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Instytut Nauk o Ziemi Uniwersytet Marii Curie Skłodowskiej, 20-033 Lublin, ul. Akademicka 19, Poland
*stanislaw.chmiel@poczta.umcs.lublin.pl, **stbar@o2.pl, ***Krzysztof.Siwek@umcs.pl

STANISŁAW CHMIEL*, STEFAN BARTOSZEWSKI**, KRZYSZTOF SIWEK***

Chemical denudation rates in the Wydrzyca catchment (Bellsund, Spitsbergen)

Wielkość denudacji chemicznej w zlewni Wydrzycy (Bellsund, Spitsbergen)

Key words: Spitsbergen, permafrost, runoff, hydrochemistry, chemical denudation

Słowa kluczowe: Spitsbergen, zmarzlina, odpływ, hydrochemia, denudacja chemiczna

INTRODUCTION

Evaluation of the level of chemical denudation in the polar regions, identified as rising rocks weathering as the result of increased carbon dioxide concentration in the atmosphere and in the active layer of permafrost became a very important issue in the last period. The last five-year period of the 20th century has been characterized by an overall tendency of continuous if not accelerated glacier melting. The mean specific net balance (-446 mm) of the relevant reference glaciers for the five years 1995/1996–1999/2000 was higher than the mean of the years 1980–1995 (-215 mm). The difference corresponds to an increase in additional energy flux of about 2.24 $W \cdot m^{-2}$ or about 0.45 $W \cdot m^{-2}$ per year (Haeberli et al. 2005). An abrupt rise of average seasonal and annual surface air temperature in the period 1995–2005 occurred in the Pacific and Atlantic sectors of Arctic. This period has been the warmest since at least the 17th century. In particular, 2005 was an exceptionally warm year (>2°C in relation to the 1951–1990 average) and was warmer than 1938, the warmest year in the 20th century (Przybylak 2007). Spitsbergen is considered to offer the closest modern analogue to the late glacial conditions when the continental ice sheets retreated and large areas of land became ice-free and subject to subaerial

chemical weathering (Krawczyk, Pettersson 2007). Global warming might cause loss of carbon from terrestrial ecosystems, leading to an increase of atmospheric CO_2 levels.

According to Hodson et al. (2000), specific annual discharge is the most significant control on chemical denudation in the glaciarized basins, and basin lithology is an important secondary control, with carbonate-rich and basaltic lithologies currently showing the greatest chemical denudation rates. Estimates of transient CO_2 drawdown are directly associated with specific annual discharge and rock type.

The most common chemical denudation rates are expressed in $m^3 \cdot km^{-2} \cdot yr^{1}$, which is equivalent unit $mm \cdot yr^{1}$. Rates are also expressed in mass units ($t \cdot km^{-2} \cdot yr^{1}$), derived from the division of the annual solute load by basin area. To convert to volume units load is divided by rock density, usually 2.7 $g \cdot cm^{-3}$.

Corbel (1957) made the first estimates of chemical denudation rates on Spitsbergen, he suggested the total rate of denudation as much as 40 $m^3 \cdot km^{-2} \cdot yr^{1}$, for the Kongsfjorden region he proposed 16 $m^3 \cdot km^{-2} \cdot yr^{1}$. In further researches chemical denudation rates have been estimated on the basis of discharge and specific conductivity record. In ice-free catchment Fuglebekken in 1979–1980 chemical denudation was between 6–7 $m^3 \cdot km^{-2} \cdot yr^{1}$ (Krawczyk 1994); Barsch et al. (1994) obtained a similar 4–6 $m^3 \cdot km^{-2} \cdot yr^{1}$ for Beinbekken in 1990–1991. The estimated chemical denudation rate for 2000, calculated for the Londonelva (the only one hydrological basin studied on Spitsbergen located entirely on soluble carbonate rocks) was 5.8 $m^3 \cdot km^{-2} \cdot yr^{1}$ (Krawczyk, Pettersson 2007).

Studies of chemical denudation were carried out during the geographical expeditions of the Maria Curie-Skłodowska University research workers to Spitsbergen in 1988, 1989, 1990 and 1993. Bartoszewski and Magierski (1989) determined 7 $m^3 \cdot km^{-2} \cdot yr^{1}$ (July 1 – September 21, 1988), Michalczyk and Magierski (1990) obtained 9 $m^3 \cdot km^{-2} \cdot yr^{1}$ (July 5 – September 8, 1989) for the Wydrzyca Stream.

