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Character and rate of denudation in a High Arctic glacierized catchment (Ebbaelva, Central Spitsbergen)

Józef Szpikowski [a,b], Grażyna Szpikowska [b], Zbigniew Zwoliński [a,*], Grzegorz Rachlewicz [a], Andrzej Kostrzewski [a], Marek Marciniak [c], Krzysztof Dragon [d]

[a] Institute of Geoecology and Geoinformation, Adam Mickiewicz University, Poznań, Poland
[b] Geoecological Station in Storkowo, Adam Mickiewicz University, Storkowo, Poland
[c] Institute of Physical Geography and Environmental Planning, Adam Mickiewicz University, Poznań, Poland
[d] Institute of Geology, Adam Mickiewicz University, Poznań, Poland

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ABSTRACT

A series of investigations of water and sediment discharge from the glacierized Ebba River catchment (53 km^2, located in the Billefjorden area in the central part of Spitsbergen) was carried out during the ablation seasons of 2008–2010. The study included hydrometric measurements at the catchment closing profile, identification of meteorological factors, and specification of the suspended and dissolved sediment load and of the water's chemical composition. The study evidenced a typical water regime for proglacial rivers, as well as its diversification in subsequent ablation seasons being determined mainly by thermal conditions. Moreover, during the study, the chemical (1 t km^{-2} d^{-1}) and mechanical denudation (2.7 t km^{-2} d^{-1}) indices were calculated. These rates documented the independent nature of the water supply system and the water and matter dynamics of the glacierized catchment.

1. Introduction

Fluvial transport and denudation in glacierized and non-glacierized catchments in polar areas constitute an important indicator of contemporary landscape transformations (Pulina et al., 1984; Choiński, 1989; Kostrzewski et al., 1989; Scherer and Parlow, 1994; Hodgkins and Tranter, 1998; Mercier, 2001; Laffly and Mercier, 2002; Hodgkins et al., 2003; Zwoliński, 2007a; Zwoliński et al., 2008; Rachlewicz, 2009; Beylich et al., 2010). At present, we have relatively right information on the conditioning and course of fluvial fluxes or mechanical and chemical denudation indices concerning the western coast of Spitsbergen (Helldén, 1974; Szczepanik, 1982; Etzelmüller et al., 1993; Hodgkins et al., 1998; Hodson and Ferguson, 1999; Gude, 2000; Hodson et al., 2000, 2002) but not for the central part of this island. The current study encompassed a short series of measurements, which considerably limits comparative study, and the results reflect the weather conditions of a few ablation seasons. Geomorphological studies were carried out in the Ebba catchment (Fig. 1) during the summer season (July–August) of 2008–2010, complementing in part the previous research. The purposes of the studies carried out on fluvial transport and denudation variability in the Ebba catchment were as follows:

- qualitative and quantitative analyses of the water discharge dynamics and substances transported in the partly glacier covered Ebba River catchment,
- indication of factors influencing the system of sediment supply, circulation and load in the slope and fluvial systems in the ablation season of July–August (2008–2010),
- determination of the mechanical and chemical denudation in the Ebba catchment.

2. Regional setting

The area studied is situated in the central part of Spitsbergen, and encompasses Ebbadalen, which is drained by the Ebbaelva discharging into the Petuniabukta, which is at the northern end of Billefjorden (Rachlewicz et al., 2012) (Fig. 1). The Ebba River flows along a 2 km wide and ca. 4 km long valley stretching from the east to the west. The Ebba Valley is a typical postglacial valley limited by the Lovehovden (610 m a.s.l.), Hultberget (719 m a.s.l.) and Pukkelkammen (760 m a.s.l.)

* Corresponding author at: Institute of Geoecology and Geoinformation, Adam Mickiewicz University, Dzięgielowa 27, 61-680 Poznań, Poland.
E-mail addresses: szpiko@amu.edu.pl (J. Szpikowski), grania@amu.edu.pl (G. Szpikowska), zbzw@amu.edu.pl (Z. Zwoliński), grzera@amu.edu.pl (G. Rachlewicz), anko@amu.edu.pl (A. Kostrzewski), mmarc@amu.edu.pl (M. Marciniak), smok@amu.edu.pl (K. Dragon).

