Stanisław Chmiel
Stefan Bartoszewski
Zdzisław Michalczyk

4.2. Hydrochemistry

The physico-chemical properties of waters in the Bellsund region were determined during the summer of Maria Curie-Skłodowska University Spitsbergen Expeditions. The water for analysis was sampled directly from precipitation, snow cover, glacier meltwaters, active layer, springs, rivers and lakes. The hydrochemical studies carried out over several years during the polar summer focused on the quantification of the chemical and mechanical denudation rates in the glacierised Scottelva (Scott River) catchment and the non-glacierised Tyvjobekken (Wydrzyca Stream) catchment, and the determination of a the spatial and temporal variability of the ionic composition of water. The role of the atmospheric component in shaping the hydrochemical properties, the level of water pollution with eutrophic substances and heavy metals, and the role of waters in carbon dioxide emissions from the polar areas were also studied. The said problems were described in detail in the publications of the Lublin center (Bartoszewski 1988; Bartoszewski & Repelewska-Pękalowa 1988ab, 1999; Bartoszewski & Magierski 1989ab; Repelewska-Pękalowa & Magierski 1989; Magierski *et al.* 1990; Michalczyk & Magierski 1990; Bartoszewski *et al.* 1991; Bartoszewski et. al. 1993; Chmiel *et al.* 2007; Krawczyk & Bartoszewski 2008; Krawczyk *et al.* 2008; Zagórski *et al.* 2008a; Chmiel *et al.* 2009; Chmiel *et al.* 2011; Chmiel *et al.* 2012).

The physico-chemical properties of water samples were determined in the 80's and the 90's of the 20th century, using the methods suggested by Markowicz & Pulina (1979). Total hardness and calcium content were determined by the versenate method, magnesium content was calculated from the difference between the two values, alkalinity (Alkal) was determined using hydrochloric acid and methyl orange indicator, chlorides – by the argentometric method, sulfates – by the versenate method with barium chloride, sodium and potassium – by flame photometry, pH and specific electrolytic conductivity (SEC) by the electrometric method and suspended sediment (SS) by weighing. In 2002 and 2005, anions and cations were analysed using ion chromatography; the methods used for determining alkalinity, water pH, specific electrolytic conductivity, and suspended sediment level (SS) remained unchanged. In 2005, the content of dissolved heavy metals – Zn, Cu, Cd and Pb was determined (UV-photo-oxidation as pretreatment) by the voltammetric method, the content of Fe and Mn – by the photometric method, while the content of orthophosphates, silica and total organic carbon (TOC) – by the spectrophotometric method.

Rainwater

The physico-chemical composition of rainwater in the Bellsund region was studied in 2002 and 2005 (Chmiel *et al.* 2007, Krawczyk *et al.* 2008, Chmiel *et al.* 2011). Study was characterised on the samples collected in the diurnal cycle in the vicinity of the Calypsobyen station. Rainwater was characterised by a slightly acidic to slightly alkaline pH and a low content of mineral substances, ranging from several to several dozen $mg \cdot dm^{-3}$ (Fig. 4.2.1, Table 4.2.1). The chemistry of rain water was to a large extent determined by marine aerosols, which had an impact on the domination of Na^+ and Cl^- ions in the hydrochemical water type. Na^+ and Cl^- ion concentration levels were associated with the direction of the inflow of air masses – the highest concentrations were recorded in the case of air masses carrying marine aerosols and coming from the east. Na^+ and Cl^- concentration levels were significantly lower in the case of air masses coming from the west and the north; in such cases the hydrochemical water type was additionally shaped by Ca^{2+} and HCO_3^- ions. Air masses from Europe played an important part in shaping the levels of nitrates and sulfates in the Bellsund region (Krawczyk *et al.* 2008). They increased the acidity of precipitation and the contribution of anthropogenic ions in the water ion balance.

Glacierised areas

The hydrochemical studies of glacierised areas were carried out over many years in the surroundings of Calypsobyen. Main study area was the Scottbreen and Scottelva catchment (Bartoszewski & Repelewska-Pękalowa 1988ab; Bartoszewski & Magierski 1989ab, 2003; Michalczyk & Magierski 1990; Bartoszewski *et al.* 1991, 1993; Bartoszewski 1994; Chlebowski 1999; Chmiel *et al.* 2007; Krawczyk & Bartoszewski 2008; Chmiel *et al.* 2009; Chmiel *et al.* 2012). Apart from Scottelva catchment, short-term measurements were also taken in the catchments of the: Renardbreen, Blomlielva, Tjørnelva, Dyrstadelva, Logna, Dunderelva and Chamberlinelva (e.g. Bartoszewski & Repelewska-Pękalowa 1988ab; Bartoszewski *et al.* 1991; Chlebowski 1991; Chmiel *et al.* 2007)

Supraglacial waters, studied on the basis of the Scottbreen and Renardbreen, demonstrated high hydrochemical variability (Figs. 4.2.1 and 4.2.2, Table 4.2.2). In the upper sections of the glaciers, supraglacial waters coming from the melting of the snow cover and ice were characterised by low mineralisation and a slightly acidic pH.

