Proceedings of the

10th I.A.G./A.I.G. working group SEDIBUD

(Sediment Budgets in Cold Environments)

Workshop

MONITORING OF GEOMORPHOLOGICAL PROCESSES IN COLD ENVIRONMENTS UNDER CLIMATE CHANGE –

Bansko, Bulgaria, 7-10 September 2016

Banderitsa Valley (in the bottom Banderitsa stair cirques) - picture by Ahinora Baltakova

Program

7.09.2016	15:00	Sofia – Bansko organized transport departure from Sofia University "St. Kliment Ohridski" (optional)
	18:00	Arrival and check in at Tanne Hotel
	19:00	Welcome note by organizers and the working group Chair
	19:30	Dinner/Icebreaker
8.09.2016	8:00	Breakfast
	9:00	Keynote by Ahinora Baltakova and the Bulgarian team: Geomorphological processes under climate change in the high mountain area of Pirin

Session 1, Chaired by Achim Beylich

9:30	Dimitar Krenchev Spatial distribution of rock falls in the high mountain area of Pirin, Bulgaria
10:00	Flaviu Meseşan et al. Debris-flow and snow-avalanche activity on the same forested debris cones: reconstructed events and process differentiation based on tree-ring analysis in Făgăraş Mountains (Southern Carpathians, Romania)
10:30	Coffee break
11:00	Daniel Germain Spatiotemporal quantitative modeling of sediment fluxes on fine-grained scree slopes in cold temperate climate of Eastern Canada
11:30	Jasper Knight et al. Plant ecology and geomorphology of a low alpine summit in southern Africa
12:00	Mircea Voiculescu et al. Biogenic activity as a sediment source in subalpine prairies of Parâng Mountains, Southern Carpathians, Romania: A preliminary quantitative analysis for sediment budget
12:30	Lunch

Session 2, Chaired by Ahinora Baltakova

14:00	Alexandru Onaca et al. Assessing the types of layering within the alpine talus slopes of the Făgăraș Mountains (Romania) using GPR measurements
14:30	Iulian - Horia Holobaca Recent retreat of the Elbrus glacier system
15:00	Sonya Stoyanova et al.

Fluvial processes and sediment dynamics of the slope-channel system in Sinanitsa valley, Pirin, Bulgaria

15:30 Coffee

16:00 Petko Bozhkov
Preliminary results from field experiment using soil erosion plots in Zemen Gorge, West Bulgaria

16:30 Mateusz C. Strzelecki et al.
In search for the model of the interaction of paraglacial and periglacial processes in the Arctic coastal zone

Poster session

17:00 Achim A. Beylich and the SEDIBUD Team
The I.A.G. / A.I.G. SEDIBUD (Sediment Budgets in Cold Environments) Program (2005 – 2017): Key outcomes, products and current activities

Achim A. Beylich
Integrating comparable field datasets from selected cold-climate catchment geosystems for analyzing environmental controls of contemporary solute and sedimentary fluxes in cold-climate regions

Achim A. Beylich et al.
Environmental controls, sediment sources, spatiotemporal variability and rates of fluvial sediment transport in partly glacierized mountain catchments in the fjord landscape of western Norway

Katja Laute and Achim A. Beylich
Potential effects of climate change on snow avalanche activity in western Norway

Mateusz C. Strzelecki et al.
POROCO - Mechanisms controlling the geomorphology and evolution of rocky coasts in polar climate – first results from Svalbard and South Shetland Islands

18:00 Discussion
18:30 SEDIBUD-business meeting
19:30 Official dinner

9.09.2016 8:00 Breakfast
9:00 Excursion to the Vihren peak (2914 m) with the Banderitsa valley and the double cirque Kazanite (lunch on the go)
19:00 Dinner

10.09.2016 8:00 Breakfast
9:00 Final and workshop closing remarks
10:00 Bansko – Sofia organized transport departure (optional)

Geomorphological processes under climate change in the high mountain area of Pirin

Keynote

Ahinora Baltakova[1], Rossitza Kenderova[1], Georgi Rachev[1],
Dimitar Krenchev[1], Sonya Stoyanova[1]

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Climate has been changing constantly throughout the geologic history and our time is only an episode of this cycle. The most fresh and impressive remnants from different conditions are from the Pleistocene ice ages, which could be found also in the Bulgarian highest mountains. In the high mountain area of Pirin we can observe as well various landforms associated with the recent postglacial stage but not very active today – taluses and screes, blockfields and blockstreams that are covered with vegetation or exposed. It is not very clear to which moment after the glaciers retreat they belong to. Palynological records suggest several fluctuations during the Holocene but there are documentaries, which whiteness severe mountain climate only 60-50 years ago. Unfortunately, available meteorological archives for the high mountain areas in Bulgaria are more than insufficient to make general conclusions. We could use only analogies from similar locations in Europe in order to reconstruct past environments. At this moment it is necessary to follow what is the environment behavior in the current climate condition and this is the goal of our investigation. Such study was never been a subject to other researchers in Bulgaria up to now.

Since the fall of 2011 the team from Sofia University "St. Kliment Ohridski" is dedicated to the observation of slope and fluvial processes activity in Pirin. We are making field measurements together with soil and air temperature monitoring in 3 main key sites (2 of which have been proposed for key sites of SEDIBUD's network): Begovitsa Valley, the foot of the Vihren Summit (Banderitsa Valley) and Sinanitsa Valley. Unfortunately poor funding is slowing the installation of proper equipment (we can afford only low budget loggers and meteostations, which often require maintenance and data archive) and our data base is still thin but now we have first data for the country,

which is going to provide impressions about every particular landform response towards every single weather event.

