Proceedings of the

8th I.A.G./A.I.G. working group SEDIBUD

(Sediment Budgets in Cold Environments)

Workshop

"Sediment Cascades in Cold Climate Geosystems"

Zugspitze/Reintal, Bavaria/Germany, September 1-3/4, 2014

edited by David Morche, Michael Krautblatter, Achim Beylich & Tobias Heckmann

Karst plateau Zugspitzplatt (foreground) and the Reintal valley (background) (photo David Morche)

Program

01.09.2014	13:00	Eibsee to UFS cable car travel
	15:00	Welcome note by organisers and the working group Chair
	15:30	**Coffee**
	16:00	Indoor-excursion to the TUM-Permafrost monitoring site
	19:00	Dinner/Icebreaker
02.09.2014	8:00	Breakfast
	9:00	**Keynote** by Michael Krautblatter Rock slope erosion and deposition under changing climatic conditions: Lessons learnt at the Zugspitze

1. Session chaired by Achim Beylich

9:45	Ahinora Baltakova et al. Establishment of monitoring sites of seasonally frozen ground in the Pirin Mountain
10:15	Jan Blöthe et al. Residence time of large valley fills in the NW Himalayas
10:45	**Coffee**
11:15	Armelle Decaulne et al. Dating and geomorphology of the Vatn landslide, Northern Iceland
11:45	Katja Laute & Achim Beylich Controls and geomorphic importance of an extreme snow avalanche event (Bødalen)
12:15	Lunch at the Restaurant SonnAlpin/Zugspitzplatt

2. Session chaired by Jan Blöthe

14:00	Kerry Leith et al. Deglaciation and stress-induced fracture propagation on the Zugspitzplatt, SE Germany
14:30	John Dixon Contemporary solute and sedimentary fluxes in Arctic and Sub-Arctic environments -current knowledge
15:00	Achim Beylich & Katja Laute Spatiotemporal variability of fluvial bedload transport in partly glacierized drainage basin systems in the fjord landscape of western Norway
15:30	**Coffee**

3. Session chaired by Sabine Kraushaar

16:00 Eric Rascher et al.

Comparative analysis of sediment routing in two different alpine catchments

16:30 Grzegorz Rachlewicz

Annual glacial and denudation budget of two catchments in contrasting Svalbard climate conditions

17:00 **Postersession**

Waldemar Kociuba

Bedload flux changeability in the proglacial river catchment (Scott River, Svalbard SW)

Terrestrial Laser Scanning as a tool to measurement transformations of fluvial forms and processes in the Arctic environment

Mark Allan et al.

Landslides above Glaciers: Quantification of their magnitude-frequency in the European Alps using Structure from Motion photogrammetry

Adrian C. Ardelean et al.

Quantifying sediment storage within a small alpine catchment of the Făgăraș Mountains (Doamnei Valley, 3.5 km^2)

Henning Baewert et al.

Quantifying the activity of a rock slope connected to a valley glacier

Rupert Bainbridge et al.

Lost Landslides: Tracing the reworking of rock-avalanches in the Southern Alps, New Zealand

Ludwig Hilger et al.

Rock fall, avalanche and debris flow sediment transport in the upper Kaunertal catchment, Ötztal Alps, Austria

Sabine Kraushaar et al.

Supportive methods for sediment budgeting: Stable Isotopes measurements of perennial springs in the Kaunertal valley

Katja Laute & Achim Beylich

Sediment delivery from headwater slope systems and relief development in mountain valleys in western Norway

Ricardo Carrillo et al.

Hysteretic patterns of suspended sediment discharge in a glacierized Andean catchment

Martin Stocker-Waldhuber et al.

Vibroseismic investigations of a deep funnel-shaped depression at the tongue of Gepatschferner

		Achim Beylich & Katja Laute Sedimentary source-to-sink fluxes in valley-fjord systems in western Norway
	19:00	Dinner
03.09.2014	8:00	Breakfast
	9:00	Posters and for SEDIBUD-book chapter authors discussion on the SEDIBUD-book
	10:00	SEDIBUD-business meeting
	11:15	Final and workshop closing remarks
	11:30	Lunch at the Restaurant SonnAlpin/Zugspitzplatt
	13:00	Excursion Zugspitzplatt to Reintalangerhütte
	19:00	Dinner at Reintalangerhütte
04.09.2014	7:00	Breakfast
	8:00	Excursion Reintalangerhütte (km 0) to Garmisch-Partenkirchen (km 16) with lunch at the Bockhütte (km 5) with the famous Partnach gorge as final highlight (km 14-15), possible transportation by car for max. 16 people from km 7 to Garmisch-Partenkirchen

Rock slope erosion and deposition under changing climatic conditions: Lessons learnt at the Zugspitze

Keynote

Michael Krautblatter, Philip Mamot, Riccardo Scandroglio

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The Zugspitze is the enigmatic highest peak of Germany above the deeply carved out and densely populated Garmisch Basin. While its name refers to its avalanche activity, the unusual Holocene and present-day activity of rockfall and rock slope failures have contributed enormously to the appearance of the Wetterstein Mountains and the Garmisch Basin and reflect that rockfall is a major natural hazard, as Walther Penck already exemplified in 1912. Intense research in the last decade has revealed interesting new evidence with regard to its (i) elevated rockfall production, (ii) the permafrost influence on rock instability and (iii) highly mobilised rock avalanche deposition patterns.