Their physico-chemical composition was similar to that of rainwater, where Na^+, Cl^- and Ca^{2+}, Mg^{2+} and HCO_3^- ions prevailed. Significant changes in the chemical composition of waters flowing on the surface of glaciers (supraglacial waters) were recorded in places where they came into contact with aeolian material (Photo 4.2.1). In such cases water mineralisation and the share of Ca^{2+}, Mg^{2+}, HCO_3^- ions in ion balance increased, while the concentrations of other ions were at a very low level. The main transformation of the physico-chemical composition of glacier meltwaters was recorded at the front of glaciers, where the supra- and subglacial drainage waters came into contact with the ground (Photo 4.2.2). Subglacial waters contained as much as several g·dm^{-3} of suspended sediment (SS), while total dissolved solids content (TDS) reached several dozen mg·dm^{-3} (~50 mg·dm^{-3}). The pH of the said waters was very high, reaching up to 10 units. The chemical composition of subglacial waters was dominated by HCO_3^-, Ca^{2+} and Mg^{2+} ions. The mineralisation of proglacial waters increased downstream, mainly as a result of dissolution of carbonate minerals (calcite and dolomite) contained in suspended sediment. As for suspended sediment, its concentration decreased downstream from several g·dm^{-3} to several hundred mg·dm^{-3} (Bartoszewski & Repelewska-Pękalowa 1988ab; Chmiel *et al.* 2012).

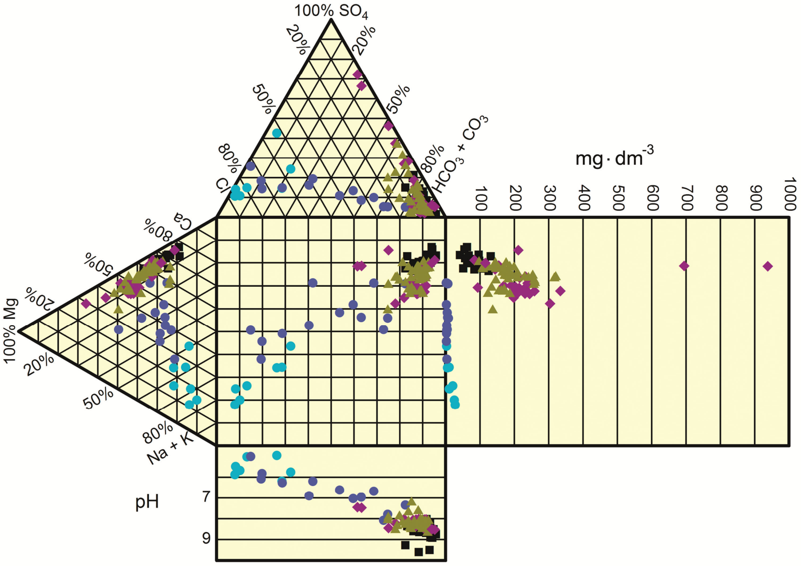

Fig. 4.2.1. Hydro-chemical variability of waters in the Bellsund region in summer 2005: rain water (light-blue circle), supraglacial stream (blue circle), subglacial stream and proglacial rivers (black square), groundwaters in periglacial areas (maroon diamond), surface waters in periglacial areas (green triangle).

The mineralogical composition of suspended sediment carried in the water of the Scottelva was dominated by quartz (~50%), dolomite (~20%), calcite and muscovite/sericite (~10% each). Smaller amounts of plagioclase (albite) and chlorite (~4% each), iron oxides and hydroxides ~0.5% were also present (Chmiel *et al.* 2009). Among the observed minerals, calcite and dolomite are the ones which dissolve (relatively) most readily in natural conditions. The carbonate minerals dissolved with the help of carbon dioxide, the amount of which was the function of its content in the atmospheric air.

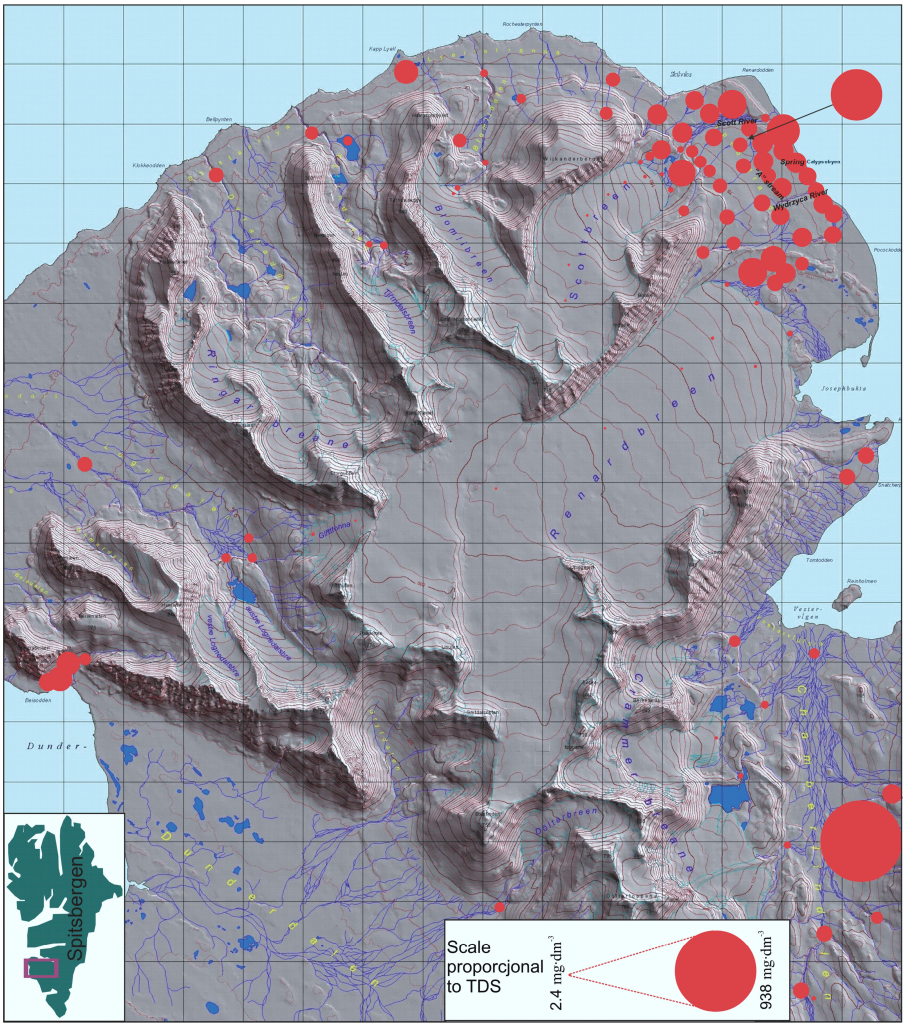

Fig. 4.2.2. Total dissolved solids concentration variability (TDS in mg·dm^{-3}) in the waters of the Bellsund region (background: shade map of relief, Zagórski 2002).