Based on these results we have the first quantitative proof that above 2200 m in Pirin the top surface layer seasonally freezes (regardless the slope aspect) for more than 6 months. Important parts of this period are the freeze-thaw cycles, which are most common in the beginning of the winter (October – December). Usually the transition of top surface temperature through the freezing point is more than twice per day, which causes rock shattering and rock falls increased activity. During the period with sustainable snow cover (this period begins from the end of January for the last two years) the snow is the main agent for slope movements. The avalanche activity became constant through the winter season in the last years because of the higher air temperatures during the whole period. However, up to now our results do not show serious movements in the avalanche fans, which is indicator for poor transport availability in the observed landforms.

In the period of snow melting (May-July) when air temperatures are constantly positive, processes associated with over moist of grunt are prevailing – solifluxion, high speed creep and debris flow on slope surfaces; slumping and peat formation on plane surfaces, cirques sinks and valley floodplains. In the peat and on deeply weathered granites the rill and gully erosion also show significant activity in the summer season. These processes are definitely more active in the period of our observations, which is in contrast with the reports for high rock fall activity in territories with recent glaciers retreat in the Alps, for example.

Continuation of this research will provide tendencies in the data and is going to contribute the knowledge about processes response under changing conditions. Analogies with other corresponding territories will help to deal with the data gaps and the explanation of landforms, result from other environment background.

Spatial distribution of rock falls in high mountain area of Pirin, Bulgaria

Dimitar Krenchev

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About 40% of the area above the treeline in the Pirin Mountains are affected by rock falls and related landforms. These processes occur in the higher parts of the cirques and valley slopes where the slope exceeds 40º. As a result, at the foot of the slopes large scree and talus cone are formed.

The main aim of this study is to analyze and evaluate the spatial distribution of rockfall processes and related landforms in the high parts of the Pirin Mountains. For this purpose we used the following methods: satellite image analysis to identify and mapping the areas of rockfall activities, digital elevation model (DEM) analysis in GIS environment to evaluate the spatial distribution of rockfall depositions and field observations and measurements.

The study area includes the highest part of the mountain (198 km²), above treeline (1800 - 2900 m a. s. l) which has typical alpine landscape dominated by large cirques, U-shaped valleys and moraine ridges. About 60% of the study area is located between 2200 - 2500 m a.s.l. The average gradient of the slopes at this altitude is 25º and 32% of them have gradient above 30º. The prevailing geomorphological processes are frost weathering, rock fall, solifluxion, creep etc.

The results of the investigation show that rock fall sediments and related landforms occupy 70 km² of the research area. About 71% (50 km²) of the scree, talus cones and block fields are located in height between 2200 and 2500 m a. s. l. Around 51% of the scree slopes are with inclination between 20º and 30º. Other 25% lie on the slopes with gradient 10-20º. In analyzing the relationship between slope aspect and spatial distribution of the rock fall deposition was established that 30% of them are located on the slopes with northern and northeastern exposure which is 7-8% higher than the other. This is related to local climatic conditions on the northern slopes of the mountain where the frost weathering is much more intensive. The field observations and measurements of rock fall deposits also show that activity of the process is not uniform in the warm and cold period of the year. The intensity is higher in April and May when the sediments thaw.

Debris-flow and snow-avalanche activity on the same forested debris cones: reconstructed events and process differentiation based on tree-ring analysis in Făgăraş Mountains (Southern Carpathians, Romania)

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The alpine slopes of Făgăraş Mountains (Southern Carpathians, Romania) are prone to debris flows and snow avalanche activity, but in these remote mountainous areas the geomorphic process activity is not monitored. Contemporary debris flows and snow avalanches can travel hundreds of meters on steep slopes and cross the coniferous forest stands. Many of the resulted debris cones in the runout zones of debris flow and avalanche paths are colonized by coniferous forests and consequently the trees may frequently be damaged by process activity. Trees register all the external disturbances in their growth pattern, including the influence of geomorphic process activity. In these geomorphologically active areas, where the monitoring by other methods is usually lacking, tree-ring analysis may serve to reconstruct the event history with annual or seasonal resolution. The main objective of our study was to reconstruct the event history on two separate debris cones by analyzing the tree-growth reactions of damaged trees. A variety of dendrogeomorphic methods have been applied here, in order to gain a better understanding of debris flow and snow avalanche activity in terms of frequency and spatial extent at the surface of the two debris cones investigated. The samples (cores, wedges and discs) gathered from 224 Norway spruce (*Picea abies* (L.) Karst.) trees provided a record of events since the beginning of the 20th century. Despite of some inherent limitations of dendrogeomorphic methods applied in this study, tree-ring analysis proved to be a reliable source of information for the event reconstruction and process differentiation in the case of the forested debris cones successively disturbed by debris flow and snow-avalanche activities.

Spatiotemporal quantitative modeling of sediment fluxes on fine-grained scree slopes in cold temperate climate of Eastern Canada

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Fine-grained scree-slopes of Eastern Canada appear very sensitive to climate changes because of their composition, which is made of small, very mobile fragments. Here I report, through the use of several methodologies (painted lines, dendrogeomorphology, sediment traps, ^{14}C dating, of burial soils, etc.) the sediment fluxes related to various hillslope processes at different spatiotemporal scales. Indeed, the annual observations since 1979 allowed a better understanding of the timing, triggering conditions and sediment fluxes on these scree slopes. The results show that in summer season, individual particles tend to accumulate near the base of the rockwall (talus shift of 15 cm/year) until mobilised by cold season dynamics such as frost-coated clast flows, which account for at least 95% of the yearly sediment budget, corresponding to an average sediment flux of 1.1 m^3/m/year entering the forest on the lower part of the slope. In comparison, the extreme debris-flow event recorded in 2009 (> 10 000 m3) corresponds to only 0.57 m^3/m/year entering the forest. According to the 36 years of observation, a modest sediment flux of 0.016 m^3/m/year is found. The sediment flux decrease to 0.0175 m^3/m/year when considering 7400 years, the total length of the period since the occurrence of the first debris flow that reached the rock glacier front at the foot of the slope. In light of these data, it appears that the frost-coated clast flows are the most significant active geomorphic process on the scree slope. Over the long term, the extreme events such as the debris flows of 2009 likely play a minor role in the overall sediment budget of the slope, as evidenced by the forest edge, which is being buried instead by frost-coated clast flow activity. Increased geomorphic activity is interpreted as a consequence of the climate change experienced during the twentieth century.