STUDY AREA

Major tectonic element in NW Wedel Jarlsberg Land is Renardbreen Block (Middle-Late Proterozoic metasediments). There are consisting strongly folded and faulted diamictities with intercalations of quartzite and quartzitic sandstone (Birkenmajer 2004). The Renardbreen Block consists entirely of Proterozoic rocks which are represented by: the Bergskardet Formation green and black schists/phyllites, yellowish weathered sandstones/conglomerates with sandstone intercalations and dispersed dolostone clasts), the Kapp Lyell diamictite unit/formation of the Upper Proterozoic Sofiebogen Group), further subdivided into: the yellow diamictite (mainly sandstones and schists with dolostone, limestone and quartzitic clasts), and the green diamictite (chlorites with dolostone, limestone and quartzite clasts).

At its northeastern margin, the Renardbreen Block is delimited from Tertiary strata of the Calypsostranda Graben by the dip-slip Calypsostranda Fault (NW–SE). The

Calypsostranda Graben is about 6 km long and more than 1.5 km wide, its Paleogene sediment pile exceeds 250 m in thickness (Birkenmajer 2006). Late paleogene sediments fill of the Calypsostranda Graben has been subdivided into two formations: the lower terrestrial Skilvika Formation, and the upper marine Renardodden Formation (Dallmann et al. 1990; Birkenmajer 2006).

Between Skilvika and Calypsobyen the Renardodden Formation consists of a succession of grey, massive, usually fine grained, well cemented or friable sandstone layers with intercalations of well rounded quartz and quartzite gravel, sometimes with horizons of carbonate concretions, with infrequent shale intercalations. Plant detritus and fragments of black coal occur in the sandstones (Birkenmajer 2006).

Basal beds of the Skilvika Formation are poorly exposed (mostly as scree) in the southern part of Calypsostranda, in the head part of the Wydrzyca Stream (i.e. Tyvjobekken valley Birkenmajer 2006). There are loose blocks of green, fine grained, platy sandstone and green sedimentary breccia consisting of shale pellets. There are also blocks of breccia consisting of phyllites.

The ground surface in the coastal zone is built of a few meters thick Quaternary deposits: gravels, sands, clays, silts, as well as paleogene sandstones (Pękala, Repelowska-Pękalowa 1990).

The Wydrzyca Stream catchment (77° 33' N, 14° 30' E) was subjected to hydrometric monitoring in the summer of 2005 (Fig. 1). Non-glacierized catchment of the Wydrzyca Stream covers 1.29 km^2 area. The length of the river is 1.2 km and average gradient is 41‰. The river is formed by two seasonal streams starting their courses on the slope of Bohlinryggen at the height 100 m a.s.l. After one kilometer course they join the stream draining out part of outside outwash of Renard Glacier. Ecosystems of the moist tundra with patches of mosses, often on the peat bedrock are dominant. This is an area of underground and surface runoff, with numerous cryogenic hollows filled with water. The water gauge located below the outlet of the is 0.7 km long gorge valley.

The hydrologic gauge station in the Wydrzyca catchment supplied discharge summer season data since 1986 with interruption in 1991–1993, 1994–2000 and in 2003–2004.

METHODS

Water stages of the Wydrzyca Stream were registered by limnimeter ASTER in the period: July 14 – September 1, 2005. Periodical measurements of water discharge and gauge data allowed to calculate the rating curves and to determine the amount of runoff.

The hydrochemical investigations carried out in the period July 14 – August 21, 2005 included everyday collect of water samples from the Wydrzyca Stream. Pre-

cipitation waters were collected in Calypsobyen into polyethylene container placed 1 m above the ground every 24 hours. The patrol hydrochemical investigations were also carried out in Calypsostranda. They included the waters in the frontal moraine of Scott Glacier and tundra.