Table 4.2.1. Physico-chemical composition of rainwater in the Calypsobyen region during the polar summer of 2002 (Krawczyk *et al.* 2008) and 2005 (Chmiel *et al.* 2011).

Year	Values	pH	SEC µS·cm^{-1} in 25^{o}C	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	NH_4^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}
				mg·dm^{-3}								
	min.	4.65	14.7	0.52	0.17	1.15	0.12	-	6.1	1.42	0.67	0,00
2002	**average**	**4.94**	**34.8**	**2.72**	**0.28**	**4.00**	**0.35**	**-**	**10.9**	**5.50**	**1.58**	**0.87**
	max.	7.57	121	12.3	2.36	9.18	1.13	-	13.4	28.26	4.46	1.49
	min.	4.96	3.9	0.1	<0.1	0.2	<0.1	0.03	<1.2	0.4	0.2	<0.01
2005	**average**	**5.49**	**9.5**	**0.52**	**0.26**	**2.19**	**0.16**	**0.15**	**1.5**	**3.69**	**0.91**	**0.49**
	max.	5.79	63.2	2.0	1.1	14.3	1.6	0.35	12.2	28.4	4.4	1.2

Table 4.2.2. Characteristic indicators of physico-chemical properties of waters in the Bellsund region (range: min-max/median), based on water samples collected in the period from 20th July to 20th August, 1995 (location of measuring points – see: Fig. 4.2.2).

Parameter [unit]	Glacial areas		Periglacial areas	
	Supraglacial waters (n=13)	Subglacial waters and proglacial rivers(n=24)	Groundwaters-springs, seepages, leakages (n=25)	Rivers, streams, lakes (n=46)
Temperature [°C]	0.3-0.7/0.4	0.5-4.3/1.0	0.5-9.3/5.7	2.0-7.6/4.6
pH	5.01-8.08/6.68	8.02-9.60/8.56	7.45-8.27/8.11	7.23-8.68/8.3
SEC [$\mu S \cdot cm^{-1}$ in 25°C]	3.5-16.7/7.1	43-263/89	220-1180/255	102-403/198
TDS [$mg \cdot dm^{-3}$]	2.4-8.4/3.9	38-218/76	186-938/220	91-346/173
SS [$mg \cdot dm^{-3}$]	<2-38/8	16-3200/58	<2-9/2	<2-21/9
Ca^{2+} [$mg \cdot dm^{-3}$]	<0.1-0.95/0.4	7.5-45.6/13.1	23.3-163.5/26.6	12.5-46.3/25.4
Mg^{2+} [$mg \cdot dm^{-3}$]	<0.1-0.58/0.2	1.5-7.8/3.6	12.2-56.2/15.1	4.5-27.9/10.5
Na^{+} [$mg \cdot dm^{-3}$]	<0.1-0.76/0.4	0.5-2.7/1.2	4.6-11.8/6.6	1.9-13.2/3.4
K^{+} [$mg \cdot dm^{-3}$]	<0.1-0.1/<0.1	<0.1-2.4/0.2	0.1-9.0/0.4	0.1-2.0/0.3
NH_4^{+} [$mg \cdot dm^{-3}$]	0.02-0.18/0.11	<0.01-0.81/0.10	<0.01-0.35/0.12	0.01-0.68/0.15
HCO_3^{-}/CO_3^{2-} [$mval \cdot dm^{-3}$]	<0.02-0.08/0.02	0.49-1.79/0.91	2.25-3.93/2.56	1.08-3.46/1.94
Cl^{-}[$mg \cdot dm^{-3}$]	0.33-1.25/0.71	0.97-4.28/1.70	5.12-14.60/9.36	2.55-20.41/5.58
SO_4^{2-} [$mg \cdot dm^{-3}$]	0.17-0.44/0.23	0.65-63.1/4.90	2.59-462/7.4	1.29-78.7/7.6
NO_3^{-} [$mg \cdot dm^{-3}$]	<0.01-0.01/ <0.01	<0.01-0.30/0.08	0.06-1.52/0.39	0.07-12.6/0.67
PO_4^{3-} [$mg \cdot dm^{-3}$]	<0.01-0.07/0.04	0.05-0.21/0.11	0.03-0.28/0.14	0.01-1.11/0.11
TOC [$mg \cdot dm^{-3}$]	<1.0-<1.0/<1.0	<1.0-4.3/<1.0	<1.0-1.2/<1.0	<1.0-9.4/<1.0

In mid-polar-summer, morainic and outwash plain drainage waters had a significantly smaller impact on the shaping of the chemistry of water in proglacial rivers. The morainic and outwah plane waters played an increasingly important role in late polar summer (Bartoszewski & Magierski 1989a; Bartoszewski *et al.* 1991), especially when the outflow from the glacier started to decay. In glacier catchments devoid of direct river drainage (with the river beginning with springs below terminal moraines), proglacial rivers were characterised by low content of suspended sediment (from several to several dozen $mg \cdot dm^{-3}$). The material transported with supra- and subglacial waters was deposited in ice-dammed lakes between glacier fronts and moraine ridges, which prevented the free channeled outflow of water from the glacier.