Plant ecology and geomorphology of a low alpine summit in southern Africa

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In the Drakensberg Mountains of eastern Lesotho, periglacial sorted circles, stone-banked lobes and turf-banked lobes, blockfields, boulder streams and wetland thúfur (earth hummocks) are present. These features are largely relict under today's climate, but some miniature sorted circles and thúfur may still be active. These features are found around the summit of Mafadi (3450 m; 29°12'0.65"S, 29°21'22.5"E), the highest peak in South Africa, where bedrock is Jurassic basalt. Here, periglacial features of likely various ages (from LGM to contemporary) have been occupied and disturbed by soil formation and vegetation growth. In this study we use a mixed methodology to investigate the relationships between periglacial landforms and their associated ecosystems, and the relative age relationships of these components. The context for this study is that this nutrient-limited low-alpine ecosystem (the Drakensberg Alpine Centre) shows a strong dependency on the stability and properties of the land surface. Any disturbance of the land surface by periglacial frost-heave, which can also result in changes in grain size, moisture and nutrient content, could impact on the ability of plant species to become established.

Landforms around Mafadi include (1) sorted circles (15-120 cm diameter) that are located mainly on shallow-sloping interfluves. These vary in sorting properties but commonly have vertically aligned clasts on circle margins. (2) Stone runs/boulder streams (1.8-8 m diameter, 6-30 m long in surface expression) are found on south-facing slopes and are composed of angular boulders (1.4 m dimensions). Flow levees and lobate structures within and at the end of the boulder streams, and internal ripples, are commonly seen. These landforms may have origins as debris flows. (3) Stone- and turf-banked lobes (exceptionally <7 m wide, 2 m high, 30 m long but more commonly 4 m wide and 8-10 m long) are arcuate structures with terminal banks that are 20-40 cm high and 0.5-1 m wide.

Internally, clasts are commonly vertically aligned, may be imbricated, and clast size tends to increase toward lobe margins.

A distinctive low-alpine flora is found in association with these different periglacial forms. For example, *Helichrysum trilineatum* is located mainly on the coarser and more stable edges of sorted circles, while the centers of circles only contain occasional plants. *Erica thodei* is located mainly at the front of stone- and earth-banked lobes in areas of higher moisture retention, and not in the center of these landforms. The distributions and diameter of these shrubby species, together with the tufted grass *Pentameris* sp., and herbs *Crassula setulosa* and *Craterocapsa congesta*, were noted. From some lobes, woody plant stems were sampled for dendrochronology and thus the age of these individuals. In addition, the relative weathering and thus age of surface clasts within and on the outside of the lobes was evaluated using an Equotip device. Although we do not yet have results from many of these lines of evidence, the relationships between periglacial geomorphology and alpine plant ecosystems is not well understood from southern Africa, but is important with respect to ecosystem responses to ongoing climate change and the maintenance of biodiversity.

Biogenic activity as a sediment source in subalpine prairies of Parâng Mountains, Southern Carpathians, Romania: A preliminary quantitative analysis for sediment budget

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For the last decades, the activity of animals has been explored and reported as a potential source of natural hazards. For example, destruction of a beaver dam might trigger a flash flood down the river. However, sediment source or sediment budget related to animal activity has so far received very little attention from geoscientists. The main goal of this study is to quantify the biogenic activity of the European snow vole (*Chionomys nivalis*) in the subalpine prairies of the Parâng Mountains, Romanian Carpathians. Only the direct action of this rodent was analyzed, namely the distribution of burrows, quantitative analysis of the mounds, rate of sediment displacement caused by burrowing and digging of tunnels, which can serve as water conduits and soil disturbances increasing then the surficial erosion. When the soil is removed from the tunnel of the burrow to the surface, new landforms are created, bioturbation process became evident and new areas of erosion appear.

The investigation was carried at the end of May when the impact of bioturbation by *Chionomys nivalis* was the most visible, and continued until the beginning of July 2016 when the biogenic activity started to decrease. Data were collected at five different plots 7 x 7m, 10 x 10m and 12 x12m, depending on local abundance of burrows, in subalpine prairies at altitudes between 2130 and 2147 m. 362 burrows mounds were mapped and measured (aspect of burrow entrance to determine the preferential orientation, mound length, width, height and slope measured on the steepest parts as potential for erosion). Each soil disturbance (n=362) was also weighed with a high-resolution numerical balance (0.001 g) and the excavated volumes of sediments were calculated by measuring the volumes of the each mound (length x height x width). Finally, burrows were classified in three types taking into account the freshness of the sediments excavated: *actives* with fresh sediments or tracks at the entrance; *old* or *abandoned* where the mound still exist but the entrance in the burrow is plugged

with sediments; and *inactive* or *eroded* where the sediments completely disappeared being exposed to wind and rain erosion and the burrow entrance cannot be identified.

Based on these field observations, the preliminary results show an average density of 55 to 71 burrows on 100 m² and mainly three preferred aspects: South-East, South and South-West. As expected, the higher density of burrows was identified on slopes away from the dominant wind direction (North and North-West). The biogenic activity of *Chionomys nivalis* was located on gentle slope of 10-15 degrees, but some observations revealed that this activity is more intense on steeper slope (20-25 degrees). The amount of soil displaced is highly variable at a local scale ranging from a few grams to 6.540 kg, more exactly the maximum values at plot A was 1.540 kg, at plot B – 4.150 kg, at plot C – 1.250 kg, at plot D – 2.960 kg and at plot E – 6,540 kg. These data offer a maximum excavated volume of 56160 cm² of sediments (recorded in plot E) and a medium value of the sediments flux of 223.56 g/m² (plot A), 1526 g/m² (plot B), 275 g/m² (plot C), 209.51 g/m² (plot D) and 579.36 g/m² (plot E). If the burrows mapped in May (plot A and B) are all actives, the other three plots (C, D, E) mapped in July show a decrease of actives burrows. It means that, once the sediments are freshly exposed, they become available for redistribution by other geomorphic processes such as wind, pluvial erosion, and runoff of snowmelt and particularly on steep slopes. In that regard, the biogenic activity by *Chionomys nivalis* should be considered as a significant geomorphic process for sediment flux and sediment budget in the subalpine level of mountainous environments.