(i) Elevated rockfall activity with regard to all magnitudes spanning from fragmental debris falls (<10 m³) to multiple modern bergsturz (>1 mio. m³) deposits in the last 500 years have been intensively monitored in the Wetterstein mountains and their activity exceeds previous inventories even from the Himalayas (Krautblatter et al. 2012). There are still multiple hypotheses what drives this enormous rockfall activity but it is likely the tectonic disposition to steep smooth overthrust faults, enormous topographically induced stresses and special mechanical properties of Wetterstein limestone are important factors.

(ii) There is a long history of permafrost-related stability and water inundation problems at the Zugspitze starting with the construction of the cog-wheel train tunnel in the 1930s. In the last two years, we have systematically analysed the mechanical behaviour of frozen and thawed Wetterstein Limestone in terms of compressive and tensile strength, elastic properties, p- and s-wave propagation and electrical properties. Through this and detailed field observations we start to understand how thawing affects the mechanical rock/ice mass behaviour (Krautblatter et al. 2013) and how man made constructions and rockfalls interfere with degrading permafrost.

(iii) The most prominent evidence of rock slope failure is the Eibsee rock avalanche (0.3 km³). However, the complexity evident in this particular rock avalanche deposit has been

poorly addressed. Up to 800 m long longitudinal and transverse ridges indicate, according to recent findings on granular models, zones of massive compressive and extensional regimes during the runout of the rock avalanche. It appears that the rock avalanche has been separated in a highly mobile half with a high runup on the opposite and a long runout and a much less mobile second half. We have checked different sources of evidence for a Paleo-Eibsee that could have acted to lubricate and fluidise the highly-mobile portion of the rock avalanche (mechanical overview: Pudasaini and Krautblatter, subm.). Here we also present unpublished data of altogether more than 4 km of geophysics in the Eibsee deposits and the outcome of multiple mapping projects.

This talk follows the assumed path of the Eibsee rock avalanche 3700 years ago and highlights research challenges in detachment, potential permafrost preconditioning and triggering and complex deposition due to a partly fluidised/lubricated rock avalanche.

Penck W. 1912: Naturgewalten im Hochgebirge. Strecker & Schröder Verlag.

Krautblatter, M., Moser, M., Schrott, L., Wolf, J. and Morche, D. 2012: Significance of rockfall magnitude and solute transport for rock slope erosion and geomorphic work in an Alpine trough valley (Reintal, German Alps).. *Geomorphology*. 167-168, 31-44. DOI:10.1016/j.geomorph.2012.04.007

Krautblatter M., Funk D. & Günzel F. K. 2013: Why permafrost rocks become unstable: a rock-ice-mechanical model in time and space" *Earth Surface Processes and Landforms. 38*, Issue 8, 876-887

Pudasaini, S. and Krautblatter M. submitted : A two-phase mechanical model for rock-ice avalanches. Journal of Geophyiscal Research – Earth Surface.

Establishment of monitoring sites of seasonally frozen ground in the Pirin Mountain

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The climatic studies in the Pirin Mt. in SW Bulgaria up to now concern broader territories and characterize only air temperature and precipitation. Because of our interest in the highest mountains in Bulgaria, in 2011-2012 we have installed three soil surface thermometers in the Golyam Kazan cirque (North Pirin, eastern exposition) and Sinanitsa cirque (North Pirin, western exposition). Our microclimatic and parallel geomorphologic studies ascertained sites with seasonally frozen ground above 2200 m a.s.l.

Seasonally frozen ground in non-permafrost environment, with its altitude, longitude, depth and duration, is of great importance for studying the global warming effect in the high mountain areas. This is the reason for us to start a non-limited by time program for studying the seasonally frozen ground in the Pirin Mt. with the following actions:

- Localizing the range of the seasonally frozen ground on slopes with different exposition.
- Observation of processes related to frost action (gelifluction, creep, frost shattering,cryoturbation etc.).
- Remote sensing analysis of the area above the treeline by using satellite and orthophoto images and starting of detailed geomorphological mapping.

Because of our previous observations and data, we decided to concentrate our studies in the summer of 2014 in the following three sites:

1. Golyam Kazan cirque - 41°46', 23°24', 2428-2461 m, area: 0.5 km^2, period of monitoring – since November 2011 to now,
2. Sinanitsa cirque - 41°43', 23°21', 2209 m, area: 0.4 km^2, period of monitoring – since October, 2012 to nowand
3. Begovitsa valley and cirque, at altitude about 2200-2240 m, since the summer of 2014.

These three sites cover a high altitude area with present intensive weathering and snow action and also relict glacial forms. Our study program is related with two finished scientific projects. It provides good possibilities for stationary studies for field observations for years ahead and opportunities to be involved in bigger projects and researches.

