NÁTTÚRUSTOFA
Norðurlands vestra

First Science Meeting of the European Science Foundation ESF - Network SEDIFLUX

SEDImentary source-to-sink-FLUXes in cold environments

Sauðárkrókur, Iceland,
June 18th - June 21st, 2004

Extended Abstracts of Science Meeting Contributions

Editors: A.A. Beylich, Þ. Sæmundsson,
A. Decaulne & O. Sandberg

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Abstract:
This report contains accepted extended abstracts of paper and poster contributions submitted to the first ESF Network SEDIFLUX Science Meeting held at the Natural Research Centre of North-western Iceland in Sauðárkrókur, Iceland, from June 18th to 21st, 2004.

Keywords:
Sedimentary Source-to-Sink-Fluxes in Cold Environments, sediment fluxes, source, sink, cold environment, weathering, slope processes, fluvial transport, coastal processes, sedimentation, Iceland, ESF.

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- **Science Meeting Programme and Schedule**
- **Extended Abstracts of Science Meeting Contributions**
- **Short Description of Field Trips**
- **List of Registered Participants of the Science Meeting**

http://www.eld.geo.uu.se/swe/hemsidor/achim/esf.htm
http://www.esf.org
http://www.nnv.is

Preface

The First Science Meeting of the European Science Foundation (ESF) Network SEDIFLUX (Sedimentary Source-to-Sink-Fluxes in Cold Environments) takes place from June 18th - June 21st, 2004, at the Natural Research Centre of North-western Iceland in Sauðárkrókur, Iceland.

We are pleased to welcome more than 40 workshop participants from 12 different countries. The 39 workshop contributions (23 talks and 16 poster presentations) cover a wide spectrum, including different topics on Sedimentary Source-to-Sink-Fluxes in Cold Environments, Process Monitoring and Modelling, Analysis of Sediment Sinks/Storages, Source-to-Sink-Correlations, Sediment Budget Studies, Landscape Ecology, and detailed information on SEDIFLUX and other related multi-disciplinary and multi-national research networks and programmes.

This volume contains the final Science Meeting programme and schedule, all accepted (yes-/no-decision) extended abstracts of workshop contributions, a short description of the two field excursions and a list with the names and addresses of all registered Science Meeting participants who receive support by ESF funding (SEDIFLUX members).

The organizers of the first SEDIFLUX Science Meeting warmly welcome all workshop participants.

We would like to wish you all a very nice and interesting stay in Sauðárkrókur !

Yours sincerely,

Achim A. Beylich (Uppsala),
Co-ordinator of SEDIFLUX and Science Meeting Organizer

Þorsteinn Sæmundsson (Sauðárkrókur),
Director of the Natural Research Centre of North-western Iceland, Sauðárkrókur, and Science Meeting Organizer

Armelle Decaulne (Clermont-Ferrand),
Science Meeting co-Organizer

Olga Sandberg (Göteborg),
Science Meeting co-Organizer

Sauðárkrókur, June 18th, 2004

Science Meeting Programme & Schedule

June 18th, 2004

Bus excursion from Reykjavík to Sauðárkrókur (NW Iceland)

- Departure from Reykjavík

Departure from Reykjavík at 8:30.
First meeting point (pick up) is the bus station at Laekjartorg, which is down town Reykjavík, at 7:45. Second meeting point is the Hotel Fosshotel Lind at Rauðarárstígur 18, at 8:10, and the last meeting point is the City Youth Hostel at Sundlaugavegur 34, at 8:30.

- Expected arrival in Sauðárkrókur

During the trip to Sauðárkrókur we take the main road, road 1, along the western side of Iceland. On the way we stop at several locations and look at the local geology and landscape. Lunch packages will be distributed during the trip. It is estimated that we arrive in Sauðárkrókur at 18:00. The bus stops at the Hotel Fosshotel Áning, Sauðárkrókur.

Cocktail reception

At 19:00 we are invited to a cocktail reception, sponsored by the Skagafjörður District Heating and Waterworks Company. The location is only a 5 minutes walk from the Hotel.

Dinner

Dinner is at 21:00 at the Ólafshús restaurant in the centre of the town of Sauðárkrókur. About 15 min walk from the cocktail reception.

June 19th, 2004

Natural Research Centre of North-Western Iceland, Sauðárkrókur

Introduction

08.00 - 08.20
Achim A. Beylich (Uppsala) & SEDIFLUX Coord. Comm.: The ESF Network SEDIFLUX: "Sedimentary Source-to-Sink-Fluxes in Cold Environments" - an introduction.

08.20 - 08.30
Welcome by Dr. Þorsteinn Sæmundsson, Director of the Natural Research Centre of North-western Iceland, Sauðárkrókur.

Paper presentations

Invited Keynote Lectures

08.30 - 09.10
Olav Slaymaker (Vancouver): Towards the identification of scaling relations in drainage basin sediment budgets.

09.10 - 09.50
Norikazu Matsuoka (Tsukuba): Towards construction of a global network of monitoring periglacial processes.

Paper session 1

9.50 - 10.10
Samuel Etienne (Clermont-Ferrand) & Marie-Francoise André (Clermont-Ferrand): Variability of weathering processes hierarchy through weathering balances of several north-Atlantic periglacial environments (Iceland, Labrador, Lapland, Spitsbergen).

10.10 - 10.30
Oliver Sass (Augsburg): Quantification of alpine rockwall retreat by aid of georadar and geoelectric measurements.

10.30 - 10.50
Christof Kneisel (Würzburg): Assessment of subsurface lithology in periglacial environments using geophysical techniques.

Coffee break

10.50 - 11.10

Paper session 2

11.10 - 11.30
Þorsteinn Sæmundsson (Sauðárkrókur), Halldór G. Pétursson (Akureyri) & Hoskuldur B. Jónsson (Akureyri): Monitoring of a large landslide in the Almenningar area, N-Iceland.

11.30 - 11.50
Jan Boelhouwers (Uppsala): Environmental controls on solifluction processes in the Abisko region, northern Sweden: a progress report.

11.50 - 12.10
Olga Sandberg (Göteborg) & Achim A. Beylich (Uppsala): Analysing denudative slope processes by combining process measurements with mapping and dating techniques and a GIS based integration of biological and geomorphological data - first results from Latnjavagge, Swedish Lapland.

Paper session 3

12.10 - 12.30
Armelle Decaulne (Clermont-Ferrand) & Þorsteinn Sæmundsson (Sauðárkrókur): Present-day geomorphic efficiency of slope processes in the Icelandic Westfjords. Some considerations on snow avalanches and debris-flow impact.

12.30 - 12.50
Denis Mercier (Paris), Samuel Etienne (Clermont-Ferrand) & Dominique Sellier (Nantes): Recent paraglacial slope deformation in Kongsfjorden area, West Spitsbergen (Svalbard).

12.50 - 13.10
Charles Le Coeur (Paris): Partial reactivation of an alpine rock glacier: response to Little Ice Age climatic change?

Lunch

13.20 - 14.20 at the Ólafshús restaurant.

Poster session 1

14.30 - 15.15

Ivar Berthling (Trondheim), Bernd Etzelmüller (Oslo), Christine Kielland Larsen (Oslo) & Knut Nordahl (Lysaker): Sediment fluxes from creep processes at Jomfrunut, southern Norway.

Armelle Decaulne (Clermont-Ferrand) & Þorsteinn Sæmundsson (Sauðárkrókur): The June 10th--12th, 1999 snowmelt triggered debris flows in the Gleiđarhjalli area, north-western Iceland.