Assessing the types of layering within the alpine talus slopes of the Făgăraș Mountains (Romania) using GPR measurements

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The presence of stratified talus deposits was reported in many different mountain environments. Their presence within the Făgăraș Mountains was first outlined by Urdea (1995). Although the scientific literature offers a series of explanations regarding the genesis and development of talus slopes (Francou 1990, Sass 2006, Krautblatter and Dikau 2007, Sass and Krautblatter 2007), sediment stores are quite inaccessible as exposures are sparse. The current approach aims both to describe the internal structure of talus deposits, within the alpine environment of the Făgăraș Mountains, as well as to determine the internal stratification of talus slopes, in order to identify the main morphogenetic processes which acted during the Holocene.

Ground penetrating radar (GPR) measurements (100 MHz antennae) were performed on 43 talus slopes located within the central part of the Făgăraș Mountains (Bâlea and Capra glacial cirques and Doamnei glacial valley), in order to gain insight into the internal structure of the investigated landforms. The local lithology consists of crystalline schists, limestone and crystalline dolomite, belonging to the Suru Formation of the Făgăraș Subgroup.

The GPR technique proved to be suitable in detecting both the overall thickness of the talus deposits, as well as their internal stratification. The results pointed out that rockfall related processes and debris flows contributed significantly to the formation of talus deposits, while their activity was highly controlled by the Holocene climatic oscillations. Three main different genetic types of layering were identified within the investigated talus slopes:

(i) stratified slope deposits with alternating periods of intense rockfalls and intermediate storage depletion;

(ii) post-depositional sediment redistribution by surficial debris flows;

(iii) weak layering interrupted by high-magnitude rockfalls.

References:

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Recent retreat of the Elbrus glacier system

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The glacier system covering Europe's highest mountain, Elbrus, has exhibited an accelerated retreat since 1980. Some studies have related this retreat to a significant summer temperature increasing trend. Relief- and aspect-related parameters for the glacierized area have an important impact on glacier changes. In this paper, the changes in glacier area are identified, quantified and correlated with relief parameters for the period 1985–2007. Spatial analysis was performed using the GLAM-CD (Glacier Mapper – Change Detector) algorithm. The input data for this algorithm were Landsat 5 images, the Aster Global Digital Elevation and the glacier outlines from the GLIMS project (Global Land Ice Measurements from Space). Regression analyses between glacier area losses and relief-related parameters indicate a significant positive relation with the altitude and a significant negative relation with the glacier surface area. In this context, we used a correlated component regression to model these relations. The model explains >50% of the total variation.

Fluvial processes and sediment dynamics of the slope-channel system in Sinanitsa valley, the Pirin Mountains, Southwestern Bulgaria

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Sinanitsa is a U-shaped relict glacial valley on the west slope of highest part of the Pirin Mountains (above 1800 m a.s.l.) in the catchment of Vlahina River, left tributary in the Struma River's drainage system. The specific focus of this study is addressing the connection between the river channel and related slope systems.

In this current study we represent the results from slope dynamics and fluvio-morphologic processes within the period of observation, since 2013.

Coarse sediment on slopes create typical depositional landforms like talus cones, mass movement deposits and rock glaciers. In one observed site on slope coarse sediment is transferred into the river and in another two sites sediments have no connection with the channel. However, the local conditions in the Sinanitsa cirque hamper the slope-channel coupling and the coarse sediment are trapped within a subsystem. There are tree reference marks along a talus in the cirque – in the eroded, transported and accumulative zones of the talus related to the lake.

Channel geometry is analyzed on the basis of cross-sectional surveys. Between 2020 and 2066 m a.s.l. 5 cross-sections on the Sinanitsa River were surveyed. Channel cross-sections were established perpendicular to the direction of the flow and its depths were measured in every 10 cm. The main morphological features across the river valley were identified. Samples for grain-size analysis are collected from the river bottom. Variations in size of channel deposits may reveal changes in the flow regime of Sinanitsa River through time.

The studied area characterize typical for Bulgaria high altitude cold environment, where frequent fluctuations around freezing, lack of vegetation, weathering, low temperatures, seasonal freezing and thawing of regolith and soil tend to encourage particular types of geomorphological processes.

Preliminary results from field experiment using soil erosion plots in Zemen Gorge, West Bulgaria

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Struma River flows through a sequence of 12 gorges formed between the mountains of West Bulgaria. The fifth one is the Zemen Gorge, located between Konjavska and Zemenska Mountains in the southern part of Kraishte Region – a transition zone between the Balkanides belt and the Rhodopes Massif. Geomorphological and sedimentological research is taking place in this area for slope processes and fluvial dynamic since 2015.

In this particular study are presented preliminary short-term results from ongoing field experiment using soil erosion plots. Estimating the quantity of transported material from a given land area during any specific time (expressed in $g/m^2/day$) is considered to be aim of presented research. Soil erosion plots were installed at three key sites with similar environmental conditions, different degree of declivity and uniform geology. This key sites are selected based on the results form morphometric and remote sensing analysis, the representativeness of the site and the accessibility of each location. The main purpose of the plots is to collect moving downwards slope materials. Therefore the construction is consisted of two main elements – a border layout (surrounding 1 m^2) and a catch pit (a collector with depth of 0.2 m and length of 1 m covered with plastic). The plots are designed to be small, mobile and easy to maintain. The actual field measurements of the sediments in the catch pit are made at irregular intervals of time. Accumulated material are carefully removed, dried out (if needed) and then weighted. Grain size analysis is used to determine the particle size distribution in each sample. Standard statistical parameters are used along with histograms and cumulative curves to present the results. Coarser materials (pebbles and cobbles) is measured separately in order to determine shape, mean roundness and predominate transport (dragging/saltation) of the particles. Other types of field measurements was also used in addition to laboratory data to describe the geomorphic situation.