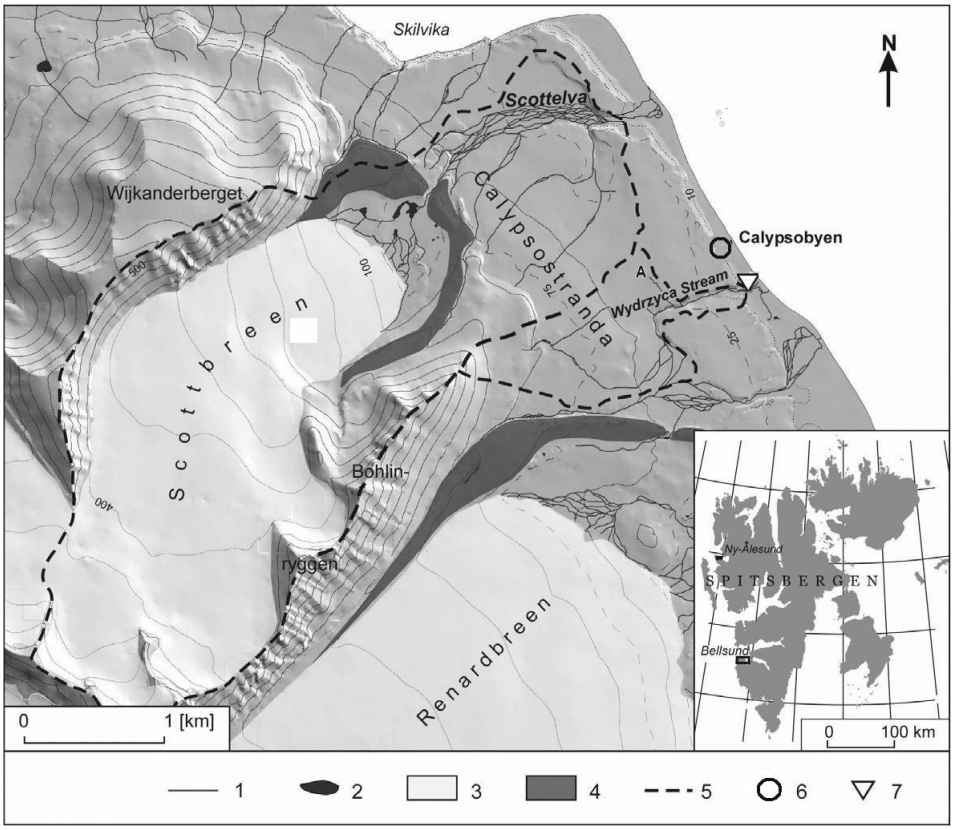

Fig. 1. Research area (1 – mountain massifs, 2 – lakes, 3 – glaciers, 4 – moraines, 5 – watershed, 6 – Calypsobyen station, 7 – Wydrzyca Stream gauging site). The shade map made using the Digital Terrain Model (DTM) obtained from the aerial photos from 1990 (Zagórski 2005)

Water samples (not filtered) were determined for pH, specific electrolytic conductivity (SEC), total organic carbon (TOC), biochemical oxygen demand (BOD), chemical oxygen demand (COD), alkalinity (ALK), silica (SiO_2), and orthophosphates (PO_4^{3-}). These indices measurements were made in the field laboratory in Calypsobyen. Water for further investigations was filtered using cellulose acetate membranes with a retention diameter of 0.45 μm. Filtered water was stored in: 12 mL polyethylene phials for determination of anions and 125 mL HDPE Nalgene bottles (then acidified

with nitric acid to pH~2) for determination of cations. Samples of waters for further determinations were transported to the laboratory of the Department of Hydrography, the Maria Curie-Skłodowska University in Lublin.

Water pH and SEC were measured using an InoLab 1 device (WTW firm) which was compatible with the pH electrode HI 1230 (Hanna Instrument) and the conductometric electrode Tetra C (WTW). SEC was determined from nonlinear temperature correction up to 20°C taking into account the corrections according to the German standard DIN 38404. Determination of anions (sulphates, chlorides, nitrates, nitrites, bromides and fluorides) and cations (calcium, magnesium, sodium, potassium, ammonium) were made using ion chromatography MIC 3 (Metrohm firm, Switzerland). Anions separation was made using the Metrosep A Supp 5-250 column (suppressed, conductivity detection, injection volume 20 μL) and cations separation using the Metrosep C 2-150 column (non-suppressed, conductivity detection, injection volume 100 μL). Detection limits of anions and cations analysis were <0.01 $mg \cdot dm^{-3}$. Alkalinity was determined by titration using hydrochloric acid and methyl orange indicator. Total suspended solids (TSS) was determined by weight after filtering of 1 dm^3 water on a GF/C glass fiber and the residue retained on the filter was drained to constant mass weight in 105°C. Silica and orthophosphates were determined using the photometer DR/890 (Hach firm); silica was determined by the method Hach 8185, orthophosphate was determined by the Hach 8048 method. Calcium was also determined using the versenate method. TOC, BOD and COD were determined by means of spectrophotometer UV Pastel (Secoman firm). Total Dissolved Solids (TDS) value was calculated as the sum of ions.