Manfred Frühauf (Halle/Saale): Periglacial deposits in the Harz-mountains of Germany - origin, structure and geoecological relevance for land use.

Jan-Christoph Otto (Bonn): Quantification and visualisation of sediment bodies in a high alpine geosystem.

Halldór G. Pétursson (Akureyri) & Þorsteinn Sæmundsson (Sauðárkrókur): The 1995 Sölvadalur debris slide in Central North Iceland.

Tomasz Sapota (Uppsala), Ala Aldahan (Uppsala) & Göran Possnert (Uppsala): Sediment flux and lithofacies in Lake Baikal (Siberia, Russia): a spatial and temporal perspective.

Paul Sumner (Pretoria) & Werner Nel (Unitra, Umtata): Environmental controls and rates of rock weathering on sub-Antarctic Marion Island.

Working Group Meetings 1

15.30 - 19.15
Definition of Working Groups.

Dinner

19.30 - 22.00 at the Ólafshús restaurant.

after 23.00: Dance for those who are interested and still have the energy.

June 20th, 2004

Natural Research Centre of North-Western Iceland, Sauðárkrókur

Paper presentations

Invited Keynote Lecture

09.00 – 09.40
Philip A. Wookey (Stirling): Experiences with ITEX (the International Tundra Experiment): could SEDIFLUX benefit from lessons learned?

Paper session 4

09.40 - 10.00
Bernd Etzelmüller (Oslo), B. Wangensteen (Oslo), H. Farbrot (Oslo), A. Gudmundsson (Reykjavik), Ole Humlum (Oslo), T. Eiken (Oslo) & Andreas Kääb (Zürich): Surface displacement, volume changes and Holocene sediment flux rates for active rock glaciers and moving debris bodies on Iceland – examples from the Tröllaskagi Peninsula, northern Iceland, and the Seyðisfjörður area, eastern Iceland.

10.00 - 10.20
Jukka Käyhkö (Turku), Andrew J. Russell (Newcastle), Nigle Mountney (Keele), Petteri Alho (Turku) & Jonathan L. Carrivick (Keele): Fluvio-aeolian interactions within the Northern Volcanic Zone (NVZ) sedimentary system, NE Iceland.

10.20 - 10.40
Andrew J. Russell (Newcastle), Jukka Käyhkö (Turku), Fiona S. Tweed (Staffordshire), Petteri Alho (Turku), Jonathan L. Carrivick (Keele), Philip M. Marren (Witwatersrand), Nigel J. Cassidy (Keele), E. Lucy Rushmer (Keele), Nigel P. Mountney (Keele) & Jamie Pringle (Keele): Jökulhlaups impacts within the Jökulsá á Fjöllum system, NE Iceland: implications for sediment transfer.

Coffee break

10.40 - 11.00

Paper session 5

11.00 - 11.20
Vyacheslav V. Gordeev (Moscow): Riverine sediment flux to the Arctic: an overview.

11.20 - 11.40
Jórunn Harðardóttir (Reykjavik) & Árni Snorrason (Reykjavík): Recent developments in the sediment monitoring network of Icelandic rivers.

11.40 - 12.00
Jeff Warburton (Durham), Martin Evans (Manchester) & Richard Johnson (Penrith): Significance of mineral / organic components in the sediment flux from upland catchments.

Paper session 6

12.00 - 12.20
Karl-Heinz Schmidt (Halle/Saale) & David Morche (Halle/Saale): Sediment budgets of two small catchments in the Bavarian Alps, Germany.

12.20 - 12.40
Achim A. Beylich (Uppsala), Ulf Molau (Göteborg), Olga Sandberg (Göteborg), Karin Lindblad (Göteborg) & Heikki Seppä (Helsinki): Integrating sediment budget studies and ecology at the landscape level - results from ongoing monitoring programmes in Latnjavagge, northernmost Swedish Lapland.

12.40 - 13.00
Ulf Molau (Göteborg): The issue of scales in landscape ecology - in time and space.

13.00 - 13.20
Volker Rachold (Potsdam): Permafrost Coasts of the Arctic.

Lunch

13.30 - 14.30 at the Ólafshús restaurant.

Poster session 2

14.40 - 15.40

Achim A. Beylich (Uppsala), Olga Sandberg (Göteborg), Ulf Molau (Göteborg), Karin Lindblad (Göteborg) & Susan Wache (Halle/Saale): Sediment sources and spatio-temporal variability of fluvial sediment transfers in arctic-oceanic Latnjavagge, Swedish Lapland.

Robert G. Björk (Göteborg), Leif Klemedtsson (Göteborg), Ulf Molau (Göteborg) & Anna Stenström (Göteborg): The effect of long-term temperature enhancement on potential denitrification across different subarctic-alpine plant communities.

Jonathan L. Carrivick (Keele), Andrew J. Russell (Newcastle) & Fiona S. Tweed (Staffordshire): Glacier Outburst Floods (jökulhlaups) from Kverkfjöll, Iceland: flood routeways, flow characteristics and sedimentary impacts.

Jonathan L. Carrivick (Keele): Palaeohydraulics of a glacier outburst flood (jökulhlaup) from Kverkfjöll, Iceland.

Valentin Golosov (Moscow), Vladimir Belyaev (Moscow) & Maxim Markelov (Moscow): Application of radionuclide techniques for evaluation of sediment redistribution.

Jórunn Harðardóttir (Reykjavík), Árni Snorrason (Reykjavík), Snorri Zóphóníasson (Reykjavík) & Svanur Pálsson (Reykjavík): Sediment discharge in jökulhlaups in the Skaftá river, South Iceland.

Andrew J. Russell (Newcastle), Matthew J. Roberts (Reykjavík), Helen Fay (Staffordshire), Fiona S. Tweed (Staffordshire) & Philip M. Marren (Witwatersrand): Jökulhlaups as agents of glacial sediment transfer.

Fiona S. Tweed (Staffordshire), Matthew J. Roberts (Reykjavik) & Andrew J. Russell (Newcastle): Hydrologic monitoring of supercooled discharge from Icelandic glaciers: hydrodynamic and sedimentary significance.

Jeff Warburton (Durham) & Alan Dykes (Huddersfield): Rapid mass wasting of peat hillslopes under an extreme rainfall event – a sediment budget appraisal.

Working Group Meetings 2

15.50 - 18.45
Organisation of Working Groups.

Dinner

19.00 - 21.00 at the Ólafshús restaurant.

Evening discussion

21.00 - at the bar
If the weather is nice: watching the midnight sun, down at the beach !

June 21st, 2004

Bus excursion from Sauðárkrókur to Reykjavík

Departure from Sauðárkrókur at 8:00 from the Hotel Fosshotel Áning.

On the way to Reykjavik we take the highland road, Kjölur, between the Langjökull and Hofsjökull glaciers, if the condition of the road is in order. On the way we stop at several interesting localities.

It is estimated that we arrive in Reykjavík around 20.00, possibly later.

Lunch and dinner packages will be distributed during the trip.