The study area characterize typical low altitude temperate environment in which geomorphologic processes are triggered by various factors. The velocity, intensity, frequency and spatial distribution of slope processes is related with the slope angle itself, inputs of precipitation and presence or absence of vegetation canopy. Soil erosion plots provide data about sediment yield of a given hillslope and changes in the topography. For this reasons, obtained data with some consideration of its accuracy can be used as a component of a sediment budget. Installed plots are significant part of monitoring network for morphological changes in – something that is very rare in Bulgaria and therefore they aim mapping and land management decisions. However more data is required in order to understand the seasonal rates of erosion and accumulation.

In search for the model of the interaction of paraglacial and periglacial processes in the Arctic coastal zone

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The coastal zone is a key interface where environmental changes impact directly on Arctic communities (Forbes *et al.*, 2011). Recent rapid warming of the Arctic atmosphere has intensified the operation of the geomorphic processes that control coastal evolution (Overduin *et al.*, 2014), causing increased degradation of permafrost (e.g. Wobus *et al.*, 2011), enhanced sediment supply from deglaciated catchments (e.g. Strzelecki *et al.*, 2015), and prolonged periods of open-water conditions and wave activity (e.g. Barnhart *et al.*, 2014). Despite the potential significance of these climate-driven processes, relatively little is known of the physical processes that control past, present and future Arctic coastal geomorphology and, according to Lantuit *et al.*, (2010), only about 1% of the Arctic coastlines have been investigated in sufficient detail to allow quantitative analysis of the processes operating on them. In this paper, we summarize the results of several coastal studies carried out by Polish and international research teams along coast of Svalbard during the last decade years. We reconstruct the recent (post-LIA) and long-term (Holocene) evolution of coasts in western, central and southern Spitsbergen to illustrate the highly variable coastal zone responses to both paraglacial and periglacial landscape transformation associated with deglaciation and intensification of periglacial processes.

Our results emphasise the role of climate changes in controlling sediment fluxes from deglaciated valleys to the coastal zone. Under intervals characterized by a warming climate, retreating local ice masses, a shortened sea-ice seasons and melting permafrost most of studied coastal systems rapidly responded to excess of freshly released sediments and experienced significant geomorphological

changes leading to development of new coastal landforms (e.g. spits) and progradation of existing forms (e.g beach-ridge plains, barriers) Our research was based on a combination of methods including aerial photogrammetric and GIS analyses, sedimentological tests of coastal deposits, isotopic dating, geophysical surveying and field-based geomorphological mapping in Billefjorden, Tempelfjorden, Bellsund and Hornsund. The approach is potentially applicable elsewhere in Svalbard and the High Arctic to address questions of RSL change and coastal zone formation chronology, and hence wider questions regarding palaeoclimate and ice load history. We discuss our new data in the context of previously published coastal evolution studies from Svalbard. The study highlights the need for a greater understanding of the controls on High Arctic coastal sediment budgets, especially given the potential for future accelerated warming and sea-level rise.

This paper is a contribution to the National Science Centre project 'Model of the interaction of paraglacial and periglacial processes in the coastal zone and their influence on the development of Arctic littoral relief' (award no. 2013/08/S/ST10/00585). Matt Strzelecki is supported by the National Science Centre Postdoctoral Fellowship and Foundation for Polish Science HOMING PLUS grant no. 2013-8/12 and START scholarship. This research is a contribution to the Palaeo-Arctic Spatial and Temporal Gateways Programme and the IAG Sediment Budgets in Cold Environments Working Group.

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The I.A.G. / A.I.G. SEDIBUD (Sediment Budgets in Cold Environments) Program (2005 – 2017): Key outcomes, products and current activities

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Amplified climate change and ecological sensitivity of polar and high-altitude cold climate environments has been highlighted as a key global environmental issue. Projected climate change in cold regions is expected to alter melt-season duration and intensity, along with the number of extreme rainfall events, total annual precipitation and the balance between snowfall and rainfall. Similarly, changes to the thermal balance are expected to reduce the extent of permafrost and seasonal ground frost and increase active layer depths. These combined effects will undoubtedly change Earth surface environments in cold regions and will alter the fluxes of sediments, solutes and nutrients. However, the absence of quantitative data and coordinated analysis to understand the sensitivity of the Earth surface environment are acute in cold regions.

The SEDIBUD (Sediment Budgets in Cold Environments) Program, building on the European Science Foundation (ESF) Network SEDIFLUX (Sedimentary Source-to-Sink Fluxes in Cold Environments, since 2004) was formed in 2005 as a new Program (Working Group) of the International Association of Geomorphologists (I.A.G. / A.I.G.) to address this key knowledge gap. SEDIBUD (2005 – 2017) has currently about 400 members worldwide and the Steering Committee of this international program is composed of eleven scientists from ten different countries.

The central research question of this global program is to:

Assess and model the contemporary sedimentary fluxes in cold climates, with emphasis on both particulate and dissolved components.

Research carried out at 56 defined SEDIBUD key test sites (selected catchment systems) varies by scientific program, logistics and available resources, but typically represent interdisciplinary collaborations of geomorphologists, hydrologists, ecologists, permafrost scientists and glaciologists with different levels of detail. SEDIBUD has developed a key set of primary research data requirements intended incorporate results from these varied projects and allow quantitative analysis

across the program. SEDIBUD key test sites provide field data on annual climatic conditions, total discharge and particulate and dissolved fluxes and yields as well as information on other relevant Earth surface processes. A number of selected key test sites are providing high-resolution data on climatic conditions, runoff and fluvial fluxes and yields, which in addition to the annual data contribute to the SEDIBUD metadata database.