Residence time of large valley fills in the NW Himalayas

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Intermediate sediment storage in large valley fills modulates bedrock incision, decouples rivers from adjacent hillslopes and buffers and/or enhances sediment fluxes. Despite their crucial role in a sediment budget, the magnitude and longevity of intermittent sediment storage remains largely unclear in large drainage basins, such as the Indus, Ganges and Brahmaputra basins that drain the Himalayas. Along the Tibetan plateau margin, however, broad alluviated valleys host large sedimentary fills, potentially buffering sediment delivery through the system.

We assess the sedimentary volumes stored in valley fills and their residence times within the fluvial system grounding on two different approaches: First, we combine Optically Stimulated Luminescence and ^{10}Be surface exposure dating techniques to obtain absolute ages for fluvial terraces in the arid Transhimlayan region of Zanskar and Ladakh, NW India. Second, we use a probabilistic volume-area scaling approach to estimate the volumes stored in valley fills that we mapped from DEM data along the entire Himalayan arc. Assuming constant aggradation and evacuation rates, we convert these volumes to residence times.

Our results reveal a striking pattern of sediment storage along the Himalayan arc with the majority of sedimentary bodies located in the Western and Eastern Himalayas, leaving the central Himalayas nearly devoid of any intermontane valley fills. We derived median residence times between ~3 and ~32 kyr for Himalayan valley fills, though individual fills may persist for >100 kyr. This is in good agreement with absolute ages of fluvial terraces in the NW Himalayas that show ages between 20 and 50 ka for terrace flights stranded ~30 m above current river level and ages of >200 kyr for larger and higher terraces. Finally, we estimate the total volume of sediment stored in Himalayan valley fills to be ~690 km^3, sufficient to sustain modern erosion rates for several millennia, if fluxes were only sourced from stored material.

Dating and geomorphology of the Vatn landslide and direct vicinity, Northern Iceland

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The Vatn landslide is located in the Skagafjördur fjord, northern Iceland (65°57,337'N, 19°23,900'W). The slide deposit exhibits a short spatial dispersion and longitudinal runout.By examining stratigraphic sections along the ditch, and opening log sections on the flat area at the slide contact and onto the slide deposit, numerous dating elements were obtained. The lower pits are rich in organic material and tephra layers (the oldest one, H4, is dated to 3,826±12 cal. yr BP), while the upper pit revealed little accumulation over the slide deposit surface, exhibiting only tephra layers separated by poor organic units.The combination of radiometric method and geochemical analysis of the tephra layers results in a good time constrain for the landslide occurrence, before 9070±86 cal. BP and 8677±181 cal. BP (oldest tree remnants) and after the deposition of the Saksunarvatn tephra (10,200 BP).

Such a result reinforces the hypothesis of a major paraglacial geomorphologic activity at the early Holocene time, leading to numerous slope failures following the last glacial maximum retreat. The presence of the raised beach at the lower contact with the landslide seems to indicate an occurrence later than 11,000-11,400 cal BP (interpolated age of the raised beaches located at 22-31 masl).

Controls and geomorphic importance of an extreme snow avalanche event (Bødalen)

Katja Laute, Achim A. Beylich

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During the winter-spring period 2011/2012 an extreme snow avalanche occurred within the upper valley part of a steep and glacier-connected mountain catchment (Bødalen) in western Norway. Compared to annually occurring snow avalanches, so-called "extreme snow avalanche events" are more difficult to monitor and to study as they are characterized by recurrence intervals often longer than a decade.

Morphometric and meteorological controls of the observed snow avalanche event, its geomorphic effects as well as its related relative role in mass transport as compared to the annually monitored snow avalanche activity within the Bødalen catchment were explored. Maximum values of snow height, velocity and pressure were predicted by applying a numerical run-out simulation. The formation of this snow avalanche resulted from the combination of extraordinary meteorological conditions and a favorable morphometric setting of the source area. The snow avalanche path covered a total distance of 2900 m. Within the run-out zone a total debris mass of 460 t was remobilized and transported further down-valley by this avalanche event. Compared to annually occurring snow avalanches within the Bødalen drainage basin the relative importance of extreme-sized snow avalanches is comparably low with respect to direct erosion and sediment transfer along rockwalls. However, extreme-sized snow avalanches play a significant role with respect to the remobilization of debris/sediment as well as to sediment transport down-valley including recognizable transfers of debris into the main stream channels of the drainage basin system.

The obtained results point out that this kind of extreme events must be considered within studies of drainage basin sedimentary budgets.

Deglaciation and stress-induced fracture propagation on the Zugspitzplatt, SE Germany

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Rates of sediment production in alpine regions are regulated by rates of chemical weathering and fracture propagation in near-surface bedrock. These, in turn, reflect the interaction of environmental stresses derived from chemical and mechanical processes as bedrock is exhumed through the crust and exposed to the atmosphere. While pure chemical and mechanical processes have long been recognized as effective contributors to sediment production in calcareous bedrock (such as that which dominates the Zugspitzplatt and Reintal region of SE Germany), insights from materials science and fracture mechanics suggest stress corrosion driven by a combination of the two factors may play an even more important role.