Arrival in Reykjavík and end of first SEDIFLUX Science Meeting

Science Meeting Organisers

Achim A. Beylich, *Department of Earth Sciences, Geocentrum, Uppsala University, Sweden*; Achim.Beylich@geo.uu.se

Þorsteinn Sæmundsson, *Natural Research Centre of North-western Iceland, Saudarkrokur, Iceland*; nnv@nnv.is

Armelle Decaulne, *Laboratory of Physical Geography, University of Clermont-Ferrand, France*; armld@yahoo.fr

Olga Sandberg, *Botanical Institute and Earth Sciences Centre, University of Göteborg, Sweden*; olga@gfs.gu.se

Science Meeting Presentations

Accepted Extended Abstracts

Invited Keynote Lectures

Towards the identification of scaling relations in drainage basin sediment budgets

Olav Slaymaker

Department of Geography, The University of British Columbia, Vancouver, Canada

The issue of transferring knowledge between systems of different magnitude is the issue of scaling. Three distinct conceptual approaches are evident in the geomorphic literature: (1) a fractal approach which explores power laws over a range of scales (Rodriguez-Iturbe & Rinaldo, 1997) and starts from an assumption of self-similarity in the landscape; (2) a theory hierarchy approach (Benda, 1999) whereby different theories are invoked at different spatial scales, provide different kinds of understanding and communication between scales is achieved by "coarse graining"; and (3) a panarchy approach (Holling, 2001) which assumes that there are understandable mechanisms for communicating information upwards in scale by "small, rapid processes" and that these linking processes, interacting with boundary conditions set by "large, slow processes", account for emergent properties of the system. A fourth approach can be classified as an empirical hybrid of two or more of the foregoing approaches (e.g. Church et al., 1999). There are no "a priori" ways of choosing between these approaches in dealing with drainage basin sediment budgets until more research on linking processes and emergent properties of basin sediment systems has been done.

Drainage basin sediment budgets are made up of sediment inputs, storage and outputs and have been commonly reported in the literature without explicit discussion of the role of spatial scale. Even Horton (1945) extrapolated results from laboratory and plot scales to the erosional development of large drainage basins without paying explicit attention to the problem of scale linkage (Chorley, 1995). Slaymaker (1972) made a heroic attempt to analyse scale effects on sediment budgets in mid-Wales via instrumented plots, stream reaches and 10 small watersheds. The hierarchical sampling design which he adopted was statistically sound, but his assumption that the sediment transporting processes on slopes and in channels could be scaled up to the scale of the region (1,500 sq.kms) was a serious flaw.

- Fractality. Power laws, which are the signature of fractals, have been observed over a wide range of scales in river basin morphology (Klinkenberg, 1992). Nevertheless, Church & Mark (1980) showed that allometry is more common than isometry in geomorphic systems (i.e. that scale distortions are common). One way of reconciling these apparently contradictory observations is through the concept of multifractality. To the extent that drainage basins display fractal behaviour, sediment inputs should be linked across spatial scales (Hovius et al., 1997) but evidence for multifractality is more common. Multifractality is explained in terms of distinct process domains (e.g. Montgomery & Dietrich, 1992) and increasingly clear evidence of the domains of slope processes, slope-channel coupling processes and fluvial processes obeying distinct fractal relations has been forthcoming (e.g. Dadson, 2002; White, 2002).
- Theory hierarchy. According to Benda (1999), site scale theories involve Newtonian mechanics of landslides and of sediment transport; small watershed level theories deal with the behaviour of population distributions of watershed processes and large watershed level theories concern the evolution of channel networks and hillslopes. Each level of the hierarchy may produce different kinds of knowledge which are mutually exclusive but not contradictory. He has reasoned that appropriate data on sediment sources, channel forms, sediment storage forms and sediment output distributions are still unavailable and has therefore turned to computer simulated data. Benda & Dunne (1997a; 1997b) and Benda & Miller (2001) have reported simulations of stochastic inputs of landscape parameters, climate, soil infiltration fields and sediment supply over a range of temporal and spatial scales. Some of their findings are illustrated.
- Panarchy. Alternatively, Holling (2001) proposes a panarchy model to describe the behaviour of ecological systems of differing spatial and temporal scales. His model assumes that ecological systems communicate information upward by small rapid processes and the larger, slow processes set the

upper boundary conditions. The most impressive attempt to deal with the scale problem in a panarchic sense within the geomorphic literature is that by Cammeraat (2002), in which he compares the functioning of geomorphological systems in a water deficit region (southeast Spain) and in a water surplus region (Luxembourg). He succeeds in defining three scale levels: the plot scale with individual plants and microtopographical depressions, functio-ning at event and seasonal temporal scales; a hillslope scale covering human time scales; and a catchment scale, covering landscape development time scales. This was not new. But what was new was the successful identification of linking mechanisms between scales and these are processes that operate at and between the different scales, leading to emergent properties at higher scale levels. The evolution of the system is recognized as highly dependent on feed-back dominated processes at the fine and intermediate scales.

- Hybrid approaches. Slaymaker (1987), Church & Slaymaker (1989), Church et al. (1999) and Schiefer et al. (2001) have analysed the dependence of sediment output on spatial scale for a region as large as Canada. Theirs are pragmatic analyses of suspended sediment observations, based on the Water Survey of Canada archive and field measurement programmes. They have established regional scaling relations for the variation of suspended sediment load with drainage basin area and have adjusted the data to common areal bases to portray regional variations. For most regions the specific sediment yield increases downstream, indicating regional degradation of river valleys. After smoothing results by kriging, error estimates for locally predicted values of sediment yield are calculated. The final product is a series of maps showing regional variations of sediment yield based on 1, 100 and 10,000 square kilometre standard areas. These Canadian examples deal with sediment output only, but may suggest a way forward for dealing with the other components of the sediment budget.

In considering the design of the experiments and field measurement programmes in the SEDIFLUX network, the question of scale and scaling relations deserves high priority.

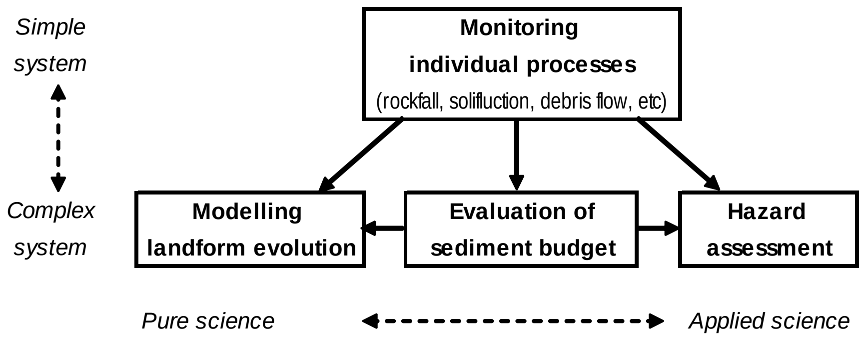
Towards construction of a global network of monitoring periglacial processes

Norikazu Matsuoka

Institute of Geosciences, University of Tsukuba, Ibaraki, Japan

The last five years of the International Permafrost Association (IPA) working group (WG) on "Periglacial Processes and Environments" has focused on compiling a handbook on field techniques on periglacial processes. In 2004 the WG is reorganized as the new WG "Periglacial Processes and Climate". One of the objectives of the new WG is to construct a global monitoring network with updated field techniques.

Fig. 1. The outcome of process monitoring.



Such a network will permit us to assess spatial and temporal variability of periglacial processes with climate. On a local scale, the state-of-art technology will encourage, not only understanding of individual processes operating at monitoring sites, but also evaluating sediment budget (in a specific landform or a drainage basin), modelling landform evolution and predicting natural hazards (Fig. 1).