Analyses were performed with the use of standard solutions produced by Merck and Accustandard and certified materials: CRM RAIN-97, SRM 1643e Trace Elements in Water, LMO CBE-WJ-03 water from oligotrophic Hańcza Lake. Correctness of analyses was checked using the ionic balance method. Charge errors of analyses were in the range below ±3.0%.

RESULTS

HYDROLOGY

The seasonal volumes of water flowing into the Recherche Fiord from the Wydrzyca catchment ranged in the period 1986–2005 between $52 \cdot 10^3$ m^3 (July 23 – August 31, 1986) and 472 $\cdot 10^3$ m^3 (June 14 – August 17, 1987). Outflow from the Wydrzyca catchment begins in the first decade of June and terminates in the end of September (Bartoszewski 1998). Average seasonal discharges varied from 84 $dm^3 \cdot s^{-1}$ (1986) to 14 $dm^3 \cdot s^{-1}$ (1987). Specific discharge ranged between 12 and 65 $dm^3 \cdot s^{-1} \cdot km^{-2}$.

The discharge course was controlled by two phenomena, snow melting and rainfalls. A decreasing tendency of discharge intensity related to the reduction of still

occurring snow patches in the upper part of the catchment and to the depletion of water resources in the active permafrost layer were observed until the third decade of August. At the beginning of investigations the compact snow cover on Calypsostranda had already vanished, but in the Wydrzyca Stream valley and the mountain part of the catchment there were still snow patches up to 3 m thick.

Meteorological data from Calypsobyen show that the research period, July 14 – September 1, 2005, was similar to the previous seasons (Bartoszewski et al. 2006). The average daily air temperature was 5.1°C. The highest temperature of 7.6°C was on August 28 and the lowest of 2.1°C on September 1. The total seasonal precipitation was 56.7 mm, more than half of it, 29.4 mm, fell during the second half of August. July was dry (until July 27), with only 2.4 mm of rainfall. The highest rainfall occurred on July 28 (14.2 mm). Discharge increased to 50 $dm^3 \cdot s^{-1}$ on July 28. Rainfalls, which took place in July and in the first half of August, resulted in small freshet, but generally the Wydrzyca Stream discharge decrease to the minimum 14.2 $dm^3 \cdot s^{-1}$ was observed.

The situation changed in the final period of the research. In the last pentad of August intensive, lasting a few days rainfalls occurred due to inflow of moist air masses from over the Atlantic Ocean (total precipitation reached almost 30 mm). As a result, rapid tundra streams freshet and increase of water resources retained in the active permafrost layer were observed. The Wydrzyca Stream discharge reached maximum 107 $dm^3 \cdot s^{-1}$ on August 28.

Figure 2 shows the changes in discharge of the Wydrzyca Stream, daily precipitation and average daily air temperature in Calypsobyen in the research period, July 14 – September 1, 125 $\cdot 10^3$ m^3 of water outflowed. The average discharge was 30 $dm^3 \cdot s^{-1}$, which corresponds to the runoff index 97 mm and the specific discharge 23 $dm^3 \cdot s^{-1} \cdot km^{-2}$.

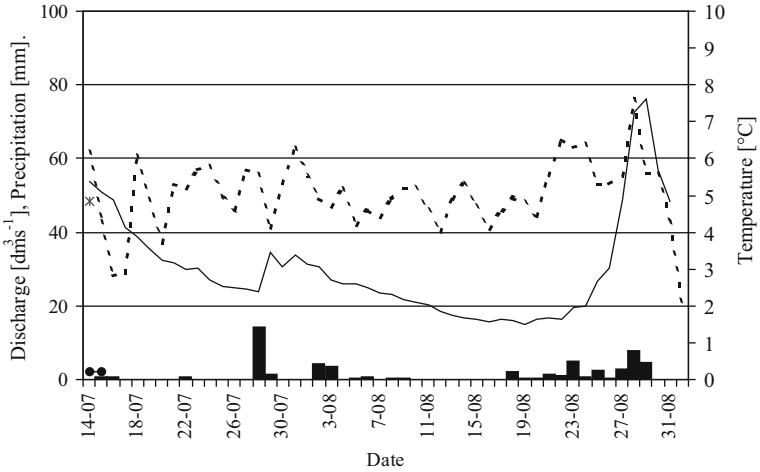

Fig. 2. The Wydrzyca Stream discharge (solid line), daily precipitation (filled bars) and average daily air temperature (dotted line) in the summer season 2005

