1987), one can notice that the ion outflow from the Ebbaelva drainage basin in 1985 approximated to the maximum values recorded in drainage basins situated on carbonate rocks is very humid temperate and tropical climates. On the other hand, suspended material transport was comparable to average values of small glacial rivers under mountain conditions (Dedkov and Mozzherin 1984 after Walling and Webb 1987).

The values obtained, even assuming the most conservative extrapolation variant for the whole of the ablation period, considerably exceed the estimated rates of average mechanical and chemical denudation of Spitsbergen drainage basins given by Pulina (1986).

These results must no doubts be attributed to the extreme meteorological conditions of the observation period. The magnitude of the temporal variability in hydrological and denudation processes under the Spitsbergen climate is very big, which is best illustrated by a comparison of the present findings with those obtained by Choiński (*this volume*) for the cool July of 1987. The mean discharge of the Ebba River was 3.1 times lower in 1987 than in 1985, mean suspended material concentration was 2.1 times lower, and the mean diurnal suspended load was 10.1 times smaller.

Thus, in the light of the above data, the determination of reliable, average magnitudes of regional denudation of the Spitsbergen drainage basins requires many years of studies in selected, representative basins.

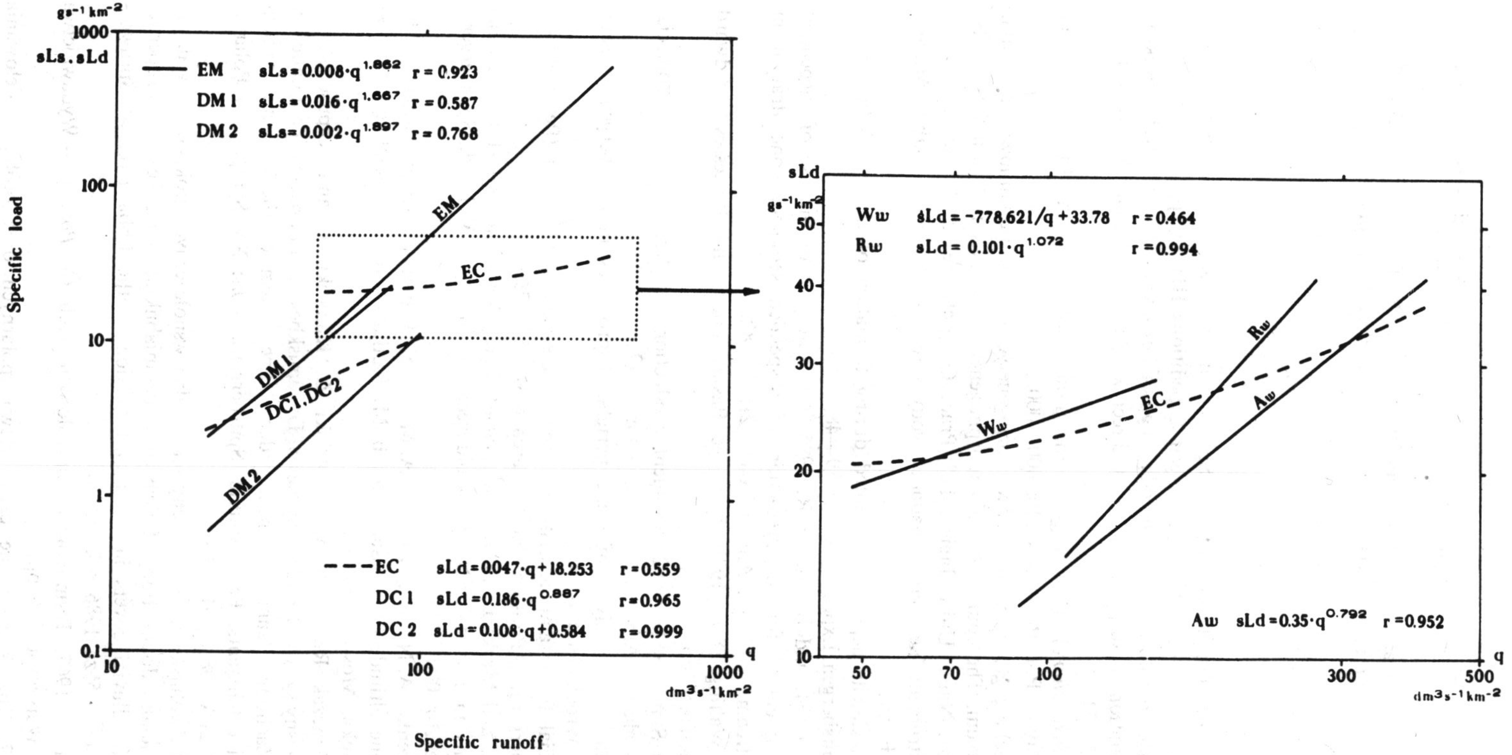

Fig. 25. Dependence of specific loads of dissolved material (sLd) and suspended sediment (sLs) on specific runoff (q) in the Ebbaelva and *Dynamiskbekken* drainage basins:

EM — suspended sediment load, the Ebbaelva drainage basin, DM1 — suspended sediment load, station E, the *Dynamiskbekken* catchment, DM2 — suspended sediment load, stations N and S, the *Dynamiskbekken* catchment, EC — dissolved load, the Ebbaelva drainage basin, DC1 — dissolved load, station E, the *Dynamiskbekken* catchment, DC2 — dissolved load, stations N and S, the *Dynamiskbekken* catchment, Ww — dissolved load in "winter" water, Aw — dissolved load in ablation water, Rw — dissolved load during rain-induced flood