Automated monitoring systems allow acquisition of year-round data at locations accessible only in summer (like many periglacial sites), whereas manual methods compensate parameters unfavourable for automation (e.g. movement of boulders, water chemistry) and allow widespread observations. Monitoring also benefits from collection of other basic data, including atmospheric information (from nearby station), topographic information (from DEM, contour map) and geological information (from geological map, drilling/excavation, geophysical sounding). Techniques have recently significantly progressed for monitoring thermal regimes of the active layer and permafrost and for geophysical sounding of subsurface permafrost. However, most of the techniques for monitoring geomorphic processes are still immature. In particular, there is a lack of sensors for recording various kinds of debris movement, which constitute the core parameters in sediment budget models.

The monitored parameters vary site-to-site with the purpose, spatial scale, topography, geology, environmental factors and prevailing processes (Fig. 2). Thus, distinction is proposed between "process" and "environmental" parameters and between "common" and "site-specific" parameters. The process parameters (a possible sensor is shown in the square bracket) involve, for example in a bedrock-coarse debris system, bedrock fracturing [crack extensometer], rockfalls [acoustic or vibration sensor?] and rock glacier creep [inclinometer]: they are mostly site-specific. For a drainage basin dominated by fine debris, monitoring may cover frost heave [dilatometer], solifluction [strain probe], debris flow [wire sensor], river-bank erosion [dilatometer], fluvial/glaciofluvial transportation [electric conductivity sensor for solution, turbidity sensor for suspension, pressure sensor for bedload?] and eolian erosion/transportation [dilatometer]. The common environmental parameters may involve air and ground temperatures, solar radiation, precipitation and/or snow depth and ground moisture, whereas other environmental parameters, such as wind direction and speed, stream discharge and groundwater level, are site-specific.

In addition to the length of monitoring, the choice of parameters is critical in modelling landform evolution. The rock glacier development is, like other debris transport systems, constrained by the continuity (sediment budget) and a flow law. A small rock glacier in the Swiss Alps has undergone automatic or manual measurements of debris production, transport and ground temperature. The rock glacier showed rapid movement with a large inter-annual fluctuation that mainly reflects winter snow regimes. The advance of the rock glacier is too rapid to balance with the debris supply from the backwall. A numerical simulation suggests deceleration of movement and subsequent permafrost degradation in a few decades.

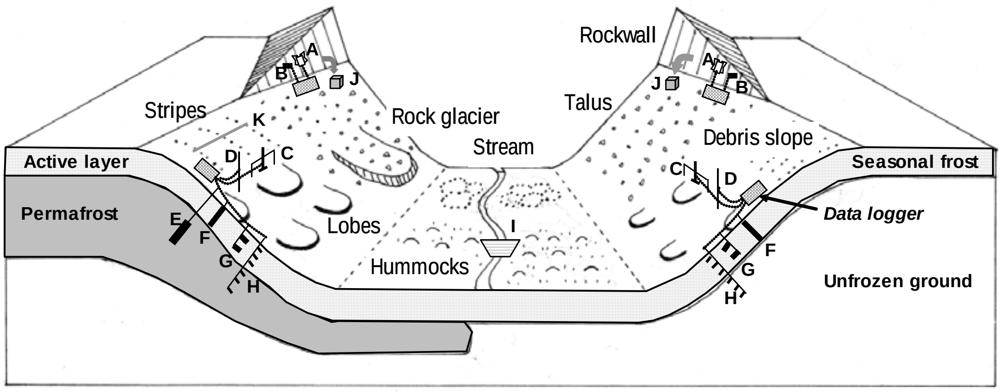


Fig. 2. A monitoring system in a periglacial basin. Automatic observations involve joint opening (A), rock temperature (B), frost heave (C), snow depth (D), permafrost creep (E), solifluction (F), soil moisture (G), soil temperature (H) and discharge, turbidity and electric conductivity (I). Manual observations involve rockfall (J) and surface movement (K).

The monitoring system should be designed to provide long-term data that can distinguish inter-annual variability of movement from long-term trends. As a small-scale geomorphic system, stone-banked lobes in the Japanese and Swiss Alps have undergone ten years of monitoring of frost heave, solifluction, snow depth, soil temperature and moisture. The data show that, although similar processes recur annually, the length of the snow-cover period affects significantly inter-annual variation in soil movement.

As a first step to the global monitoring network, the new WG encourages (1) further improvement of technology, (2) standardization of sensors and/or methods and (3) construction of a model experimental site. For this purpose, we have to define the common parameters and promote low-cost, high-resolution methods. A favourable model site experiences a variety of processes in a homogeneous geology as well as allows frequent visits throughout the year.

Experiences with ITEX (the International Tundra Experiment): could SEDIFLUX benefit from lessons learned?

Philip A. Wookey

School of Biological and Environmental Sciences, University of Stirling, Stirling FK9 4LA, Scotland UK

This presentation will set forth some personal views on ITEX, and how experience gained in ITEX might be of benefit in the development of SEDIFLUX. The author was the third Chair of ITEX (from April 1996 to October 2003), following-on from Patrick Webber (Michigan State University) and Ulf Molau (University of Gothenburg).

The International Tundra EXperiment (ITEX) unites an international network of research scientists through the implementation of experiments focusing on the impact of climate change on selected circumpolar, cold-adapted plant species, in tundra and alpine vegetation. Currently, research teams from 11 countries - including all the Arctic nations - carry out similar, multi-year environmental manipulation experiments (at more than two dozen sites in total) that allow them to compare inter-annual, and treatment-related, variations in plant performance (e.g. phenological development, growth, gas exchange, cover/community change), and other ecosystem processes (e.g. decomposition and nutrient cycling). Collectively, the ITEX network is able to pool its data sets to examine vegetation response at varying levels, for example genetic (from ecotype to functional type), spatially (from habitats, through landscapes, to ecosystems, and regions), and temporally (the longest ITEX data sets available now cover over 10 years). The truly international nature of ITEX has provided 'value-added' (the programme is greater than the sum of its parts), and this has been strengthened by the use of 'meta-statistical' analyses of the results from many sites combined in order to make broadly-applicable statements on ecosystem responses to change, rather than just site-specific. The network thus enables fundamental ecological theory to be tested robustly at multiple sites.

ITEX has been in operation since its design and launch in December 1990 at a meeting held at the Michigan State University W.K. Kellogg Biological Station (see Webber & Walker 1991, *Arctic and Alpine Research* 23:124). Currently there are 90 ITEX and ITEX-related publications on the database (www.itex-science.net), including one special issue of the journal *Global Change Biology*, and a meta-analysis of ITEX early results (years 1-4) published in *Ecological Monographs*. The database, however, undoubtedly underestimates the total ITEX science output, and the output in terms of PhD theses is also impressive.

So, how has ITEX progressed thus far, and have lessons been learned that could be useful for SEDIFLUX? Arguably, ITEX's greatest assets have included (i) a core group of dedicated and enthusiastic scientists with the necessary vision to drive the process forwards (please note that, as 3rd ITEX Chair, the author of this abstract inherited a fully-functional programme, and therefore takes no credit for launching ITEX!), and (ii) a focused research programme that is flexible enough to be applicable in contrasting geographical/socio-economic settings, yet clearly-enough defined to allow for quantitative and objective inter-site comparisons. As stated on the ITEX home-page ('About Us': http://www.itex-science.net/about.cfm) "*Participation in ITEX may be at several levels of complexity and sophistication depending on interests and available funding support. Each ITEX site operates some form of warming experiment*". Another key 'ingredient' of ITEX has been, and remains, the existence of a Manual which sets forth, in considerable detail, information on suitable experimental approaches, species-specific metrics that are appropriate for long-term measurement and inter-site and species comparisons, and information on the monitoring of abiotic environment (including active-layer depths, air and soil temperatures). ITEX has long since been associated with the International Permafrost Association (IPA: http://www.geo.uio.no/IPA/), and contributed to the Circumpolar Active Layer Monitoring (CALM) Programme Network.