RAIN WATER CHEMISTRY

Researches of physicochemical properties of precipitation waters collected in the period July 14 – August 21, 2005 showed weighted average value SEC counted on the basis of 15 samples and established as 17.8 $\mu S \cdot cm^{-1}$, which corresponds to the sum of ions as 11 $mg \cdot dm^{-3}$. Precipitation waters were characterized by slightly acidic reaction and low content of mineral substances from a few to several $mg \cdot dm^{-3}$. Chemistry of atmospheric precipitation was mainly shaped by marine aerosols which contributed to predominance of Na and Cl ions (Table 1). Their concentration as well as bromine ion are connected with air masses. The highest values of marine aerosols concentration were recorded with air masses comming from the eastern direction (Na – 14.2 $mg \cdot dm^{-3}$, Cl – 28.4 $mg \cdot dm^{-3}$), the lowest ones from the western and northern directions (Na – 0.2 $mg \cdot dm^{-3}$, Cl – 0.4 $mg \cdot dm^{-3}$). Weighted average of TDS value calculated as the sum of ions in precipitation collected in summer season 2005 was 11 $mg \cdot dm^{-3}$, ions of marine origin making up about 60%.

Table 1. Participation of components concentrations of oceanic and continental origin in precipitation in Calypsobyen in summer 2005 (*sea water composition by Duce, Hoffman 1976)

Index	Chemical composition of water		Origin of index in precipitation (%)	
	marine* $meq \cdot L^{-1}$	precipitation $meq \cdot L^{-1}$	oceanic	non-marine salt
Na	485	0.095	94	6
K	10.6	0.004	49	51
Mg	110.2	0.022	88	12
Ca	21.4	0.026	15	85
NH_4	$2 \cdot 10^{-6}$	0.008	0	100
Cl	566	0.104	100	0
SO_4	58.6	0.019	58	42
NO_3	$5 \cdot 10^{-6}$	0.008	0	100
HCO_3/CO_3	2.4	0.025	2	98

WATER CHEMISTRY OF THE WYDRZYCA STREAM

Waters of the Wydrzyca Stream showed high level of TDS reaching almost 200 $mg \cdot dm^{-3}$ (Table 2), their reaction was slightly alkaline (8 – 8.5) and temperature varied from 4 to 8°C. In relation to hydrochemistry, these are HCO_3-Ca-Mg waters type. Products of carbonate minerals solution (HCO_3, Ca, Mg), up to of 90% in TDS, were

characterized by the highest content in the Wydrzyca Stream waters. Bicarbonates made up about 80% of anions sum in mval·dm^{-3}, chlorides – 12%, and sulphates – 8%. Calcium ions made up 62% of the cation sum in mval·dm^{-3}, magnesium ions – 30%, sodium and potassium – 3%.

Table 2. Runoff and indices of physicochemical properties of waters in the Wydrzyca Stream in the period July 14 – August 21 2005 (values: LQ – lower quartile, UQ – upper quartile, CC – changeability coefficient – standard deviation/average deviation, R – correlation coefficient)