The physico-chemical properties of water in proglacial rivers are highly variable. The nature of diurnal and seasonal changes was associated with the intensification of glacier ablation processes resulting from changes of air temperature, precipitation and snow cover melting. The most significant changes in water chemistry were recorded at the beginning and at the end of the active hydrological season. During the polar summer, cyclical diurnal changes were mainly conditioned by glacier ablation. This phenomenon was documented in the study conducted on 23rd-24th July, 2005 – the samples for analysis were collected at 2-3-hour intervals (Fig. 4.2.3). Among the physico-chemical properties studied during the polar summer, suspended sediment showed the greatest variability (Fig. 4.2.4).The rise of the Scottelva was associated with the increase of the suspended sediment load carried in the water, the pH of water, and the content of NH_4^+ and NO_2^- ions. The value of the remaining indicators decreased (Fig. 4.2.5).

Photo 4.2.1. A supraglacial stream on the Renardbreen (Photo S. Chmiel 2005).

Photo 4.2.2. Water flowing out of the mouth of the Scottbreen (Photo S. Chmiel 2005).

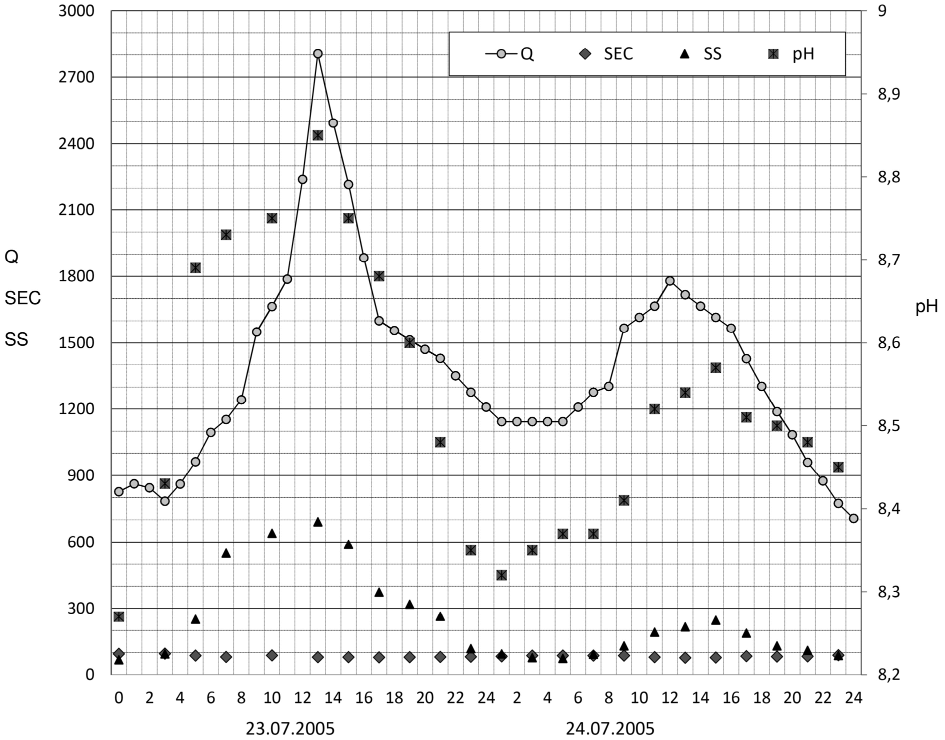

Fig. 4.2.3. Changes in volumetric flow rate (Q – $dm^3 \cdot s^{-1}$), specific electrolytic conductivity of water (SEC – $\mu S \cdot cm^{-1}$), suspended sediment concentration (SS – $mg \cdot dm^{-3}$) and water reaction (pH) on 23rd-24th July, 2005.

Non-glacierised areas

In periglacial areas, groundwaters were studied on the basis of the samples collected from springs, seepages, leakages and piezometers sampling the active layer. During the polar summer, the temperature of groundwaters ranged from ~0.5°C to nearly 10°C (Table 4.2.2). The pH was slightly alkaline, while the level of mineralisation amounted to ca. 200 $mg \cdot dm^{-3}$. As for hydrochemical classification, the most common water types included: Ca-Mg-HCO_3 and Ca-Mg-HCO_3-SO_4, occasionally, Mg-Ca-HCO_3, Ca-Mg-HCO_3-SO_4, Ca-Mg-SO_4-HCO_3 were also found. The dominance of carbonate mineral dissolution products was linked with the geology of study area which was determined by rocks of the Hecla Hoek Formation (Dallmann *et al.* 1990; Birkenmajer 2004), containing large amounts of carbonate minerals. Variable amounts of quartz, calcite, dolomite, sericite, chlorite and mica were also found in the mineralogical composition of these rocks (Chlebowski 1989ab). Waters rich in SO_4^{2+} were discovered in the area of ice-cored moraines of the Renardbreen and Scottbreen, in the Chamberlinelva catchment and in the mouth of the Rensdyrbekken (Reindeer Stream) (Photo 4.2.3).

The content of atmospheric substances in groundwaters, determined on the basis of chlorides concentration, reached up to 10% of TDS.