ITEX has also always been a meeting-place, and support network, for doctoral researchers, and they have brought with them an enormous resource in terms of enthusiasm, open-mindedness and drive. The role of younger researchers in the success of ITEX cannot be overestimated, and more experienced researchers within ITEX have also benefited greatly from the exchange of views, ideas, and experience among these groups. Senior scientists are often heavily committed in terms of teaching and administrative duties, so that the development of a vibrant and supportive network of younger scientists (doctoral and post-doc) is a key in the maintenance and successful development of a viable medium- to long-term programme.

So the main lessons, in my view, that might be transferable to SEDIFLUX are as follows:

- The programme needs to be focused yet flexible. Having a core programme that is realistic (and meaningful) for all participants to undertake, yet which can be complemented by supplementary measurements and site-specific studies, is likely to stand the test of time. The core programme should allow for rigorous inter-site analyses and synthesis, while site-specific studies might provide the basis for novel PhD theses, for example;
- SEDIFLUX could probably benefit from a Chair and a Steering Group, who provide leadership, but are not autocratic. The Steering Group might have national representatives, and an important element of their job should be to establish good networks nationally, and maintain up-to-date information on funding agencies, user-groups etc. They can also advise national participants, and provide a link back to the leadership;
- SEDIFLUX might consider developing a Manual of protocols and analytical procedures that is accessible to all, and which allows for updating. In ITEX the Manual has been pivotal to the successful implementation of experiments and monitoring at contrasting locations, both in the Arctic and in the alpine;
- Keep SEDIFLUX 'well-connected' with complementary programmes internationally: this is important both for the visibility of the programme, and in terms of influence;
- Keep SEDIFLUX young at heart, and prepared both to support, and to learn from, younger researchers;
- Meet regularly. ITEX has a history of meetings of (approximately) annual frequency (with minor deviations): The most recent ITEX meeting (the12th) was held at Chena Hot Springs Resort, Fairbanks, Alaska, between 26-29 September 2003. These meetings have usually been very informal, yet clearly structured, and hopefully with a good balance between plenary presentations (often from PhD students) and debates/working groups. A key ingredient has been the notion that science should be fun, and enthusiasm is contagious. We work at locations very far away from one another, but ITEX has had the feel of a family, thanks, in large part, to the meetings, and to the atmosphere that they create.

Science Meeting Paper Presentations

The ESF Network SEDIFLUX: "Sedimentary Source-to-Sink-Fluxes in Cold Environments"– an introduction

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Climate change will cause major changes in the Earth surface systems and the most dramatic changes are expected to occur in the cold climate environments of the Earth. Cold climate landscapes are some of the last wilderness areas containing specialized and diverse plants and animals as well as large stores of soil carbon. Geomorphological processes, operating at the Earth`s surface, transfering sediments and changing landforms are dependent on climate, vegetation cover and human impacts and will be significantly affected by climate change. In this context it is a major challenge to develop a better understanding of the complex ecosystems and the mechanisms and climatic controls of sedimentary transfer processes in cold environments. More reliable modelling of sediment transfer processes operating under present-day climatic settings is needed to determine the consequences of predicted climate change. It is necessary to collect and to compare data and knowledge from a wide range of different high latitude and high altitude environments and to develop more standardized methods and approaches for future research on sediment fluxes and relationships between climate and sedimentary transfer processes. In Europe the wide range of high latitude and high altitude environments provides great potential to investigate climate-process relationships and to model the effects of climate change by using space for time substitution. The highly relevant questions to be addressed need a multidisciplinary approach and the joining of forces and expertise from different scientific fields. Especially a closer cooperation between geoscientists and biologists/ecologists is urgently needed and links between running global change programmes (ITEX etc.) and the ESF Network introduced here will be of major importance. The ESF Network "Sedimentary Source-to-Sink-Fluxes in Cold Environments" (SEDIFLUX, 2004 – 2006), will bring together leading scientists, key researchers, young scientists and research teams from different fields. The large number of projects run by the ESF Network participants demonstrates the high level of research activity of scientists working on sediment fluxes in different cold environments. The Network will form a framework for an integrated and multidisciplinary investigation of the research topic and will be a catalyst for strengthening and extending contacts and exchange. The Coordination Committee of SEDIFLUX consists of scientists from eight countries:

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Samuel Etienne, Clermont-Ferrand, France
Bernd Etzelmüller, Oslo, Norway
Vyacheslav V. Gordeev, Moscow, Russia
Jukka Käyhkö, Turku, Finland
Volker Rachold, Potsdam, Germany
Andrew J. Russell, Newcastle, UK
Karl-Heinz Schmidt, Halle/S., Germany
Þorsteinn Sæmundsson, Sauðárkrókur, Iceland
Fiona S. Tweed, Staffordshire, UK
Jeff Warburton, Durham, UK

The ESF Network will be organized in different working groups. The following working groups are planned for a first phase (1st and 2nd workshop) of SEDIFLUX: Weathering, Erosion, Chemical denudation, Mass transfers, Fluvial transfers and jökulhlaups, Sinks, Data management, Sediment Budgets, Source-to-sink-fluxes/correlations. An integration of these working groups (formation of new and integrating working groups) within the second phase (3rd and 4th workshop) of SEDIFLUX is planned.

Network activities include four Workshops in Sauðárkrókur, Iceland (June 18th – 21st, 2004), Clermont-Ferrand, France (January 20th – 22nd, 2005), London, UK (autumn of 2005) and Kevo, Finland (autumn of 2006), Coordination Committee meetings attached to the workshops, a SEDIFLUX session at the Second General Assembly of the EGU, April 2005, Vienna, Austria, journal publications (special issues), publication of abstract volumes, publication of science meetings reports, preparation and publication of a SEDIFLUX handbook, and the diffusion and dissemination of Network activities and outputs by using electronic media (webpages, newsletters, forum) and public media (press, TV).

A strong monitoring and operational data collection and more standardized methods will provide a baseline for the development of reliable models and for future research in the changing cold environments. Significant links with other established networks, programmes and organisations will be developed. Apart from further collaborations and collaborative research activities, project and programme applications at the European level will be discussed and initiated.

Integrating sediment budget studies and ecology at the landscape level – results from ongoing monitoring programmes in Latnjavagge, northernmost Swedish Lapland

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The integration of sediment budget studies and ecology with an integrated study of geomorphological and ecological patterns and processes at the landscape level has been realized by combining data sets generated from different ongoing process geomorphological and ecological monitoring programmes and studies in the Latnjavagge drainage basin (9 km²; 950 – 1440 m a.s.l.; 68°20`N, 18°30`E) in northernmost Swedish Lapland (see also Beylich *et al.*; Sandberg & Beylich, this volume). The different monitoring programmes and studies have been operated from the Latnjajaure Field Station (LFS) since 1998/1999. LFS, situated in the Latnjavagge drainage basin at 981 m a.s.l., is headed by Ulf Molau (Göteborg), belongs to the Abisko Scientific Research Station (ANS) and is owned by The Royal Swedish Academy of Sciences (KVA). Latnjavagge is a representative catchment for the higher mountain area in the Abisko region in northernmost Swedish Lapland. This periglacial drainage basin represents major environmental features of this arctic-oceanic mountainous area.