Index	Units	Min	LQ	Mean	Median	UQ	Max	CC	R (from Q)
Q	dm^3·s^{-1}	29	31	32.1	32	33	38	0.05	1
pH	-	8.00	8.16	8.24	8.24	8.34	8.47	0.02	-0.19
TSS	mg·dm^{-3}	< 1	6	7.6	7	8	13	-	-
TDS	mg·dm^{-3}	156	167	181	179	194	204	0.09	-0.08
SEC	µS·cm^{-1}	173	188.6	206.4	201	225.5	240	0.09	-0.08
ALK.	mval·dm^{-3}	1.80	1.97	2.14	2.10	2.30	2.45	0.08	-0.06
Cl^-	mg·dm^{-3}	5.37	5.78	5.99	5.95	6.22	6.51	0.05	-0.19
SO_4^{2-}	mg·dm^{-3}	4.71	6.01	7.54	7.46	9.23	10.88	0.26	0.08
NO_3^-	mg·dm^{-3}	0.40	0.45	0.62	0.69	0.74	0.80	0.24	0,03
NO_2^-	mg·dm^{-3}	0.004	0.009	0.013	0.011	0.015	0.035	0.007	-0.02
PO_4^{3-}	mg·dm^{-3}	0.05	0.09	0.10	0.11	0.12	0.14	0.20	-0,05
F^-	mg·dm^{-3}	0.007	0.001	0.011	0.011	0.012	0.012	0.18	-0.14
Br^-	mg·dm^{-3}	0.011	0.014	0.014	0.015	0.015	0.017	0.07	-0.24
Ca^{2+}	mg·dm^{-3}	20.7	22.0	22.5	22.4	23.0	24.3	0.04	-0.24
Mg^{2+}	mg·dm^{-3}	7.4	8.2	8.8	8.7	9.5	10.5	0.09	-0.14
Na^+	mg·dm^{-3}	4.01	4.13	4.24	4.24	4.31	4.54	0.03	-0.31
K^+	mg·dm^{-3}	0.32	0.37	0.41	0.40	0.44	0.50	0.12	-0.16
NH_4^+	mg·dm^{-3}	0.03	0.11	0.23	0.16	0.28	0.65	0.74	-0.05
SiO_2	mg·dm^{-3}	0.3	1.1	1.2	1.3	1.4	1.6	0.25	0.03
TOC	mg·dm^{-3}	< 1	1.1	1.3	1.4	1.5	1.6	-	-
BOD	mgO_2·dm^{-3}	< 0.5	0.8	1.1	1.2	1.4	2.1	-	-
COD	mgO_2·dm^{-3}	< 2.0	2.5	3.2	2.9	3.8	5.0	-	-

The water investigations of the Wydrzyca Stream showed mostly low content of biogenic substance. The contents of NO_2^- did not exceed 0.035 mg·dm^{-3}, NO_3^- 0.8 mg·dm^{-3}, NH_4^+ 0.65 mg·dm^{-3} and PO_4^{3-} 0.14 mg·dm^{-3}. Changes of nitrite, ammonium, and phosphate ions concentrations were quite accidental and did not exhibit significant response to supply conditions. In the case of nitrates, as well as sulphates regular increase in their concentration during the polar summer was observed. It can

be a result of decreased participation of snow melting waters in runoff in relation to waters coming from the zone of underground drainage, increased evapotranspiration, leaching of substances deposited in the lowering layer of permafrost, as well as the effect of precipitation of substances resulted in the process of organic matter mineralization in the soil. Concentration of organic carbon and synthetic indices: biochemical and chemical oxygen demand by waters were recorded as low. The silica content was also low.

Studies of the Wydrzyca Stream waters physicochemical properties changeability is characteristic of this area in the polar summer. These properties show low correlation coefficients of runoff and physicochemical indices and low changeability in the terms of basic physicochemical indices. This indicates small effects of hydrometeorological conditions on formation of indices and relatively stable biogeochemical conditions in the Calypsostranda area during the polar summer. A characteristic feature in the non-glacier covered catchments was systematic increase of most indices in the studied water samples through the study period.

CHEMICAL DENUDATION

Chemical denudation (Dc) in the Wydrzyca Stream was calculated on the basis of hydrometric and hydrochemical studies according to the following formula:

$$Dc = Q \cdot 0.0864 \cdot TDS/A,$$

where: Q – discharge ($m^3 \cdot s^{-1}$),
TDS – total dissolved solids ($mg \cdot L^{-1}$),
A – catchment area (km^2).

The method of isolation of the component of geogenic origin (Sharp et al. 1995) was used for calculation of TDS for denudation purposes. That model for chemical denudation calculations for Spitsbergen was used by Hodson et al. (2000), Krawczyk et al. (2003), Krawczyk and Pettersson (2007) and Yde et al. (2008).

To estimate TDS of the Wydrzyca Stream, which is the effect of leaching of natural minerals which build the catchment, the value of TDS was calculated on the basis of ions lessened by the level of substance provided by precipitation (Table 1). Evaluation of the influence of precipitation on the level of TDS of the Wydrzyca Stream waters should be increased by approx. 20% as a result of evapotranspiration concentration, that value is published for Spitsbergen area (Bartoszewski 1998, Hodson et al. 2000). For chemical denudation computation purposes in the Wydrzyca Stream catchment value of TDS counted from the ionic sum was reduced by ions of atmospheric origin and half of value of bicarbonates of non-erosion origin (Hem 1985).