To support these efforts, the SEDIFLUX manual and a set of framework papers and book chapters have been produced to establish the integrative approach and common methods and data standards. Comparable field-datasets from different SEDIBUD key test sites are analyzed and integrated to address key research questions of the SEDIBUD program as defined in the SEDIBUD working group objective. A key SEDIBUD synthesis book has been produced by the group and a synthesis key paper is currently in preparation. Detailed information on SEDIBUD activities, outcomes and published products is found at http://www.geomorph.org/sedibud-working-group/.

Integrating comparable field datasets from selected cold-climate catchment geosystems for analyzing environmental controls of contemporary solute and sedimentary fluxes in cold-climate regions

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It is generally accepted that the combined effects of ongoing and projected climate change are changing Earth surface environments in cold regions. However, the absence of quantitative field data and integrated quantitative analysis of contemporary solute and sedimentary fluxes to understand environmental controls of solute and sedimentary fluxes and the sensitivity of the Earth surface environment in cold regions is still acute.

In this contribution, results from longer-term process geomorphic work conducted in selected (i) partly glacierized and (ii) non-glacierized high-latitude and high-altitude cold climate catchment systems (defined SEDIBUD key test sites) in Iceland, Norway, Sweden and Finland are compared. The surface area of the six studied catchment geosystems ranges from 7.0 km^2 to 79.5 km^2, which allows a detailed field instrumentation and extensive geomorphic process monitoring and studies at these logistically easily accessible field sites. Contemporary chemical and mechanical fluvial denudation rates measured in these defined cold climate catchment systems with different cold climates, varying degrees of glacier coverage, different lithologies and general sediment availabilities, different catchment morphometries, and varying degrees of vegetation cover are presented. Field measurements in each catchment system included the quantification of fluvial solute, fluvial suspended sediment and fluvial bedload transport. By direct comparisons between the six different catchments environmental controls of the computed annual denudation rates are detected and the spatial variability of the contemporary chemical and mechanical fluvial denudation rates found across the different cold climate catchment systems is explained.

As a result, computed annual fluvial denudation rates generally increase with increasing topographic relief, increasing mean slope angles, increasing annual precipitation and increasing glacier coverage, and generally decrease with increasing vegetation coverage in catchment areas with

sedimentary covers. Lithology with low weathering resistance lead to higher fluvial denudation rates than lithology with high weathering resistance. General sediment availability within the catchment systems is another key factor controlling contemporary fluvial denudation rates. The contemporary denudation rates found across the different cold climate catchment geosystems are comparably low when compared with denudation rates in other climatic environments.

The presented approach of analyzing and integrating comparable field datasets on fluvial solute and sediment transport collected from different defined cold climate catchment geosystems with varying environmental conditions and characteristics is found to be useful for the quantitative analysis of environmental drivers and the spatiotemporal variability of contemporary solute and sedimentary fluxes, yields and denudation rates in cold climate environments. In addition, this approach can also serve to improve the possibilities of modeling anticipated effects of climate change by applying the Ergodic principle of space-for-time substitution.

Environmental controls, sediment sources, spatiotemporal variability and rates of fluvial sediment transport in partly glacierized mountain catchments in the fjord landscape of western Norway

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This work focuses on environmental controls, sediment sources, the spatiotemporal variability and quantitative rates of fluvial suspended sediment and fluvial bedload transport in the neighboring, partly glacierized and steep Erdalen (79.5 km^2) and Bødalen (60.1 km^2) mountain catchment systems in the fjord landscape of the inner Nordfjord in western Norway. Field work, including extended samplings and measurements, was carried out since 2004 in Erdalen and since 2008 in Bødalen. Fluvial sediment transport in the inner Nordfjord is altogether supply-limited and larger thermally and/or pluvially generated runoff events occurring mostly during the period April – November are needed to fluvially mobilize and transport significant amounts of sediments.

The distinct intra- and inter-annual temporal variability of suspended sediment transport detected is mostly controlled by meteorological events, with most suspended sediment transport occurring during pluvial events in autumn (September – November), followed by mostly thermally determined glacier melt in summer (July – August), and by mostly thermally determined snowmelt in spring (April – June). Extreme rainfall events (>70 mm d^{-1}) in autumn can trigger relevant debris-flow activity that can cause significant transfers of suspended sediments from ice-free surface areas with sedimentary covers into main stream channels and is particularly important for fluvial suspended sediment transport. In years with occurring relevant debris-flow activity the total annual drainage-basin wide suspended sediment yields are strongly determined by these single extreme events. The share of glacier coverage, followed by steepness of slopes, and degree of vegetation cover in ice-free surface areas with sedimentary covers are the main controls of the detected spatial variability of suspended sediment yields. The contemporary sediment delivery from glacierized surface areas

through different defined outlet glaciers shows a high spatial variability which is mostly explained by spatially variable availability of sediments in the lithologically homogenous areas. The fact that the mean annual suspended sediment yield of Bødalen is almost twice as high as the mean annual suspended sediment yield of Erdalen is to a large extent explained by the higher share of glacier coverage in Bødalen (38% of the total catchment surface area) as compared to Erdalen (18% of the total catchment surface area) and by an altogether significantly higher suspended sediment yield from the glacierized area of the Bødalen catchment compared to the glacierized surface area in Erdalen. When looking at the total annual mass of suspended sediments being fluvially exported from the entire Erdalen and Bødalen catchment systems, the total amount of suspended sediments coming from the ice-free catchment surface areas altogether dominates over the total amount of suspended sediments coming from the glacierized surface area of both catchments. Mean annual and drainage-basin wide contemporary suspended sediment yields range from 16.4 t $km^{-2}yr^{-1}$ for Erdalen to 31.3 t $km^{-2}yr^{-1}$ in Bødalen and are – due to the high resistance of the predominant gneisses towards glacial erosion and weathering, the altogether only small amounts of sediments being available within the entire catchment systems, the stable and nearly closed vegetation cover in ice-free surface areas with sedimentary covers and the given efficiency of proglacial lakes in trapping sediments supplied by defined outlet glaciers – altogether rather low when compared with mean annual suspended sediment yields of other partly glacierized catchment systems in Norway and in other cold climate environments worldwide. Contemporary suspended sediment transport accounts for a bit less than two-thirds of the total fluvial transport. The long-term (post 8150 cal yr BP) average suspended sediment yield as reconstructed from lake-floor stratigraphy has the same order of magnitude as the monitored contemporary rates, which indicates that the suspended sediment supply has been generally low and that the sedimentary system has been supply-limited since at least 8150 cal yr BP.