The analysis of sediment fluxes, denudation rates and sediment budgets in fluvial drainage basins, forming clearly defined landscape units, are major elements for the interpretation of landscape evolution. The comparison of denudation rates and sediment budgets in representative drainage basins in present periglacial environments with given morphoclimatic, ecological, topographic and lithological/geological features can give insight into the internal differentiation of the present-day periglacial environments. Data from monitoring programmes in different environments provide the possibility to use the Ergodic principle of space for time substitution.

To cast further light upon present-day denudation rates and relationships between chemical and mechanical denudation in periglacial environments, a sediment budget study was initiated in Latnjavagge in 1999. Denudative slope processes, mechanical fluvial denudation and chemical denudation have been analysed. The mean annual chemical denudation rate in the entire catchment is 5.4 t $km^{-2}yr^{-1}$. Mechanical fluvial denudation is slightly lower than chemical denudation and appears to be the second most important geomorphological process type regarding annual mass transfers [t m yr^{-1}]. Most fluvial sediment transport in creeks occurs within a few days during snowmelt generated runoff peaks. The calculated mean mechanical fluvial denudation rate at the inlet of lake Latnjajaure (0.73 km²), situated in Latnjavagge close to the catchment outlet, is 2.3 t km^{-2} yr^{-1}. At the outlet of the entire Latnjavagge drainage basin, situated below lake Latnjajaure, the mean annual mechanical fluvial denudation rate is 0.8 t $km^{-2}yr^{-1}$. Analysis of the volume of the delta of lake Latnjajaure and additional corings of lake sediments document little Holocene sediment accumulation in the Latnjajaure delta and in the five lakes in Latnjavagge.

The relatively most important denudative slope processes, regarding annual mass transfers, are rock- and boulder falls. Nevertheless, the thicknesses of material accumulated below rockwalls, rockledges etc. within the slope systems reach only at some localities more than a few metres.

Today, both chemical and mechanical denudation in the valley are of low intensity. Because of the low intensities of denudative processes, both today and during the Holocene, Postglacial modification of the glacial relief is altogether negligible. At the landscape level, there has been no adjustment of the Pleistocene glacial landforms to the denudative processes which have been operating during the Holocene. Today, there is no equilibrium between landforms and denudative processes operating in the present-day arctic-oceanic morphoclimate.

The low present-day intensities of denudative processes, with a low frequency of debris flows and slides and very little wash denudation at the slope systems, are to a large extent due to the very stable vegetation cover and the closed rhizosphere which have developed below 1300 m a.s.l. in the entire catchment area. Local disturbances of the vegetation cover and rhizosphere caused by direct human impacts like extensive reindeer grazing, hiking tourism and field research at LFS are of minor importance and do not significantly affect the present-day denudative process rates and the present-day sediment budget of the drainage basin.

Environmental controls on solifluction processes in the Abisko region, northern Sweden: a progress report

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Considerable effort has been made in obtaining movement rates of solifluction in Swedish mountains. However, a critical shortcoming is its inability to establish relationships with climate (Matthews and Berrisford, 1993). As solifluction and frost heave are considered important processes of mass transfer and soil disturbance in Swedish mountains, its relationship with climatic parameters should be known to understand current and potential impacts under various climate change scenarios.

This project aims to arrive at a spatial modeling of solifluction and frost heave processes in the Abisko region. The study will be completed along the east-west moisture gradient of the mountains between Riksgränsen and Abisko. Altitudinal gradients will establish a range of temperature and snow environments. Thus, ergodic principles are used to monitor process activity under a range of environmental conditions.

A first activity has focused on identifying the range of forms present at ten sites in the study area, their morphometry and association with, mostly non-climatic, environmental parameters. Solifluction lobe morphometrical parameters included are tread length, tread width, tread angle, riser angle. Site characteristics included are slope angle, aspect, vegetation type, altitude, soil texture and simulated radiation and temperature values (Meteonorm, 1999).

Results from linear regression tests suggest poor correlations between solifluction morphometry and the environmental parameters. Best results indicate negative correlations between lobe size parameters and altitude, temperature and radiation, explaining between 13-28% of the observed variability.

Several factors may have lead to the low correlation values. First, the population of solifluction forms sampled is unlikely to be uniform. Variations in morphology suggest different movement mechanisms along the west-east and altitudinal gradients. Second, none of the climatic parameters have been adequately analyzed to date. Solifluction is ultimately a moisture driven process and should be a key focus. Third, the number of observation sites needs to be increased substantially to allow better statistical resolution.

Objectives for further study are to describe and explain the spatial variation of solifluction forms in relation to movement mechanisms and environmental parameters, establish movement rates and associated micro-environmental controls along environmental gradients, to investigate methods of upscaling site-specific measurements to catchment scale and, ultimately, to model changes in solifluction activity under different climate change scenarios.

Present-day geomorphic efficiency of slope processes in the Icelandic Westfjords. Some considerations on snow avalanches and debris-flow impact

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The North-western part of Iceland (64-66° N, 23-24° W) is a favourable area for slope processes studies. The geology consists of Miocene basaltic lava flows, intercalated with sedimentary rock layers, that were shaped in U-shaped valleys and fjords during Pleistocene glaciations. The lava series now display flat summits from 400 to 900 m a.s.l.. Slope profiles are slightly concave, characterised by steep upper part with rockwall, moderate to steep mid parts and low slope angles in lower parts; slope variation in height is about 600-700m. Icelandic climate is subpolar-oceanic, characterised by a very changeable weather and precipitation/temperature fluctuations that frequently exceed the average. Since glacier disappearance, ca. 12,000 years ago, slope processes, i.e. landslides, snow avalanches, debris flows, rockfall and rockslides, built large evidences that suggest intense slope activity. Despite these huge and widespread slope talus and talus cones that attest indisputable slope instability during the Holocene, present-day slope processes are difficult to quantify, and their geomorphic efficiency is greatly variable from one process to another. We will focus here on snow-avalanche and debris-flow impact.

Geomorphic efficiency of snow avalanches

Whether or not the avalanche makes contact with the ground surface is the most significant point when dealing with snow avalanche geomorphic efficiency. Thus, typical landforms are created from both erosive and accumulative processes. Consequently, different types of avalanches have different impacts, and the time/period of occurrence is highly important.

Types of snow avalanches

Different types of snow avalanches have been recognised in Iceland, from the snow-avalanche Annals.

Snow avalanches during heavy snowstorm originate on leeward slopes and involve the snow of the confined or unconfined slope. The snow cover is thick and protect the ground surface, thus geomorphic impact is limited on slope. Exception has been observed in the site of Botn í Dýrafjörður when a hanging cornice fell, destabilising the whole snow cover on the slope: huge boulders were transported and deposited several tens/hundreds meters downslope and up on the opposite slope, marking the slope with numerous ploughing marks.

Snow avalanches during late winter / early spring are spring-thaw avalanches released from the top of the small chutes in the upper rockwall (Kirkjubólshlíð slope), when waterlogged hanging snow cornices collapse. As the snow moved down, it balled up and integrated unconsolidated material when crossing snow free/thin snow cover areas and clean up frost-shattering debris from the track.

Slush avalanches source-areas (Bíldudalur case study) are large rockwall indentations suitable to snow accumulation and saturation of the snowpack. The build-up of meltwater is favoured by sudden and sustained thaw due to air temperature rises and/or abundant rainfall. Frost-shattering products accumulate at the bottom of the bowl, and stones and rocks are incorporated into the flowing mass.

Snow-avalanche landforms

Due to the different kind of snow avalanches, different snow-avalanche landforms are created.