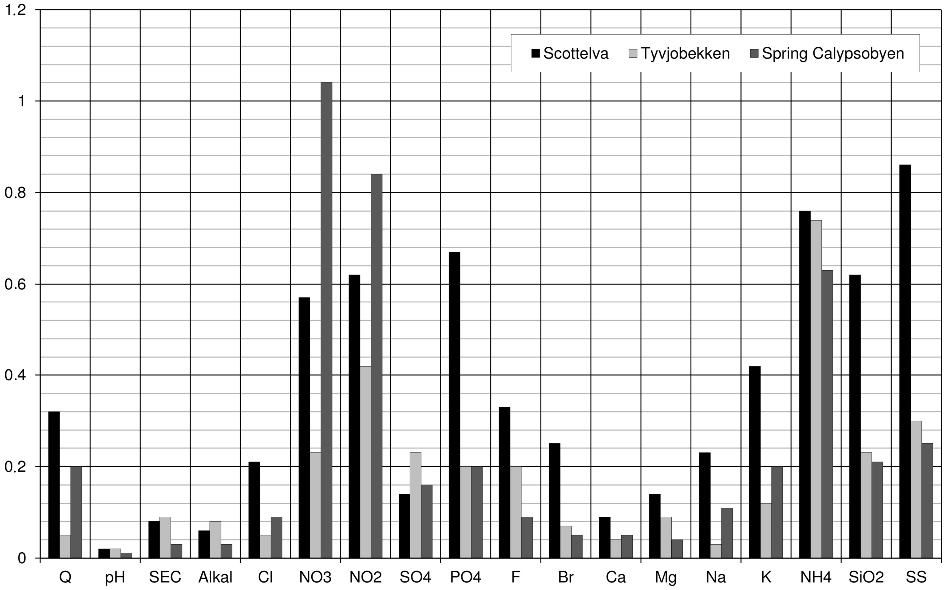

Fig. 4.2.4. Coefficients of variation of physico-chemical indicators at selected measuring stations in 2005.

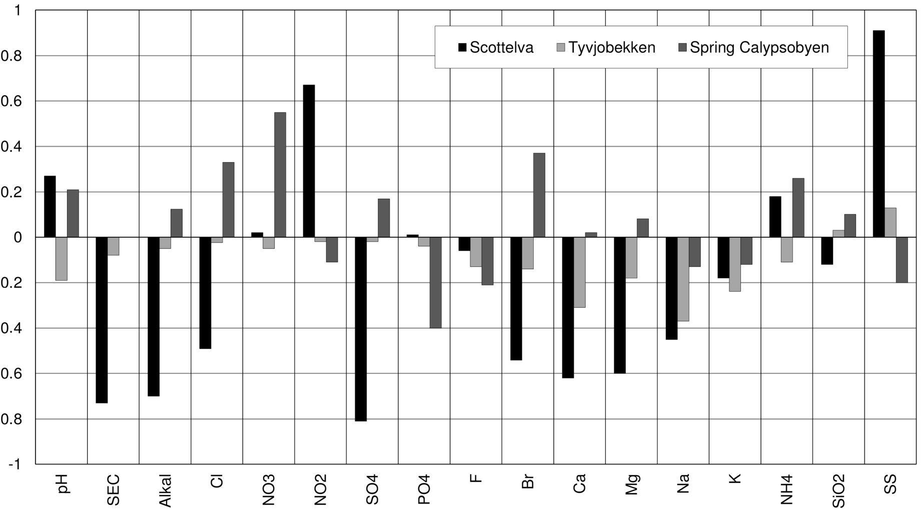

Fig. 4.2.5. Coefficients of correlation between outflow and physical and chemical indicators at the analysed stations in 2005.

Surface waters (rivers and lakes) in periglacial areas were characterised by a low concentration of suspended sediment (SS) (usually below <10 mg·dm^{-3}). Several times higher concentrations of suspended sediment were recorded during the spring thaw events and in solifluction flows from steep valley slopes. Surface waters had a slightly alkaline pH, their temperature ranged between 2°C and over 7°C, while TDS ranged between 100 mg·dm^{-3} and over 250 mg·dm^{-3}. Lower TDS rates were usually recorded in melting snow patches. Ca-Mg-HCO_3 was the dominant hydrochemical type identified among the surface waters of non-glaciersed catchments, other water types included: Mg-Ca-HCO_3, Ca-Mg-HCO_3-SO_4, Ca-Mg-SO_4-HCO_3. The increased concentrations of the main ions in the waters of of non-glaciersed areas were mainly caused by the biotic factor. The 'breathing' of the biogeochemical in soils caused the content of carbon dioxide to rise, which resulted in a higher solubility of carbonate minerals. River waters in periglacial areas usually showed higher levels of mineralisation than proglacial waters.

The study of the variability of physico-chemical properties in the diurnal cycle of the Tyvjobekken and Calypsobyen spring – behind building (A) – grevealed their significant stability (Fig. 4.2.4, Photo 4.2.3AB). The values of the coefficients of variation of the main indicators examined in 2005 were low (<0.2). This is indicative of the small impact of the hydrometrological conditions on the shaping of the analysed indicators and of the relatively stable biochemical conditions in the Calypsostranda region. The groundwaters examined in this region were characterised by a systematic increase in the level of mineralisation and the content of sulfates and nitrates.

The water tests carried out at particular stages of the hydrological cycle usually revealed low contents of biogenic substances (nitrogen and phosphorus), organic carbon and silica. However, a relatively high content of organic carbon was found in the waters flowing out of peat bogs. They were also characterised by a high content of nitrogen and phosphorus compounds. A high content of biogenic elements was also recorded in several small lakes in the study area. The increased concentrations of nitrogen and phosphorus should first and foremost be associated with a brid colonies and reindeer herds found in the vicinity of peat bogs and lakes.

The concentrations of heavy metals were usually low. As for iron and manganese, they usually amounted to several dozen µg·dm^{-3}. The concentrations of zinc and lead reached up to several µg·dm^{-3}, while the concentrations of copper and cadmium were below 1 µg·dm^{-3}. The highest content of iron (0,48 mg·dm^{-3}) was recorded in a water sample collected in the mouth of the Rensdyrbekken from a borehole drilled in sand (Chmiel *et al.* 2009) (Photo 4.2.3C).