Weighted-average of TDS (the sum of ions + silica) of the Wydrzyca Stream in the research period 2005 was 187 $mg \cdot dm^{-3}$, so the incoming ions from precipitation were established of the level slightly higher than 7% of that value (13 $mg \cdot dm^{-3}$), bicarbonate ions of

non-erosion origin – 34% (65 $mg \cdot dm^{-3}$). In the research period TDS (in crustal) value for denudation determination taken for counting was 94.6–124.7 $mg \cdot dm^{-3}$ (weighted-average 109.0 $mg \cdot dm^{-3}$), with the discharge of the Wydrzyca Stream in the range of 29–38 $dm^3 \cdot s^{-1}$.

DISCUSSION

In the groundwaters and surface waters of non-glacier covered Bellsund region predominated the ions HCO_3, Ca and Mg (Michalczyk, Magierski 1990, Bartoszewski et al. 1991, 1993; Chmiel et al. 2007). Slightly lower mineralization was exhibited in the case of runoff partialy fed from the patches of melting snow. Predominance of carbonate mineral dissolution products was the effect of – due to geological structure of this area – Hecla Hoek formation rocks (Dallmann et al. 1990; Birkenmajer 2004), containing large amounts of carbonate minerals. Various amounts of quartz, calcite, dolomite, sericite, chlorite and mica are found in the mineralogical composition of these rocks (Chlebowski 1989).

The level of dissolved carbonate minerals in the Wydrzyca Stream waters was determined using Saturation Index (SI) waters considering minerals (counted using Visual Minteq software in the temperature of 5° C) and it was established as follows: $SI_{calcite}$ = -0.3, $SI_{dolomite}$ = -0.4. Negative SI values indicate potential possibilities of minerals dissolution.

In the Bellsund area it was stated that the level of dissolved carbonates is much higher in non-glacier covered catchments than in the glacierized ones (Bartoszewski et al. 1991, 1993; Chmiel et al. 2007; Krawczyk, Bartoszewski 2008). It results from the significant role of biotic conditions in rock leaching which particularly influences carbon dioxide production (Pulina, Burzyk 2002), and which plays a significant role in carbonate material dissolution under natural conditions. Solubility of the rest of main minerals in the drainage zone of the Wydrzyca Stream does not significantly influence the TDS level.

Salts of marine origin have special importance in shaping physicochemical properties of waters in the area of Spitsbergen (Krawczyk et al. 2002; Krawczyk, Peterson 2007; Głowacki 2007; Krawczyk, Bartoszewski 2008). It is a result of location of research catchments in the coastal zone, where marine aerosols have significant participation in physicochemical composition of precipitation. Researches of physicochemical properties of precipitation waters conducted in the summer period of 2005 showed higher TDS of waters from precipitation coming from ocean masses of air than from continental ones (Chmiel et al. 2007). In the case of the Wydrzyca Stream the participation of marine salts in TDS was approx. 4%. In Spitsbergen that value usually ranges from a few to several percent (Krawczyk et al. 2003; Yde et al. 2008).

Chemical denudation can be considered as important indicator of processes, connected with climate changes taking place in the polar catchments. Counted weighted-average chemical denudation of the Wydrzyca Stream was 0.237 $t \cdot km^{-2} \cdot d^{-1}$ (0.080 $m^3 \cdot km^{-2} \cdot d^{-1}$) in the summer period 2005, in the range beetween 0.20 and

0.31 t·km^{-2}·d^{-1} (Fig. 3). This is the level usually observed in non-glacierized areas of Spitsbergen during steady weather conditions of the polar summer period (Bartoszewski, Magierski 1989; Bartoszewski, Repelewska-Pękalowa 1999; Krawczyk, Pettersson2007).