Scattered rocks (Bolungarvík-Ernir, Súðavík areas) at the base of the slope originate in the sweeping up of frost-shattering in the upper part of the slope by the avalanche. They are deposited at the foot slope, forming a diffuse accumulation. No sorting is obvious, and their size is usually large. Lichen cover is dissimilar on the surface of two boulders next to each other, and fresh deposits are numerous.

Perched boulders (Flateyri, Patreksfjörður, Kirkjubólshlíð) are seldom in north-western Iceland. Their size is very variable, no preferential orientation is distinguished, and balanced boulders are never covered with vegetation: the hypothesis is that balanced boulders are swept away by later snow avalanches and replaced by fresher boulders.

Late winter/early spring snow-avalanche deposits and avalanche boulder tongues (Kirkjubólshlíð, Kubbi-Engidalur) seem connected. Fresh ground avalanche deposits show that particle size material concentrates at the bottom of snowballs, and rock material is scattered over the snow surface. Rock material is not dominant, but particle size material colour the deposits. Its location underlines its superimposition with avalanche boulder tongues, suggesting that dirty spring snow avalanches supply material to this specific construction. Such accumulation are frequent and both roadbank and fan types are present. Relative dating by vegetation cover rates and lichenometry distinguish three generations of avalanche boulder tongues, pointing out the jerky debris supply.

Slush erosional and depositional features were observed in one site. Slush flows are known for their remarkable capacity to transport a high debris load: small stream channels on mountain slopes are incised while deposited fragments in precarious position lay on both sides of the channel, and typical slushflow whaleback accumulation is developed in the main axis of the fan at the mouth of the gully. By the mean of lichenometry and vegetation cover rate, several slush events are distinguished.

Geomorphic significance of debris flows

Debris flows are initiated on the upper part of slopes, within the major gullies or couloirs that incised the rockwall. In specific sites (Isafjordur and Sudureyri), debris flows originate at the edge of intermediate benches covered with thick debris mantle (up to 35 m), and are canalised to the talus slope by chutes in the rockwall. Release scars are present when debris flows originate with rotational slides at the edge of debris covered bench, but non-existent when originating in rockwall gullies. All slopes are concerned, whatever is its orientation. Debris flows are triggered by snowmelt (rapid snowmelt: 27 %; snowmelt associated with rain: 21 %) or rainfall (long-lasting rainfall: 27 %; intense rainfall: 13 %; intense and long-lasting rainfall: 9 %; unknown rain: 5 %).

Debris flows are widespread all over the Icelandic Westfjords and also very common in other regions. Unlike to snow avalanches, debris flows create very typical forms. Three sections are usually recognised in the field:

- The upper dissection section, where a deep channel (up to 5 m) cut the upper talus; almost non-existent levées are seen in this part.
- The median accumulative and erosive section, where large levées (individual debris-flow levées attain up to 15 m wide) border a deep channel (up to 2 m in depth).
- The accumulative lower section, where the debris flow is up to 70 m across, is characterised by small erosional activity, as suggested by the undamaged vegetation surfaces in the narrow channel.

Debris-flow deposits are located by field investigations and on aerial photographs. In all cases, the source is the same, but its way down can vary within a close space. Each debris flow follows the track dissected by previous ones in the upper part, at the mouth of the gully. Arriving in the median part, diversion of the flow can occur: when the channel is obstructed by deposits from the last pulse of previous debris flows, the mass of debris can flow over one or another levée, creating new channel and levées. Thus, the debris-flow impact area is spread within a more or less wide area from the source to the bottom of the slope. Vegetation cover helps to identify active tracks.

Differences in morphology, vegetation cover and lichenometry cover indicate that several generations of debris-flow deposits are present within the area. It is difficult to distinguish deposits from closely spaced debris-flow events, however. Because of long-lasting levées and lobes created by debris-flow process, conversely to snow-avalanche deposits, lichenometry was used to complete the historical data, and assess a better frequency occurrence.

Moreover, well-grassed levées and very fresh flows have been observed on the same slope, within a small space, indicating that local threshold in the source area is greatly different from one to another.

The life expectancy of debris-flow forms suggested above, especially the lateral levées, seems long. In fact, numerous are totally covered with vegetation. Obviously, their morphology do not have been perturbed by other processes, i.e. snow avalanches. Nevertheless, most of the debris-flow prone areas are snow-avalanche prone areas too. Because of their unequal geomorphic significance, it is more problematic to find evidences of snow-avalanche activity than debris-flow activity on the field: debris flows running on supposed avalanche boulder tongues change their surface characteristics, but relevant evidences of the converse have not been observed.

Finally, the debris-flow – snow-avalanche relationship in rather in favour of debris flows in North-western Iceland, as snow cover usually act as a protective shield during the snow-avalanche activity period: the present-day geomorphic efficiency of snow avalanches is moderate, while the debris-flow one is strong.

Variability of weathering processes hierarchy through weathering balances of several north-Atlantic periglacial environments (Iceland, Labrador, Lapland, Spitsbergen)

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High latitudes weathering landscape has been for a while the key for establishing empirically a hierarchy between weathering processes. According to lithology facieses and varying topographical situations, we discuss the question of the variability of weathering processes hierarchies in the observed landscape. Local climatic conditions and structural interferences are also considered.

Weathering comprises processes of rock degradation operating at the surface of the Earth. Zonal hierarchies of weathering processes have been built in accordance to superficial deposits observed in the landscape. For instance Quaternary deposits in European sedimentary basins exhibit a large amount of angular clasts and a small amount of clays, a facie similar to the present deposits of high latitudes. It is then assumed that the morphogenic system of Pleistocene Europe is quite similar to the present periglacial weathering system of the high latitudes/altitudes. This approach has been challenged recently (Thorn, 1988, Hall, 1995). Nesbitt & Wilson (1992), rediscovering de Martonne (1913), suggest a new approach of the weathering system considering that the weathering spectrum of superficial deposits represent more a balance between processes of debris production and processes of debris evacuation than a signature of dominant processes in a climatic zone.

Considering several periglacial environments in high latitudes of the northern hemisphere, it is clear that structural properties of rock outcrops influence greatly the weathering signature: frost sensitive rocks produce typical "periglacial" landscapes (rhyolite in central-Iceland, quartzite and slates in Labrador, limestone in West Spitsbergen), but massive rocks can be refractive to frost-driven processes, leaving the place to alternative processes: biological weathering dominates on the young basaltic plains of south Iceland (Etienne, 2002) or on granitic roches moutonnées of Swedish Lapland (André, 2002). The presence of salts, typically in coastal areas, can also fuzzy the zonal impulse: weathering of basaltic lava flows of the Reykjanes peninsula (Iceland) and granito-gneissic outcrops of Saglek end Nachvak (Labrador) is under the control of the salts which act mechanically and chemically, leading to the well-known honeycomb weathering.

These symptomatic landscapes must not hide the fact that local morphogenic agents can modify strongly the weathering landscape: the hierarchy established on a valley floor might not be transposable to the adjacent plateaus. On the contrary, variability of the weathering landscapes might not necessarily express a shift of the hierarchy: on the plateaus of South Iceland, katabatic winds inhibit biogenic rind production at the rock surface (effects of corrasion) but the process is still active in protected areas. In the same way, temporary sedimentary covers can alter the weathering landscape development.

These different examples show the caution we must bear when considering hierarchy of weathering processes in a zonal perspective. Periglacial processes dominate when they encounter favorable structural conditions (porous or densely joined rocks). Inversely, they can be totally inefficient and need preliminary preparation of the material in massive rocks. Local conditions (salt weathering, catabatic winds, jökulhlaups) can also totally overwhelm zonal processes.