Ion flow and denudation

The published study of ion flow and chemical (Cd) and mechanical (Md) denudation carried out during the expeditions to Spitsbergen presents the data from the years 1986-1990, 1993, 2002, 2005 (Bartoszewski & Repelewska-Pękalowa 1988ab, 1999; Bartoszewski & Magierski 1989ab; Michalczyk & Magierski 1990; Bartoszewski, *et al.* 1991; Bartoszewski 1994; Krawczyk & Bartoszewski 2008; Chmiel *et al.* 2011; Chmiel *et al.* 2012).

Photo 4.2.3. A- hydrological and hydrochemical investigations at the mouth of the Tyvjobekken (Photo P. Zagórski 2005), B- location of the Calypsobyen spring (arrow) behind the building (A) (Photo P. Zagórski 2011), C- ferruginous deposition in the Rensdyrbekken mouth (Photo S. Chmiel 2005).

Systematic measurements were taken in the Scottelva catchment (surface area: 10.1 km^2), representing glacierised area, and in the Tyvjobekken catchment (surface area: 1.29 km^2), representing non-glacierised area. The study was carried out using the hydrometric method, taking into account the average daily flow rate and water mineralisation (TDS) for the purpose of calculating chemical denudation, and suspended sediment for the purpose of calculating mechanical denudation. The results from the 1980's and the 1990's were calculated taking into consideration the total water mineralisation level (TDS), and thus they described ion flow. The calculations of chemical denudation after 2,000 were based on the adjusted water mineralisation level (TDS), taking into account the ions from atmospheric deposition and the presence of bicarbonates non-erosional in origin– both of these components constituted ca. 40% of total dissolved solids (TDS).The results of the study are presented in Table 4.2.3.

Ion flow from the glacierised Scottelva catchment ranged from 38 t·km^{-2} to 76 t·km^{-2}per season, while in the non-glaciersed Tyvjobekken catchment – from 18 to 33 t·km^{-2} per season. In terms of the daily transport of dissolved material, up to a dozen or so tons of dissolved flowed out from the Scottelva catchment, compared to less than 1 ton of such material which flowed out from the Tyvjobekken catchment. Chemical denudation accounted for nearly 60% of the compounds in dissolved form flowing out from the catchment area. Chemical denudation in the Scottelva catchment ranged from 0.5 t·km^{-2}·day^{-1} to over 1 t·km^{-2}·day^{-1}, while in the Tyvjobekken catchment it did not exceeded 0.5 t·km^{-2}·day^{-1}. It should, however, be emphasised that in the non-glaciersed section of the Scottelva catchment, the determined values of chemical denudation were similar to those recorded in the Tyvjobekken catchment (ca. 0.3 t·km^{-2}·day^{-1} on average). As for the glacierised section of the Scottelva catchment, the said value was usually higher (Chmiel *et al.* 2012).

Table 4.2.3. Averaged ion flow, chemical denudation and mechanical denudation rates in the Scottelva and Tyvjobekken catchments (t·km^{-2}).

Catchments	Year	1987[1] (16.06-15.08)	1988[2,3] (01.07-08.10)	1989[4] (05.07-08.09)	1986-1990[5] range	2002[6] (08.07-05.09)	2005[7,8] (14.07-01.09)	Expected range
Tyvjobekken	Ion flow	32.8	18.2	25.8	18.2-32.8	-	24.4	18-33
	Chemical denudation	19.7*	10.9*	15.5*	10.9-19.7*	-	14.1*	10-20
	Mechanical denudation	29.5	9.7	11.4	7.5-29.5	-	0.8	1-30
Scottelva	Ion flow	38.8	50.4	75.7	37.1-75.7	60.9	42.1	38-76
	Chemical denudation	23.3*	30.2*	45.4*	22.3-45.4*	39.2*	25.0*	23-46
	Mechanical denudation	113.8	147	256.5	72.9-256.9	-	126.5	70-260

[1]Bartoszewski & Repelewska-Pękalowa 1988b, [2]Bartoszewski & Magierski 1989a, [3]Bartoszewski & Magierski1989b, [4]Michalczyk & Magierski 1990, [5]Bartoszewski *et al.* 1991, [6]Krawczyk & Bartoszewski 2008, [7]Chmiel *et al.* 2011, [8]Chmiel *et al.* 2012, *Values calculated considering ions of non-erosion origin in TDS.

In years, mechanical denudation in the periglacial catchment (the Tyvjobekken) reached 1-30 t·km^{-2}during the measurement season, while in the glacierised catchment (the Scottelva) – 73-257 t·km^{-2} in the same period. The daily transport of suspended material from the Scottelva catchment ranged from several to several dozen tons, while in the Tyvjobekken catchment it was usually below 1 ton – the maximum values did not exceed 10 tons.

The levels of chemical and mechanical denudation depended on the water abundance of the river. The highest denudation rates were recorded in the periods of spring floods, raised temperatures and intensive rainfall. The lowest rates were recorded in autumn and winter time (Bartoszewski & Magierski 1989b; Michalczyk & Magierski 1990; Chmiel *et al.* 2011; Chmiel *et al.* 2012). The highest mechanical denudation rates were recorded in 1987 in the Tyvjobekken catchment and in 1988 in the Scottelva catchment. The lowest rates of ion flow and chemical denudation were recorded in the in1988 and 2005 (the Tyvjobekken catchment), and in 1987 and 2005 (the Scottelva catchment). Due to the limited period of study (Table 4.2.3), the obtained results of hydrometric and hydrochemical measurements provided a relatively accurate description of the Arctic summer months: July and August. As a result of the lack of measurements for the entire active hydrological period (usually from June through September), the presented ion flow, chemical denudation and mechanical denudation results are understated. As observed by Krawczyk & Bartoszewski (2008), the outflow of solutions for the entire active hydrological period may be higher by over 20%.