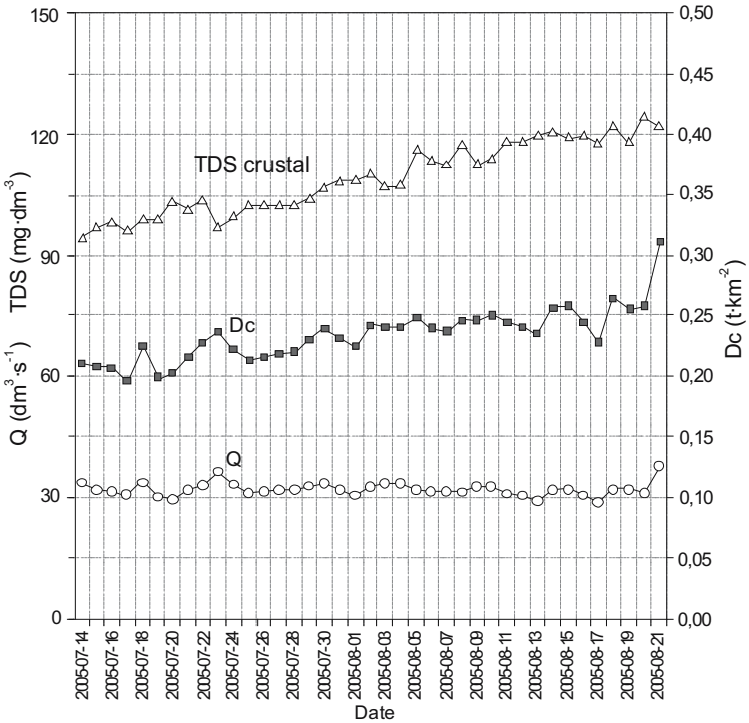

Fig. 3. Diurnal changes of discharge (Q), total dissolved solids of organic origin (TDS crustal) and chemical denudation of the Wydrzyca Stream in the summer 2005

CONCLUSIONS

Results of hydrological researches conducted in Spitsbergen in 2005 describe runoff regime and physicochemical composition of waters in non-glacierized catchment of the Wydrzyca Stream in the polar summer period.

1. Meteorological conditions and amount and dynamics of runoff from the Wydrzyca Stream catchment in 2005 were related to the average ones.

2. TDS of the Wydrzyca Stream waters was established at the level of approx. 200 mg·dm^{-3}, their reaction was slightly alkaline (8–8.5) and the temperature was 4–8° C. These were waters of HCO_3-Ca-Mg hydrochemical type. Predominance of carbonate minerals dissolution products in waters results from occurrence in the catchment containing calcite and dolomite.

3. The Wydrzyca Stream waters TDS was partly shaped by substances of atmospheric origin, also marine ones. The participation of substances of atmospheric origin in the waters of the Wydrzyca Stream was determined as 7%, of which aerosols of marine origin constituted over 4%.

4. The water investigations of the Wydrzyca Stream showed mostly low content of substances of biogenic character: contents of NO_2^- did not exceed 0.035 mg·dm^{-3}, NO_3^- 0.8 mg·dm^{-3}, NH_4^+ 0.65 mg·dm^{-3} and PO_4^{3-} 0.14 mg·dm^{-3}. Their level in the waters of the Wydrzyca Stream was significantly shaped by precipitation and ornithofauna.

5. Average daily chemical denudation of the Wydrzyca Stream in the period July 14 – August 21, 2005, was 0.237 t·km^{-2} (0.080 m^3·km^{-2}). Its level was typical of rivers draining non-glacierized catchments of Spitsbergen in steady weather conditions of the polar summer. In those conditions chemical denudation does not influence significantly changes of surface relief of the areas. Its role is connected with decalcification of the active layer of permafrost and additional inflow of CO_2 to atmosphere.

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STRESZCZENIE

Badania procesów hydrologicznych i hydrochemicznych w wybranych zlewniach rejonu Bellsundu są prowadzone od 1986 roku. Wyniki badań cech fizykochemicznych wód wykazują zróżnicowanie w zależności od zlodowacenia zlewni i wpływu czynników biotycznych oddziałujących na procesy wietrzenia skał. W wodach zlewni niezlodowaconych był widoczny udział aerozoli pochodzenia morskiego w kształtowaniu cech fizykochemicznych. Denudacja chemiczna została obliczona dla zlewni rzeki Wydrzycy (1,29 km^2). Kontrolę przepływu prowadzono w ujściowym odcinku rzeki w okresie 14.07–1.09. 2005 roku. Średni przepływ wyniósł 30 $dm^3 \cdot s^{-1}$, co odpowiada wskaźnikowi odpływu 97 mm i odpływowi jednostkowemu 23 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Codziennie pobierano próby wody i oznaczano skład jonowy. Wielkość denudacji w okresie 14.07–21.08. 2005 roku określono na 3,1 $m^3 \cdot km^{-2}$ (czyli 8,4 $t \cdot km^{-2}$). Wielkość denudacji chemicznej w innych sezonach pomiarowych zmieniała się w przedziale od 7 do 9 $m^3 \cdot km^{-2}$.