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Streszczenie

W sezonie ablacyjnym 1985 badano dynamikę i rozmiary transportu zawiesiny i substancji rozpuszczonych w zlewni zlodowaconej (Ebbaelva, 51.5 km^2) i niezlodowaconej (*Dynamiskbekken*, 1.4 km^2) w centralnej części wyspy Spitsbergen Zachodni (fig. 1—6). Jest to obszar zbudowany głównie z paleozoicznych skał osadowych (węglanowych i siarczanowych) i polarno-kontynentalnym typie klimatu (Tab. 1).

Okres obserwacyjny (28 VI do 26 VII) był esktremalnie ciepły — średnia temperatura wynosiła 8.4°C (fig. 7—9, Tab. 2—4). Wpłynęło to na rozmiary i dynamikę odpływu wody i transportowanych przez nią substancji. Sredni odpływ jednostkowy ze zlewni Ebbaelva wynosił 137.7 (50—415), a ze zlewni *Dynamiskbekken* 47.7 (21.7—88.4) dm^{3}s^{-1}km^{-2} (fig. 10—11, 15—19, Tab. 5—6). Dynamika odpływu uzależniona była od warunków termicznych i radiacyjnych (usłonecznienia i ekspozycji zlewni), opadów oraz zmiennych zasobów wód niwalnych i zmarzlinowych i wykazywała regularny cykl dobowy.

Dynamika odpływu, wyczerpywanie źródeł dostępnej do transportu zawiesiny, histeraza transportu podczas wezbrań, udział odmiennych w poziomie mineralizacji i składzie che-

micznym typów genetycznych wód, rola deszczu w mobilizacji rozpuszczalnych soli to główne czynniki wpływające na zmienność transportu fluwialnego (fig. 12—25, Tab. 7—10).

Srednie tempo denudacji mechanicznej wynosiło w zlewni Ebbaelva 12.1, a w zlewni *Dynamiskbekken* 0.55 t km^{-2}doba^{-1}. Około 60% zawiesiny, opuszczającej górną część zlewni *Dynamiskbekken* było deponowane w obrębie stożka napływowego. Analogiczne wskaźniki denudacji chemicznej wynoszą odpowiednio 2.0 i 0.58 t km^{-2}doba^{-1}.

Określenie wiarygodnych przeciętnych wartości denudacji regionalnej zlewni spitsbergeńskich wymaga ze względu na dużą zmienność z roku na rok, wieloletnich badań w wybranych, reprezentatywnych zlewniach.