Stress corrosion refers to the chemical degradation of atomic bonds under tensile loading. It allows materials to fail at constant load under stresses significantly less than the instantaneous material strength. Although this is given secondary consideration in engineering applications, where the environment is controlled and component lifetime is relatively short, this effect may accelerate fracture propagation in in natural bedrock environments where ever stresses are predominantly tensile and chemistry is favorable.

By carefully assessing bedrock stress changes in association with repeated glaciation and deglaciation around the Zugspitzplatt, we are able to identify regions of both active fracture formation during deglaciation, and enhanced tensile stresses in present-day rock slopes. We find a promising correlation between model results and large-scale fractures in the field, and present preliminary results from laboratory tests quantifying rates of stress corrosion in Carrara Marble specimens. Together, these results provide new insight into bedrock fracture and sediment production in this region, and we expect they will allow us to better predict the response of alpine rock slopes to changes in the chemistry and temperature of precipitation as a result of future climate change.

Contemporary solute and sedimentary fluxes in Arctic and Sub-Arctic environments - current knowledge

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Historically, cold climate landscapes have been viewed as homogeneous environments where their typically low annual average temperatures and long periods of snow and/or ice cover preclude substantial amounts of sediment and solute transport.

Since the late 1950s however this perspective has been slowly changing as comprehensive sediment budget studies began in a diversity of cold climate environments.

This paper examines our current knowledge about sediment and solute fluxes in Arctic and sub-Arctic environments. There is great geomorphic diversity within and between these environments and sediment and solute fluxes display considerable variability. At the drainage basin scale the relative importance of transport processes is strongly influenced by the extent of glacierization.

This paper is primarily based on the contributions to our understanding of these environments from the International Association of Geomorphologists' working Group on Sediment Budgets in Cold Climates (SEDIBUD).

Spatiotemporal variability of fluvial bedload transport in partly glacierized drainage basin systems in the fjord landscape of western Norway

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This study of fluvial bedload dynamics in different defined subsystems of the partly glacierized Erdalen (79.5 km^2) and Bødalen (60.1 km^2) drainage basins in the steep fjord landscape of western Norway provides insights into

(i) relevant sediment sources,

(ii) in-stream channel storage of bedload material,

(iii) the spatiotemporal variability and controls of bedload transport rates and bedload yields, and

(iv) the absolute and relative importance of fluvial bedload transport within the sedimentary budgets of theses steep cold climate mountain drainage basins.

Rockfalls, snow avalanches, stream channel bank erosion and fluvial transfers through small tributaries draining slope systems are relevant sediment sources for fluvial bedload transport whereas the main outlet glaciers in both drainage basins are not of importance as all bedload material delivered directly from these outlet glaciers is trapped in proglacial lakes.

Narrow valleys within both Erdalen and Bødalen display higher rates of sediment supply from slopes into main stream channels than wider valleys. Snow avalanches are the most important sediment source for fluvial bedload transport in Erdalen whereas fluvial transfers through small tributaries, followed by snow avalanches are most important in Bødalen. Longer-term in-stream channel storage of bedload material is not of great importance in the very steep Bødalen drainage basin but plays currently an important role within the Erdalen drainage basin which is characterized by a stepped longitudinal main valley bottom profile favoring the deposition of bedload material.

The mean annual bedload yields (2010 – 2013) are 2.4 t $km^{-2}yr^{-1}$ for entire Erdalen and 13.3 t $km^{-2}yr^{-1}$ for the entire Bødalen drainage basin which are comparably low values for steep and partly glacierized drainage basin systems. Due to supply-limited conditions the intensity of bedload transport is much more related to the availability of sediments than to channel discharge.

Comparative analysis of sediment routing in two different alpine catchments

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Sediment routing and sediment connectivity are key features to explain and predict sediment yields of arctic and alpine catchments. We applied a semi-quantitative modelling approach using the index of connectivity (IC) introduced by Borselli et al. (2008) and Cavalli et al. (2013) which relates upslope contributing areas to a gradient-weighted downslope flow length, and combined the model with maps of erodible sediment sources.

The aim was to display and quantify connectivity parameters of the catchments as a baseline for further research on quantitative sediment budgets. The areas of investigation are to two typical, non-glaciated alpine catchments in the eastern Austrian Alps (Schöttlbach, crystalline bedrock and Johnsbach, calcareous bedrock) with an area of approximately 70 km² each.

Numerous anthropogenic features, mainly forestry roads, led to unrealistic flowpaths when the original ALS-derives DEMs were used. To achieve a more realistic model, a 'near-natural DEM' was first created by masking out anthropogenic features and in a next step, a 'valley DEM' was designed in which the forestry roads were supplemented by simulated stormwater infrastructure to ensure water and sediment flow at the junctions of roads and channels.

The results show that the 'valley DEM' mirrors the actual conditions quite well and is necessary to calculate realistic flowpaths. The elongated Schöttlbach catchment exhibits larger areas of low or very low connectivity to the outlet than the Johnsbach catchment. At the Johnsbach, more areas of active erosion are present (6 % of the area compared to 3 % at the Schöttlbach).

The erodible sediments in the remote high-alpine areas are poorly coupled to the catchment outlet in both areas. Coupling of erodible sediments to the main creeks is mainly achieved close to the thalweg, by means of loose glacigenic sediments in the lower reaches of the Schöttlbach and large lobes of dolomite debris along the Johnsbach.