High mechanical denudation rates in the Scottelva catchment were mainly associated with intensive erosion processes in the front of the glacier. The measurements of suspended material concentration and river flow indicate that mechanical denudation in front of the Scottbreen reached up to several dozen t·km^{-2}·day^{-1}. About 90% of suspended material was deposited within the internal outwash plain (particularly in a shallow ice-dammed reservoir) and external outwash plain (Chmiel *et al.* 2012). Material depositied on outwash plains were of ten eroded and reworked during flood events (Fig. 4.1.6). The rate of mechanical denudation in the non-glacierised section of the Scottelva catchment may be assumed to be similar to that in the Tyvjobekken catchment (<1 t·km^{-2}·day^{-1}).

When it comes to the structure of the transport of dissolved and suspended material, it is possible to differentiate between glacierised and non-glacierised areas. In the case of the Scottelva catchment, the dominant form of transport was of the suspension of sediments (SS). The suspended sediments constituted ca. 75% of the total load of outflowing material (TDS+SS), geogenic solutions (Cd) constituted ca. 15%, while atmospheric solutions – ca. 1%. The lixiviation of geogenic materials from the Scottelva catchment were associated with their susceptibility to dissolution. The products of dolomite and calcite dissociation were the dominant form of dissolved materials (Table 4.2.4). The dominant mineral components in suspended sediment included: quartz, dolomite, calcite and muscovite/sericite(Table 4.2.5).

Ions transport was the dominant form of transport in the non-glacierised Tyvjobekken catchment and constituted 62% to 97% of the total load of dissolved and suspended material (TDS+SS) transported in the water. The geogenic solutions constituted 31-55% and atmospheric solutions less than 5% respectively.

Table 4.2.4. The estimated level of outflow of selected elements in dissolved and suspended sediment load from the Scottelva catchment in 2005.

Elements	Form		TDS+SS
	dissolved* [t·km^{-2}]	suspended sediment** [t·km^{-2}]	
Ca	5.89	13.66	19.55
Mg	1.51	6.27	7.78
Na	0.57	0.45	1.02
K	0.10	0.26	0.36
CO_3	14.64	25.29	39.93
SO_4	2.62	-	2.62
Cl	0.87	-	0.87
SiO_2	0.23	64.47	64.7
Fe	0.05	2.91	2.96
Al	<0.01	7.12	7.12
Mn	<0.01	0.04	0.04
Zn	<0.01	<0.01	<0.01
Pb	<0.01	<0.01	<0.01

* Values calculated on the basis of the chemical composition of water in the Scottelva (Chmiel *et al.* 2009, Chmiel *et al.* 2012).

**Values calculated on the basis of the mineral and chemical composition of suspended sediment concentracion in the Scottelva (Chmiel *et al.* 2009).

Table 4.2.5. The estimated level of selected minerals flowing out from the Scottelva catchment in dissolved and suspended sediment load in 2005.

Minerals	Form		TDS+SS
	dissolved* [t·km^{-2}]	suspended sediment** [t·km^{-2}]	
Quartz	0.23	63.37	63.60
Dolomite	10.79	25.35	36.14
Calcite	5.86	13.94	19.8
Muscovite/Sericite	0.61	12.67	13.28
Albite	0.54	5.07	5.61
Chlorite	0.11	5.07	5.18
Organic substance (inflammable)	-	0.63	0.63

* Values calculated on the basis of the chemical composition of geogenic water in the Scottelva (Chmiel *et al.* 2012).

** Values calculated on the basis of the mineralogical composition of suspended sediment concentracion in the Scottelva (Chmiel *et al.* 2009).

Summary

In the years 1986-2005 researchers from Maria Curie-Skłodowska University conducted hydrochemical research in glacierised and non-glaciers areas. The obtained results revealed the variability of the physico-chemical composition of waters at particular stages of the hydrological cycle. Temporal and spatial variability, resulting from the degree of catchment glaciation and geochemical conditions, were documented.

The rainwater was characterised by a slightly acidic pH and a low content of mineral substances, ranging from several to several dozen mg·dm^{-3}. The chemistry of precipitation was to a large extent determined by marine aerosols, which had an impact on the domination of Na^+ and Cl^- ions.

In glacierised areas, supraglacial waters were characterised by a low mineralisation level, amounting to several mg·dm^{-3}, while their ion composition was similar to that of rainwater. Significant changes in the chemical composition of the waters circulating in glaciers were recorded in places where they came into contact with aeolian material (supraglacial waters) and bedrock (subglacial waters). In such places, water mineralisation level (TDS) increased to several-several dozen mg·dm^{-3}, while the level of suspended sediment increased from several mg·dm^{-3} to several g·dm^{-3}. Transport of suspended sediment prevailed in proglacial rivers, where ion flow was less significant, since the dissolution of carbonate minerals was conditioned by the presence of carbon dioxide in the water.

HCO_3^-, Ca^{2+} and Mg^{2+} ions dominated in the groundwaters and surface waters of non-glacierised areas. The level of mineralisation of these waters amounted to 150-300 mg·dm^{-3}, while their pH was slightly alkaline. In periglacial areas, the phyciso-chemical properties of groundwaters and streams were strongly dependent on the biotic factors (nitrogen and phosphorus). As a result of biochemical transformations in the tundra ecosystem, carbon dioxide content in active layer waters increased, which in turn caused a greater solubility of carbonate minerals. In such areas fluvial transport in the form of solutions prevailed, while the transport of suspended sediments was less significant.

The dominance of the products of carbonate minerals dissolution in periglacial and glacier waters was related to the geology of the study area composed mainly by the rocks from the Hecla Hoek Formation, rich in calcites and dolomites.