During the four-year period 2010 – 2013 detailed field measurements with portable impact sensors as a non-invasive technique for indirectly determining fluvial bedload transport intensity were conducted in Erdalen and Bødalen. The collected impact sensor field data were calibrated with laboratory flume experiments, and the data from the impact sensor field measurements and the flume

experiments were combined with field data from repeated surveys of channel morphometry and sediment texture, particle tracer measurements, Helley-Smith samplings, underwater video filming and biofilm analyses. The combination of methods and techniques applied provides insights into the temporal variability and intensity of fluvial bedload transport in selected mountain streams of both catchment systems. The conducted analysis of fluvial bedload dynamics in different defined subsystems of Erdalen and Bødalen provides information on detectable relevant sediment sources, in-stream channel storage of bedload material, spatiotemporal variability and controls of bedload transport rates and bedload yields, and the absolute and relative importance of fluvial bedload transport. Rockfalls, snow avalanches, stream channel bank erosion, and fluvial transfers through small tributaries draining slope systems with sedimentary covers/deposits are relevant sediment sources for fluvial bedload transport in the main stream channels, whereas the main outlet glaciers in both catchment systems are not of importance as all bedload material delivered directly from these outlet glaciers is efficiently trapped within the existing proglacial lakes. Snow avalanches are the most important sediment source for bedload in Erdalen, whereas fluvial transfers through small tributaries followed by snow avalanches are most important in Bødalen. Narrow valleys within both catchment systems are characterized by a higher intensity of slope-channel coupling and display higher rates of sediment supply from slopes into main stream channels than wider valleys. Longer-term in-stream channel storage of bedload material is not of great importance in the steep Bødalen catchment but currently plays an important role within the Erdalen catchment, which is characterized by a stepped longitudinal main valley bottom profile favoring deposition of bedload material within the less steep main channel reaches. The computed mean annual bedload yields (2010 – 2013) are 2.4 t $km^{-2}yr^{-1}$ for the entire Erdalen and 13.3 t $km^{-2}yr^{-1}$ for the entire Bødalen catchment, which are comparably low values for steep and partly glacierized mountain catchment systems. Because of the supply-limited conditions, the intensity of fluvial bedload transport is more related to the availability of bedload material than to channel discharge. Fluvial bedload transport accounts for about one-third of the total fluvial transport in both Erdalen and Bødalen.

Altogether, mechanical fluvial denudation dominates over chemical denudation in both glacier-connected catchment systems.

Potential effects of climate change on snow avalanche activity in western Norway

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As snow avalanche formation is mainly governed by meteorological conditions as, e.g., air temperature fluctuations, heavy precipitation and wind conditions, it is likely that the frequency and magnitude of both ordinary and extreme snow avalanche events is modified through the documented effects of current and future climate change. In the Northern Hemisphere, 1983-2013 was likely the warmest 30-year period of the last 1400 years (IPCC, 2013). Meteorological records of western Norway show the general trend that the last 100 years, especially the last three decades, have been warmer and wetter than the time periods before. However, it is not evident that snow avalanche activity will increase in the near future. Today, the number of studies assessing the impact of climate change on the occurrence and magnitude of snow avalanches is limited.

This work focuses on recent and possible future effects of climate change on snow avalanche activity along the western side of the Jostedalsbreen ice cap representing one of the areas with the highest snow avalanche activity in entire Norway. We have analyzed long-term homogenized meteorological data from five meteorological stations in different elevations above sea level, three of them with a long-term record of 120 years (1895-2015). In addition to the statistical analyses of long-term datasets, gained results and insights from a four-year (2009-2012) high-resolution snow avalanche monitoring study conducted in the same study area are incorporated. The statistical analyses of mean monthly air temperature, monthly precipitation sums and mean monthly snow depths showed that there is a trend of increasing air temperatures and precipitation sums whereas no clear trend was found for mean snow depths. Magnitude-frequency analyses conducted for three defined time intervals (120, 90, 60 years) of monthly precipitation sums exhibit an increase of precipitation especially during the last 30 years with the tendency that more precipitation is occurring in February and March. Results from the four-year monitoring study detected that the main snow avalanche peak season occurs

between March and April. In addition a high statistical correlation ($R^2 = 0.8$) between the total amount of snow accumulated over the winter months and the total number of snow avalanches occurring in spring was found.

As heavy snow fall is identified as the main triggering mechanism along the SW coast of Norway an increase in the number of days with high amounts of precipitation may lead to a generally higher snow avalanche frequency. There might be more precipitation measured as rain fall at the meteorological stations (generally located in low elevations above sea level) during the future winter periods. However, this will not necessarily reduce the current and near future snow avalanche activity as snow avalanches are triggered in higher elevations above sea level where precipitation will still occur as snow fall.

POROCO - Mechanisms controlling the geomorphology and evolution of rocky coasts in polar climate – first results from Svalbard and South Shetland Islands

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A significant limit to current understanding of cold coast evolution is the paucity of field observations regarding development of rocky coastlines and, in particular, lack of precise recognition of mechanisms controlling rock coast geomorphology in polar climates.

Therefore the principle aim of our recently funded POROCO (Polar Rock Coasts) project is to quantify the processes controlling the evolution and behaviour of rock coasts in polar climates, based on representative examples from Svalbard (Arctic) and South Shetlands (Antarctic). POROCO aims to develop predictions of future rock coast change under scenarios of continued increases in air temperature, sea-level rise and the frequency and intensity of storms entering polar seas.