Landslides above Glaciers: Quantification of their magnitude-frequency in the European Alps using Structure from Motion photogrammetry

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The interactions between glacial and slope processes reflect an important but poorly understood response of alpine landscapes to climatic change. The thinning and retreating of glacial ice exposes an environment that is particularly susceptible to rapid geomorphological change such as landsliding. Advances in computer vision technology and processing capabilities have heralded a new age in three dimensional modeling of landscapes using relatively low-cost equipment, and have been shown to yield results of comparable accuracy and resolution to that of established survey techniques. The magnitude-frequency of landslides above and around wasting glaciers requires better quantification in order to develop a greater understanding of paraglacial slope adjustment.

This research aims to quantify the magnitude-frequency of landslides through surveying and modeling a number of glacial valley slopes with repeat surveys over periods of months and years, with particular focus upon the glaciers of the Mont Blanc Massif using structure from motion photogrammetry (SfM). The research will also allow a quantitative assessment of the resolution and accuracy of the SfM process which holds the potential for rapid and inexpensive 3D surveying within geomorphological studies with unprecedented ease of use.

In order to examine the spatial and temporal distribution of landslide activity, image sequences with suitable overlap for the SfM process were collected using a combination of terrestrial and aerial surveys with the use of an unmanned aerial vehicle (UAV) and a helicopter. Repeat surveys, capturing the same slopes will be used to detect change through differencing. Natural features and pre-laid targets are used as ground control points (GCPs) and referenced using a DPGS system so that the models can be placed into a real-world space.

Quantifying sediment storage within a small alpine catchment of the Făgăraș Mountains (Doamnei Valley, 3.5 km^2)

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Sediment budget analysis by means of sediment storage quantification represents an essential step in establishing postglacial evolution within the alpine environment. There is currently no data available on sediment volumes for the Romanian Carpathians, thus the present study offers preliminary data of the first approach of quantifying sediment volumes within a micro scale alpine catchment of the Făgăraș Mountains (Doamnei Valley, 3,5 km^2).

The alpine sediment flux system was analyzed with respect to the individual composing sediment storage landforms. Talus slopes (sheets and cones) were found to be the dominant landforms within the investigated area, followed by moraine deposits. Landform thickness was individually investigated, for several landforms, by GPR and ERT measurements. Cross validation results have pointed out similar results in bedrock depth detection, for the different investigation techniques utilized, thus for a better coverage and acquisition speed GPR investigations were considered sufficient for the remaining landforms (>50 profiles).

A sharp reflector was identified in all GPR profiles and interpreted as the debris/bedrock boundary, thus sediment thickness has been estimated to range from less than 6 m, at around 1600 m.a.s.l. to 15-20 m within the rock glacier situated in the upper hanging Pietroasa Valley (>2100 m.a.s.l.). Estimation of the sediment volume was performed by combining in field measurement with specific GIS modeling techniques of DEM data. The calculated mean sediment thickness was 5m within the investigated area, corresponding to an overall sediment volume of approximately 0.015 km^3.

Sediment budget analysis includes an important number of assumptions and various sources of errors, thus the preliminary results presented in the current paper may be subjected to future changes determined by a better understanding of the overall processes governing the alpine sediment flux cascading system.

Quantifying the activity of a rock slope connected to a valley glacier

Henning Baewert[1], Lucas Vehling[2], Philipp Glira[3], Martin Stocker-Waldhuber[4], David Morche[1,5]

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In mountainous catchments, rockfall is a commonly occurring geomorphic process transporting debris downslope. The dislodged portions of the rock wall can travel down slope by falling, toppling, rolling, bouncing or sliding. The rockfall debris is deposited at the foot of the rock walls, where talus cones and sheets develop. Furthermore, the ongoing glacier retreat has strong influence on the rock slope stability in alpine regions. Due to oversteepening by glacial erosion, cold climate weathering processes and debuttressing as a consequence of stress redistribution, rock slopes adjacent to shrinking glaciers generally show an enhanced geotechnical activity. Regarding the glacier sediment budget, the rockfall material deposited on a glacier is particular important, because the debris material can be transported directly and without any intermediate storage. Therefore, gravitational mass movements contribute in a substantial way to the sediment budget of a glacier.

This study tries to quantify the rock slope activity of the “Schwarze Wand”. This rock wall is located at 2400 – 2800 m.a.s.l., right above the tongue of the Gepatschferner, Tyrol (Austria) which contemporarily is affected by a high retreat rate. The rock mass consists of strong foliated paragneisses which are dissected by large joint sets. These joint sets provide sliding planes, which favor slope failures. To investigate the rock slope activity, multitemporal terrestrial laser scans were carried out in 2012 and 2013. Additionally, multitemporal airborne laserscanning data (10 points/m²) were used to trace larger scale rock slope deformations.

The investigation is part of the DFG- joint research project PROSA (High-resolution measurements of morphodynamics in rapidly changing PROglacial Systems of the Alps). The laserscanning data, as well as field observations, show enhanced rock fall activity at the scarp in the last years. This is assumed to be a consequence of an activation of a larger deep-seated gravitational slope deformation towards the glacier, which comprises at least several 100 Mio. m³.