Streszczenie

Hydrochemia

Podstawą opracowania charakterystyki hydrochemicznej były wyniki badań cech fizyczno-chemicznych wód w rejonie południowego obrzeża Bellsundu, które wykonano podczas letnich ekspedycji Uniwersytetu Marii Curie-Skłodowskiej na Spitsbergen w latach 1986-1990, 1993, 2002 i 2005. Badania hydrochemiczne prowadzone były w zlewniach zlodowaconych i niezlodowaconych, we wszystkich kolejnych fazach obiegu wody.

Wody opadowe w rejonie Calypsobyen charakteryzowały się odczynem słabo kwaśnym i niską zawartością substancji mineralnych, od kilku do kilkudziesięciu mg·dm^{-3} (ryc. 4.2.1, tabela 4.2.1). W kształtowaniu chemizmu opadów atmosferycznych decydujące znaczenie miały aerozole morskie, które wpływały na dominację jonów Na^+ i Cl^-.

Na lodowcach, wody z tającego śniegu i lodu charakteryzowały się niską mineralizacją rzędu kilku mg·dm^{-3}, zbliżoną do wód opadowych (ryc. 4.2.1, tabela 4.2.2). Istotne zmiany składu chemicznego wód supraglacjalnych następowały w miejscach kontaktu wody z materiałem eolicznym, natomiast wód subglacjalnych – z podłożem skalnym. Mineralizacja wód glacjalnych wzrastała wówczas do poziomu kilkunastu-kilkudziesięciu mg·dm^{-3}, a ilość zawiesin od kilku mg·dm^{-3} do kilku g·dm^{-3}. W rzekach proglacjalnych dominował transport materiału zawiesinowego – mniejsze znaczenie miał spływ jonowy. Wykazały to szczegółowe badania prowadzone na przykładzie Scottelvy (tabela 4.2.3).

W obszarach niezlodowaconych, w wodach podziemnych i powierzchniowych dominowały jony HCO_{3-}, Ca^{2+} i Mg^{2+} (ryc. 4.2.1, tabela 4.2.2). Mineralizacja tych wód kształtowała się w przedziale 150-300 mg·dm^{-3}, zaś ich odczyn był słabo zasadowy. Na podstawie pomiarów transportu fluwialnego Potoku Wydrzycy (Tyvjobekken) stwierdzono, że w obszarach peryglacjalnych dominował transport w postaci roztworów, mniejsze znaczenie miał transport materiału w postaci zawieszonej (tabela 4.2.3).

Na dominację produktów rozpuszczania minerałów węglanowych w wodach peryglacjalnych i glacjalnych południowego obrzeża Bellsundu miała wpływ zasobność skał formacji Hecla Hoek w minerały węglanowe: kalcyt i dolomit (tabele: 4.2.4 i 4.2.5).

Objaśnienia

Ryciny

Ryc. 4.2.1. Zróżnicowanie hydrochemiczne wód w rejonie Bellsundu, lato 2005: wody opadowe (jasno niebieskie koło), cieki supraglacjalne i subglacjalne (niebieskie koło), rzeki proglacjalne (czarny kwadrat), wody podziemne w obszarach peryglacjalnych (bordowy romb), wody powierzchniowe w obszarach peryglacjalnych (zielony trójkąt).

Ryc. 4.2.2. Zróżnicowanie całkowitej zawartość substancji rozpuszczonych (TDS w mg·dm^{-3}) w wodach rejonu Bellsundu.

Ryc. 4.2.3. Zmiany przepływu (Q – dm^{3}·s^{-1}), przewodności właściwej wody (SEC – µS·cm), zawiesiny (SS – mg·dm^{-3}) oraz odczynu wody (pH) w dniach 23.07-24.07.2005 r.

Ryc. 4.2.4. Współczynniki zmienności wskaźników fizyczno-chemicznych wybranych stacji pomiarowych w roku 2005.

Ryc. 4.2.5. Współczynniki korelacji między odpływem a wskaźnikami fizyczno-chemicznymi badanych stacji pomiarowych w 2005 r.

Fotografie

Fot. 4.2.1. Ciek supraglacjalny na Renardbreen (fot. S. Chmiel 2005).

Fot. 4.2.2. Wypływ wody z bramy Scottbreen (fot. S. Chmiel 2005).

Fot. 4.2.3. A- prace hydrologiczne i hydrochemiczne u ujścia Tyvjobekken (Potok Wydrzycy) (fot. P. Zagórski 2005), B- lokalizacja źródła w Calypsobyen (strzałka), za budynkiem (A) (fot. P. Zagórski 2011), C- wytrącenia żelaziste u ujścia Reindyrbekken (fot. S. Chmiel 2005).

Tabele

Tabela 4.2.1. Skład fizyczno-chemiczny wód opadowych rejonu Calypsostrandy w okresie lata polarnego 2002 (Krawczyk i in. 2008) oraz 2005 (Chmiel i in. 2011).

Tabela 4.2.2. Charakterystyczne wskaźniki cech fizyczno-chemicznych wód w rejonie Bellsundu (zakres: min-max/mediana) na podstawie próbek wody pobranych w okresie 20.VII-20.VIII 1995 r. (rozmieszczenie punktów pomiarowych ryc. 4.2.2).

Tabela 4.2.3. Uśrednione wartości spływu jonowego, denudacji chemicznej i mechanicznej w zlewni Scottelvy i Tyvjobekken ($t \cdot km^{-2}$).

Tabela 4.2.4. Oszacowany poziom wynoszenia wybranych pierwiastków ze zlewni Scottelvy w formie rozpuszczonej i zawiesinie 2005 r.

Tabela 4.2.5. Oszacowany poziom wybranych minerałów wynoszonych ze zlewni Scottelvy w formie rozpuszczonej i zawieszonej w 2005 r.