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mountain ranges from the north and north-east, and Wordiekammen (max. 805 m a.s.l.) from the south. The ice cap covered upper part of the Ebba catchment area is occupied by the glaciers Ebbabrenn and Bertrambrenn, lateral glacier tongues of the Mittag-Leffler glacier. The ice divide marking off the Ebba basin runs through Bastionfjellet (995 m a.s.l.), Jacksonfjellet (1227 m a.s.l.) and Flemingfjellet (1125 m a.s.l.) nunataks in the east, and the Mc Cabefjellet (990 m a.s.l.) range in the south-east. The Ebba is a proglacial river that depends on the seasonal melting of the Ebba glacier, which is a polythermal glacier that has been retreating for more than 100 years (Rachlewicz et al., 2007; Rachlewicz, 2009). According to a topographic map 1:100 000 scale (Norsk Polarinstitutt, 1988), the catchment area of the Ebba River is 53.4 km^2. The ice covered part of the catchment measures 27.4 km^2, as based on a Terra/Aster satellite image from 2002.

The longitudinal course of the Billefjorden tectonic fault has a fundamental impact on the geological structure of the study area (Dallmann et al., 2004). The mountain ranges surrounding the Ebba glacier, i.e. the upper glacierized part of the Ebba catchment area, belong to the crystalline Precambrian basement, which is formed on metamorphic rocks (mainly gneisses, amphibolites, granite gneiss, crystalline shales, and marbles). The ridges surrounding the Ebba Valley, i.e. the fluvial part of the Ebba catchment, are formed of Carboniferous rocks (mainly gypsum, anhydrites, dolomites, limestones, sandstones, and shales). The bottom of the valley and the adjacent slopes are covered by Pleistocene and Holocene sediments and are glacial, fluvioglacial and marine in origin. The vicinity of Petunia Bay, especially the area of raised marine terraces, is formed of different types of sediments derived from the ridges surrounding the Ebba Valley.

The tectonic conditionings, the layout of geological units, whose rocks show diversified resistance to weathering and erosion processes, and climatic conditions have all influenced the creation of relief within the Ebba catchment area, which, according to Kostrzewski et al. (2007), is polycyclic and polygenetic in nature. The present-day landforms are the result of the impact of several geomorphological processes (Kłysz et al., 1989; Stankowski et al., 1989; Karczewski et al., 1990). The most important processes are: glacial erosion (within the Ebba Valley), glacier ice accumulation (marginal zones of the Ebba and Bertram glaciers), fluvioglacial accumulation (outwash plain in the Ebba Valley), mass movements (rock debris and talus cones on the slopes of the Lovehovden, Hultberget, Pukkelkammen and Wordiekammen ranges and ridges), fluvial processes, and solifluction and ablation (alluvial fans descending from the ridges to the Ebba Valley bottom). Local denudation products accumulate on different types of slope, sub-slope and valley covers. Sediment discharge from the Ebba catchment in the course of the local denudation cycle takes place mainly by means of fluvial transport of dissolved, suspended and bed-load material, and ends up in the sedimentation basin in Petunia Bay. The progressing glacial ablation processes and consequently released new moraine from under the glaciers are important factors controlling sediment fluxes from polar catchments.

The study area climate conditions are shaped in particular by the North Atlantic air masses (Niedźwiedź, 2007) and modified by their morphological and altitude layout (Bednorz and Kolendowicz, 2010). The degree of climate continentality increases towards the north-east along with the distance from the western coast of the Svalbard Archipelago, as reflected in the rise in the annual air temperature and the decrease in the amount of precipitation. The annual atmospheric precipitation in the area of the Ebba catchment is ca. 150–200 mm (Kostrzewski et al., 1989; Rachlewicz, 2003a). The thermal conditions depend on solar radiation, which is dependent in turn mainly on the length of the polar day (133 days within the area under study). The ablation season, which is characterised by a temperature above 0 °C, usually lasts from mid-June until the beginning of September. It is at the same time a period of surface (pronival and pro-glacial) water activity, as well as of underground feeding in the active layer of the permafrost (Marciniak and Dragon, 2010), the maximum thickness of which is up to 100–160 cm (Rachlewicz and Szczuciński, 2008; Mazurek et al., 2012).