Lost Landslides: Fluvial reworking of rock-avalanches in the Southern Alps, New Zealand

Rupert Bainbridge, Stuart Dunning, John Woodward

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Current research does not present true magnitude-frequency relationships of rock-avalanches. Many events are censored from the record through erosional reworking (signal shredding) or burial, leaving little obvious evidence of the original deposit. Censoring of rock-avalanches needs to be better quantified in order to develop a better representation of large-scale events in the geomorphological record, and their relative importance as compared to more frequent, smaller events.

In order to quantify the erosional censoring of rock-avalanche sediment in river systems, in the Southern Alps of New Zealand, this research aims to trace rock-avalanche 'agglomerates' through the fluvial system. Agglomerates are fine grained particles composed of smaller sub-micron particles, unique to rock-avalanches. The ability to trace agglomerates through fluvial systems would provide a diagnostic test for the detection of previously undetectable deposits.

In order to examine if agglomerates persist through fluvial transport and depositional processes, fine-grained sediment samples were collected from two rock-avalanche affected rivers and >20 rivers with no known rock-avalanche activity, in the Southern Alps.

Samples for the two rock avalanche affected rivers were collected in transects downstream from source deposits and through terrace sequences in order to examine the spatial and temporal distribution of agglomerates throughout each river system. One sample per river was collected for systems with no known rock-avalanche activity to assess whether rock-avalanche agglomerates are present.

Samples are examined on a stereomicroscope to look for evidence of agglomerate particles before being examined via scanning-electron microscopy to look at detailed internal and external grain morphology.

Sedimentary source-to-sink fluxes in valley-fjord systems in western Norway

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This study has been carried out since 2004 in two selected valley-fjord systems (Erdalen and Bødalen) in Nordfjord, western Norway. Detailed and longer-term monitoring of relevant denudational surface processes in the Erdalen and Bødalen drainage basins has provided high-resolution data for analyzing and quantifying contemporary solute and sedimentary fluxes as well as sediment sources, denudation rates, and meteorological and topographical / landscape morphometric controls of denudational surface processes.

Proglacial lakes are functioning as significant sediment traps within both drainage basins and the volume and composition of lake sediments have been studied by using echo-sounder, georadar and different sediment coring techniques. Investigations on volumes and architecture of major storage elements (talus cones, valley infills, deltas at the outlets of Erdalen and Bødalen) using different geophysical methods like georadar and seismic refraction surveys have been carried out to get quantitative knowledge on Holocene process rates and sedimentary budgets. Detailed geomorphological mapping has been conducted and interpreted in combination with slope and valley morphometric analyses and digital elevation models and data.

It is found that the U-shaped valley morphometry is the main control of the spatial organization of Holocene to contemporary denudational surface processes in the Erdalen and Bødalen drainage basin systems. In Erdalen, the more clearly defined stepped longitudinal valley bottom profile combined with a greater main valley width have resulted in larger storage (larger volumes of valley infill and talus cones) and in a lower level of slope-channel coupling as compared to Bødalen. Mechanical denudation dominates over chemical denudation in both glacier-connected drainage basins.

Compared to surface process rates in other cold climate drainage basins worldwide the contemporary rates found for Erdalen and Bødalen are moderate to low. Sediment transport in both drainage basins is currently supply-limited.

Hysteretic patterns of suspended sediment discharge in a glacierized Andean catchment

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Sediment transport during flood events often reveals hysteretic patterns. Hysteresis can be clockwise (when flow discharge peaks after the peak of bedload) or counterclockwise (when flow discharge peaks before the peak of bedload), and recent indexes have been developed in order to quantify the degree of hysteretic patterns.

Hysteresis patterns and degree can be used to infer the dynamics of sediment availability, as counterclockwise and clockwise hysteresis have been interpreted as representative of limited and unlimited sediment supply conditions, respectively.

This work focuses on the temporal variability of suspended sediment transport measured in the Estero Morales, a 27 km^2 Andean catchment located in central Chile. The elevations range from 1850 m a.s.l to 3815 m a.s.l., and the basin host glaciers with a current extent of 1.8 km^2.

Runoff is dominated by snowmelt in late spring, and glacier melt from December to March. Liquid discharge and turbidity have been measured continuously from October 2013 to March 2014.

The analysis of hysteretic loops of daily discharge fluctuations of spring and summer shows that patterns are mostly clockwise during snowmelt and early glacier melt period, and counterclockwise during late glacier melting, revealing a reduction of sediment supply conditions overtime. This is confirmed by the analysis of regressions between liquid discharge and turbidity, revealing that a higher discharge is progressively needed to transport the same concentration of suspended sediments as the glacier melting season progress.

These evidences indicate that suspended sediment transport in glacierized basins is affected by complex interactions among runoff generation, and sediment availability, and that the analysis of temporal hysteresis can help inferring the activity of sediment sources at the basin scale.