Our approach utilises a rigorous, coherent and novel suite of techniques to analyse the spatially and temporally diverse range of processes and responses controlling the polar rock coast environments

- Schmidt Hammer and Equotip tests of rock surface resistance
- micro-erosion meter measurements of rock surface downwearing rates
- observations of seasonal changes in the state of permafrost developed in solid rocks using electrical resistivity tomography (ERT)
- scanning of selected cliff faces and shore platform surfaces using Terrestrial Laser Scanner (TLS)
- monitoring of thermal state of the rocky cliffs and platforms using network of thermistors
- monitoring of weather conditions and wave-activity using a system of portable weather stations, industrial cameras and tide gauges
- photogrammetric analysis of digital images of scanned cliffs and platforms and GIS processing of obtained data

In this paper we present the results of the first field campaigns of the project carried out in summer 2015 in Hornsund, SW Spitsbergen and austral summer 2016 in Admiralty Bay, South Shetland Islands that focused on:

- pilot survey of rock resistance using Schmidt Hammer Rock Tests (SHRT) and Equotip (EQ) across the modern and uplifted cliffs and

- shore platforms - pilot measurements of shore platform downwearing using the Traverse Micro-Erosion Meter (TMEM)

This lithological variability provided an excellent opportunity to examine the influence of rock resistance on the development of various coastal landforms in periglacial climate. SHRT, EQ and TMEM surveys along several morphologically different coast types demonstrated broad variety of interrelations between rock surface resistance and distance from present-day shoreline as well as thickness of sediment and snow covers. In general, rock cliff surfaces were the most resistant in their lower and middle zones which are thermally insulated by thick winter snowdrifts. Whereas the more exposed cliff tops were heavily fractured and weathered. The differences in rock resistance and downwearing rates observed along the shore platforms were highly dependent on thickness of sediment cover and shoreline configuration. These characteristics favoured stronger rock surfaces in areas exposed to the longest wave fetch, but also washing by meltwaters from decaying ice-foot. The results presented in this paper emphasize the richness of microrelief features and processes operating in polar coastal environments.

This paper is a contribution to the National Science Centre in Poland OPUS project UMO2013/11/B/ST10/00283: 'POROCO – Mechanisms controlling the evolution and geomorphology of rock coasts in polar climates'.

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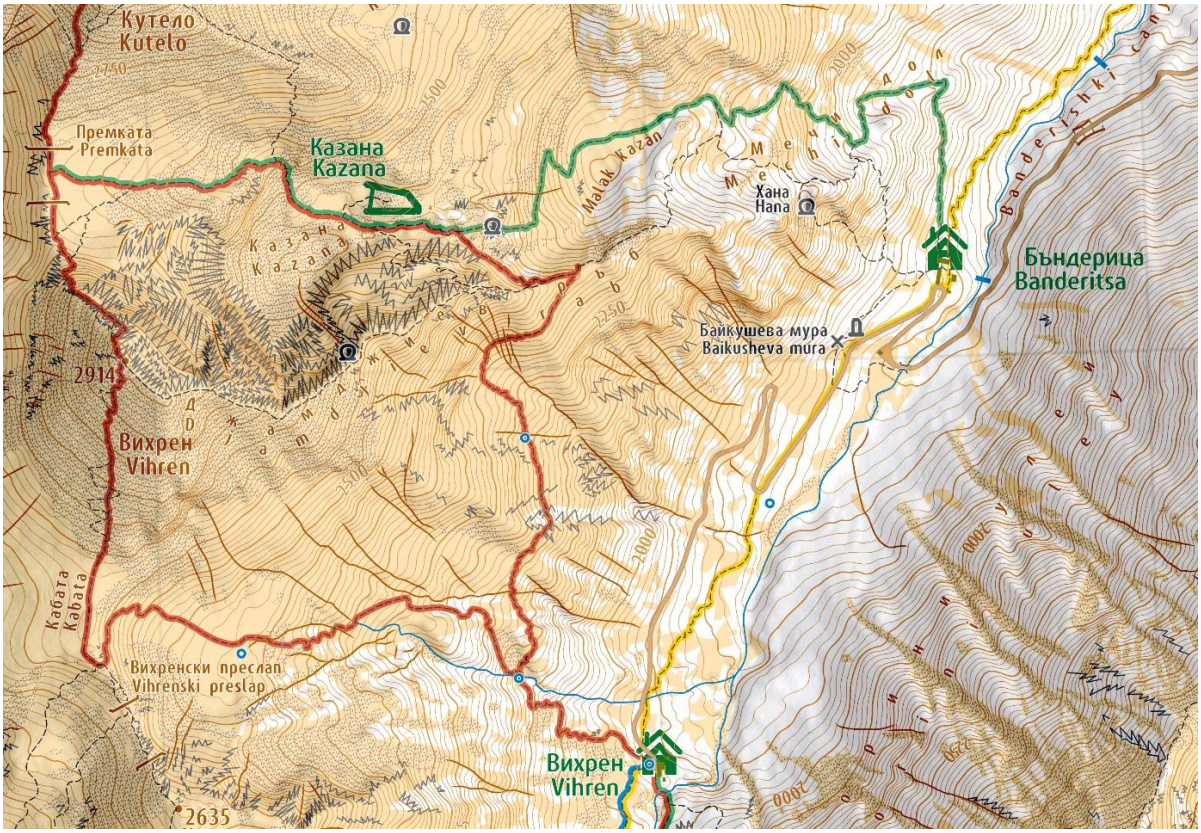
Excursion details

Bansko – Vihren hut – organized transport from the hotel

Vihren hut – Djamdjiev rab – Kazana – Malak Kazan – Mechi dol – Banderitsa hut

Banderitsa hut – Bansko – organized transport from the hotel

Map of the trekking route:



Source: http://iskartour.com/maps/pirin_north_25000/map.html