The Ebba River commences with a waterfall flowing down a 40 m rocky step, above which stretches the Ebba glacier tongue. Below the waterfall, the Ebba is fed by a right-bank tributary flowing down a 250 m rock wall below the Bertram glacier. The braided river forms an outwash plain for further 2 km. This part of the river is fed by numerous, periodical tributaries flowing down the ridges surrounding the valley. In its middle and lower reaches, the Ebba flows down a well-shaped channel among fluvioglacial and fluvial accumulation deposits and raised marine terraces. The mouth of the Ebba River, facing Petunia Bay, forms an estuary within reach of sea tides, surrounded by numerous berms (Choiński, 1989).

3. Material and methods

The monitoring system incorporated the previous arrangement of sites and applied research methods (Kostrzewski et al., 1989; Rachlewicz, 2007, 2009; Zwoliński, 2007b; Marciniak and Dragon, 2009). Studies were based on regular measurements in the hydrometric profile enclosing the catchment area (Figs. 1, 2). The water gauging station on the Ebba River was located about 200 m above the estuary at the river's mouth, beyond the range of any backwater triggered by sea tides. A staff gauge was placed to enable water level readings within an accuracy of 1 cm. Measurements at the gauging station comprised water level readings (staff gauge), water temperature measurements (with the use of mercury or an electric thermometer) and water sampling (in 0.5 or 1.0 dm^3 plastic bottles).

A water level and temperature sensor (diver) was installed alongside the staff gauge and set to take readings every 15 min (Marciniak and Dragon, 2009). Water discharge measurement was conducted in the cross profile of the channel, about 30 m below the hydrometric station, with the use of the hydrometric method applying a SEBA-Hydrometrie electromagnetic water flow metre (Dragon and Marciniak, 2010; Marciniak and Dragon, 2010). During the measurement seasons of 2008–2010, 29 measurements of instantaneous discharge for diverse water conditions were taken. Discharge curves were prepared for each particular year on the basis of the measurements of the discharge for specific water conditions. Discharges for subsequent terms of water level observation in each studied season were established on the basis of observed interdependencies. The measurements of the shape of the cross profile of the Ebba channel proved the dynamic nature of changes in the bed morphology (Marciniak and Dragon, 2009; Rachlewicz, 2009). The changeable morphodynamics of the channel trigger more frequent measurement errors of the applicable method of calculating suitable discharges according to the flow curve.

Ebba River water samples were taken twice every 24 h: at 8 AM and 8 PM LT. The measurement concerned the specific conductance of each sample (using the multifunction computer device CX-741, Elmetron). The water samples were filtered through Whatman filters (0.40–0.45 μm). Particulate matter content was specified with the use of the drying and weighing method, with determination of chlorides, nitrates and sulphates – applying the ion chromatography method (DX-120, Dionex), and magnesium determination – with the use of flame atomic absorption spectrometry (SpectrAA 20 Plus, Varian). Emission spectrometry was carried out to determine sodium and potassium (SpectrAA 20 Plus, Varian), ionised silica concentration was determined through the spectrophotometric method (Spekol 1100, Carl Zeiss Technology), and alkalinity and calcium were determined by the titration method. Ionic balance was also calculated for each water sample. The difference between the sum of anions and the sum of cations (in eq dm^{-3}) did not exceed 5% of the sum of ionic compounds.

Weather conditions were determined based on measurements taken through automatic, meteorological Davis Vantage Pro Weather Stations. Meteorological stations were situated in the following three locations (Fig. 1): on the coast of Petunia Bay near Skottehytta