Rock fall, avalanche and debris flow sediment transport in the upper Kaunertal catchment, Ötztal Alps, Austria

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The estimation of catchment-scale sediment transport by hillslope processes like avalanches, debris flows and rock fall relies on the regionalisation of local measurements. Here, we show the framework for a regionalisation of the mentioned three processes by the example of a case study in the Upper Kaunertal, Austrian Central Alps (62.5 km^2).

Rockfall deposition was measured during 12 months onto six collector nets within the study area. These measurements were combined with published mean annual rates from the literature, and a PDF was fitted to these data. A numerical model involving a random walk routing scheme and a one-parameter friction model was used to simulate rockfall trajectories, starting from potential rockfall source areas that were delineated from a digital elevation model. Rockfall rates sampled from the fitted PDF were assigned to these trajectories in order to model the spatial distribution and to estimate the amount of rockfall deposition. Graph theory and a detailed geomorphological map made it possible to quantify and localize rock fall debris transport from sources to different types of landforms.

Sediment transport by debris flows can be quantified using multi-temporal high-resolution DEMs („the so-called morphological method“). For this purpose, both airborne LiDAR data from three different surveys and georeferenced terrestiral LiDAR data can be utilized (2006 - 2012). Pre-event surface reconstruction is used to estimate the magnitude of each debris flow event. Multi-volume orthophotos (generated for 8 different flight years between 1953 and 2006) can be used to determine the planimetric area of debris flow events. An empirical area-volume relationship can then be used to quantify debris flow events before 2006.

Sediment transport by avalanches was determined by mapping full-depth avalanche deposits in the field in early 2013 and 2014. Heterogenous sediment cover was classified into five classes. The spatial distribution of these classes was mapped for each full-depth avalanche and debris on multiple test plots of each sediment class were collected from different avalanches. The sediment from the test plots was quantified in the laboratory and mean sediment masses for each sediment class were combined with the mapping results to arrive at estimates for the whole catchment.

Bedload flux changeability in the proglacial river catchment (Scott River, Svalbard SW).

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The article presents results of measurements of bedload flux, performed during the mine part of ablation seasons 2012/2013, in the proglacial gravel-bed river catchment (Scott River, Svalbard). The study revealed temporal and spatial variability of bedload flux in two cross-sections located in the lower course of the river.

Bedload flux was measured by means of a set of original River Bedload Traps (RBT) constructed by the author. A total of 487 samples of transported bedload were collected during 77 measurement days.

The mean daily bedload transport rate was varied from 0.0 to 169.4 kg m^{-1} day^{-1} at individual measurement sites. Channel-mean bedload transport rate (q_a) amounted from 4.8 to 20.4 kg m^{-1} day^{-1}, and the mean value at individual sites varied from 0.05 to 47.1 kg m^{-1} day^{-1}. In the periods analysed, in the cross-profile closing the Scott River catchment at the river's mouth, the river discharged a total of approx. 1806 (2012) and 2571 (2013) kg of bedload, with mean daily (Q_b) of approx. 187 and 248 kg day^{-1}, respectively.

The mass of bedload and rate of transport were dependent on hydrodynamic terms and stream regime, directly related to weather conditions. Also the effect of Scott Glacier retreat on discharge rate was emphasised, along with the indicative character of bedload flux. It responds to changes in the rate and magnitude of processes in a glacial catchment quite rapidly, and therefore can be treated as a good indicator of transformations occurring in the arctic zone.

The study was conducted in the scope of the 24th and 25th Polar Expeditions of the Marie Curie-Skłodowska University in Lublin to Spitsbergen, implementing grant of the National Science Centre "Mechanisms of fluvial transport and delivery of sediment to the Arctic river channels with different hydrologic regime (SW Spitsbergen)" No. 2011/01/B/ST10/06996. The paper was prepared in the scope of promotion of the project POIG.01.03.02-00-082/10 "Providing European patent protection for the device for measuring bedload transport in river beds" implemented by MCSU in Lublin.

Terrestrial Laser Scanning as a tool to measurement transformations of fluvial forms and processes in the Arctic environment

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The paper presents an example of application of the Terrestrial Laser Scanning (TLS) technology aiming at obtaining information on the structure and geometry of fluvial forms and processes shaping a postglacial gravel-bed river valley. The TLS technology has the potential to entirely replace traditional topographic measurement techniques. In order to evidence the usefulness of its application as a universal tool providing data for analysis of forms at various spatial scales, experimental field research in the Scott River catchment was carried out by means of a Leica Scan Station C10.

The case study constituted a glacial catchment typical of the Arctic morphoclimatic zone, located in the NW part of the Wedel-Jarlsberg Land (Spitsbergen, Svalbard). A complex inventory of the river-mouth zone of the valley was carried out from 9 (2010) and 11 (2013) measurement sites interrelated by 7/11 common target points. At each of the sites, a co-called 3D scan was performed resulting in a cloud of up to 19 (2010) and 19/5 (2013) M pt. Merging individual "model spaces" allowed for obtaining both a Digital Surface Model (DSM) and a spherical photography of the scanned area.

The resulting space in the form of a cloud of approx. 400 M pt was used to create a DSM of the river-mouth alluvial fan with a length of over 0.5 km and width of up to 0.4 km. The 3D accuracy (±9 mm) of the model obtained allowed for precise identification of the geometry and orientation of the valley floor forms, supply sources, and paths of load transport into the river bed, as well as identification and inventory of permanent, seasonal, and ephemeral valley and channel forms. It constituted material for comparison with results of earlier studies conducted with the application of traditional techniques of geodesy.

The study was conducted in the scope of the statutory research of FESSM MCSU "Contemporary transformation of the Spitsbergen fluvial systems" and grant of the National Science Centre "Mechanisms of fluvial transport and delivery of sediment to the Arctic river channels with different hydrologic regime (SW Spitsbergen)" No. 2011/01/B/ST10/06996.

Supportive Methods for sediment budgeting: Stable Isotopes measurements of perennial springs in the Kaunertal valley

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Sediment budgets are used to estimate sediment flux in a catchment and thus, allow identifying sediment sources necessary to manage. This is of special relevance to catchments of high morphological activity as it is the case in the alpine regions. Here the global earth warming cause the quick retreat of glaciers, leaving easily erodible sediments (e.g. lateral moraines) on steep slopes uncovered and unprotected against the high amounts of precipitation in the region.

In the PROSA project sediment fluxes are measured in the Kaunertal valley on these lateral moraines using high resolution terrestrial laser scanning (TLS) technology apart from suspended- and bed load measurements in the Fagge river. With the TLS method negative volume changes on the slopes are detected and erosion processes as responsible causes assumed.

However, the detection of perennial springs from these moraines foster the assumption that their origin might be also of melting dead ice in the moraines and not exclusively connected to runoff and interflow caused by precipitation. Melting ice would lead to a volume reduction of 9-13% and therefore account for a significant part of the measured volume reduction. In this regard, this study aims to identify the origins of the springs with the help of stable isotope measurement of deuterium and O18. Samples were taken in summer 2013 and 2014 and are supported by monthly averages of 30 years continuous isotopic measurements in similar altitude in the Alps by the Global Network for Isotopes in Precipitation.

First results of this work in progress indicate that a few springs show isotopic characterization similar to that of the glacier ice and thus are assumed to be of dead ice origin. This way delivering a potential alternative argumentation for measured volume reduction, especially when the correlate sediment volume is missing downstream.

Sediment delivery from headwater slope systems and relief development in mountain valleys in western Norway

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This study deals with the quantitative analysis of denudational slope processes and relief development in selected mountain valleys in western Norway from the end of the LGM until today. Particular attention is given to

(i) the complexity of hillslope development since the LGM in glacially formed valleys and

(ii) the assessment of the controls, rates and spatial-temporal variability of relevant denudational slope processes operating under Holocene to contemporary environmental conditions in western Norway.

Five years of process-based geomorphic research (2009 -2013) were conducted in two steep, parabolic-shaped and glacier-connected neighbouring drainage basins, Erdalen (79.5 km^2) and Bødalen (60.1 km^2), located on the western side of the Jostedalsbreen ice cap in western Norway. Distinct differences are found between single headwater systems of the Erdalen and Bødalen drainage basins

(i) regarding the absolute and relative importance of different contemporary slope processes as well as

(ii) with respect to the importance of sediment delivery from headwater systems for the sedimentary budgets of the entire drainage basin systems.

The detected differences are seen as a direct consequence of the varying glacially inherited valley morphometries which determine hillslope storage capacity, the average process transport distances and the intensity of hillslope-channel coupling. A comparison to geomorphic process rates published for other cold climate environments situated at high latitudes of the northern hemisphere permits the statement that the general intensity of present-day denudational processes in Erdalen and Bødalen is in a comparable range of magnitude. Even though denudational slope processes are leading to an ongoing valley widening the Holocene modification of the inherited glacial relief until today is regarded to be minor.

The results from the two selected typical drainage basins are considered to be representative on a regional scale for the mountainous fjord landscape in western Norway.

Vibroseismic investigations of a deep funnel-shaped depression at the tongue of Gepatschferner

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Funnel shaped surface depressions are widely spread and occur on different types of glaciers. The processes behind those depressions vary as much as their size and temporal development. Beside of the dynamic formation due to ice flow over subglacial barriers, the formation of surface depressions can originate from thermal and mechanical processes due to the subglacial drainage system, the water inflow of the surrounding slopes or even heavy precipitation events and lake outbursts. In the accumulation area, surface depressions can also be formed by wind erosion. Depending on the different processes the sinks occur within weeks, months or years.

At the tongue of Gepatschferner (46°52'30"N, 10°45'25"E) the evolution of a surface depression has been monitored for two years. Vibroseismic soundings by using a shear-wave vibrator were carried out in 2012 and 2013at two profiles on Gepatschferner with a length of 144 m each. During the same period the surface ablation at an ablation stake and its position and motion was measured with DGPS regularly. Two ALS surveys were carried out in 2012.

The observed subsidence rate was around 30 m per year and increased after a heavy precipitation event in August 2012 to about 15 m per month along with a decreasing surface velocity close to zero. At its maximum, the surface depression had a diameter of around 50 m and a depth of around 15 m at the downhill side.

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