Keywords

Weathering – erosion balance – morphogenic system – periglacial environment – biogeomorphology

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Surface displacement, volume changes and Holocene sediment flux rates for active rock glaciers and moving debris bodies on Iceland – examples from the Tröllaskagi Peninsula, northern Iceland, and the Seyðisfjörður area, eastern Iceland.

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In this study we have applied digital photogrammetry to measure horizontal and vertical velocities, volumes and Holocene sediment flux in some selected active rock glaciers and creeping debris bodies on northern and eastern Iceland. The study areas were the Tröllaskagi peninsula, located between Skagafjórdur and Eyafjórdur on Northern Iceland between 65°20' – 66°10'N and 18° - 19°30' W, and the Seyðisfjörður area in eastern Iceland. This study is part of a broader project, aiming at mapping and modelling the permafrost distribution on Iceland.

In the central Tröllaskagi peninsula we measured on active talus and glacier-derived rock glaciers at an altitude of 900-1200 m a.s.l. Geophysical and temperature measurements indicated the area being above the lower limit of mountain permafrost of the area. The displacement fields are measured based on cross-correlation matching of othophotos from 1960,1985 and 1994 derived from digital photogrammetry. Volume changes are calculated based on the differences between DTMs automatically constructed by the use of digital photogrammetry. At the road along the coast to Siglufjórdur at the northern tip of the Tröllaskagi peninsula, a moving debris body is located. The moving debris body is situated between 0 and 300 m a.s.l. Geodetic displacement measurements undertaken since 1977 by the Icelandic road authorities along the road that crosses the moving debris body, have revealed displacements of up to 1 m/yr. The movements show rather a discrete than continuous pattern with zones where the velocity along the road changes dramatically over small areas. This pattern is also confirmed by the cross-correlation matching of four sets of orthophotos from 1955, 1977, 1985 and 1994. In the same way as for the first location, volume changes are also calculated from DTMs of the respective years. At the south-eastern mountain side of Seydisfjörður thick debris covers the mountain wall up to an altitude of ca. 900-1000 m a.s.l. There is measured creep movement down slope, which, together with heavy precipitation, periodically triggers debris flows, threating infrastructure and the village. Also here, the same approach with multi-temporal air-photos from 1955, 1964 and 1994 was used to delineate material movements in the area, together with GPS-measured points from 2003.

Based on these measurements, overall sediment fluxes due to permafrost and slope creep and material production rates were calculated for these settings. Especially in the permafrost setting, extrapolation of the fluxes back in time allows for crude time estimations for landform development. For a large glacier-derived rock glacier, average velocities of up to 50 cm/yr are measured, which extrapolated would give development ages of about 3000 yr.

Riverine sediment flux to the Arctic: an overview

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Fluxes of water and suspended sediments from arctic rivers to the ocean provide an integrative signal of processes occurring in their watersheds. Shifts in these fluxes over time give clues about natural and anthropogenic changes in the Arctic.

Accurate estimates of the riverine sediment fluxes in the Arctic are fundamental to understanding land-ocean linkages, contaminant and nutrient transport, and coastal processes, and are very important for detecting future natural and anthropogenic changes (Holmes et al., 2002).

The erosion, transport and discharge of drainage basin sediment are functions of many factors, including climate, basin geology, the size of the drainage area, precipitation, discharge (volume and velocity), and human impact (GESAMP, 1993).

In the former Soviet Union sampling programs for suspended sediments were started between 1935 and 1966 for different rivers in frameworks of the State Hydrometeorological Survey. Two main approaches were used for calculations of sediment discharge – the first approach was a direct calculation of discharge from the concentration data and the corresponding water discharge measurements and the second one was indirect, using sediment rating curves.

There are many publications with the assessments of sediment fluxes in the Russian Arctic - from Shamov (1949) and Lopatin (1952) to Magritsky (2001) and Gordeev and Rachold (2003).
Discharges of water and sediments by the Mackenzie river have been monitored by Environment Canada since the early 1970's. Annual sediment discharge was estimated either directly or with sediment rating curves.

Comprehensive critical review of the existing data on sediment fluxes of the Arctic rivers was published by Holmes et al. (2002). The authors have established contemporary sediment flux estimates for Yenisey, Ob, Lena, Kolyma, Pechora, North Dvina, Mackenzie and Yukon. Gordeev and Rachold (2003) have used these estimates as a baseline for sediment and terrigenous TOC flux assessments to the Arctic Ocean (Table).

The rivers of the East Siberia in comparison with the rivers of the western part of the Russian Arctic (the boundary between two large regions crosses the Laptev Sea basin and coincides with a boundary between the Eurasian and North American tectonic plates) are characterized by higher turbidity (and lower run-off, water mineralization, organic matter and nutrients).The East Siberian rivers (Yana, Alazeya, Indigirka, Kolyma) are even more similar to the North American Arctic rivers than the rivers located westward of the Lena river (Gordeev, 2000).

If to compare the total Arctic sediment flux with the global riverine discharge, we see that the Arctic flux gives only 1.2% of the global discharge (the Arctic watershed area is about 13% of global area).

J. Syvitsky (2003) presented a new model for predicting the sediment flux of the arctic and sub-arctic rivers. This model explains why the Arctic rivers carry so little sediment when compared at the global scale. The sediment load of pan-arctic rivers is controlled by the surface temperature of the drainage basin, modifying the effects of basin area thus the volume of water discharge, and basin relief. Syvitsky concludes that for every 2°C warming there will be a 30% increase in the riverine sediment flux and for every 20% of increase in water discharge there will be a 10% increase in sediment load.

Table. Average multiannual river water and suspended matter discharges to the Arctic Ocean

Sea	Area 10^3 km^2	Water discharge, km^3/y	Total suspended matter		
			g/m^3	10^6 t/y	t/km^2•y
White and Barents	1386	463	39	17.9	12.9
Kara	6589	1480	21	30.9	4.7
Laptev	3597	738	39	28.6	7.9
East Siberian	1327	233	110	25.1	18.9
Chukchi (without Alaska)	94	20.4	34	0.7	7.4
Total Eurasian Arctic	12987	2932	36	102.2	7.9
Total Canadian Arctic	2513	367	–	125.1	49.8
Total Arctic	15500	3299	68	227.3	14.7
Global	99900	35000	528	18500	185

Recent developments in the sediment monitoring network of Icelandic rivers

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Since the first suspended sediment samples were taken from Icelandic rivers in the 1880s by the Norwegian professor Amund Helland, major advances have been made in the field of fluviosediment monitoring. Sediment monitoring has been carried out at Orkustofnun (National Energy Authority) since 1949, although during the first decade and a half the samples were collected in water bottles without the use of a suspended sediment sampler. The employment of such samplers started in early 1960s when grain size analysis of the samples was also initiated; before that the suspended sediment samples were only analyzed for total suspended and dissolved sediment concentration.

At the end of 2003, over 12000 sediment samples had been sampled and analyzed for grain size and total suspended and dissolved sediment concentration at the Hydrological Service at Orkustofnun. These samples have been taken at about 350 locations in Iceland, although the number of samples from each locality varies significantly. Today, between 400 and 600 samples are taken at 30–40 sites each year.

During the decades, the sediment monitoring network has, however, been greatly affected by many conflicting issues, including economical causes, such as changes in the internal infrastructure of the institute, budget changes and available sampling logistics, but foremost by the general interest in results from fluvial sediment analysis, which most often is associated with hydropower development and natural phenomena, such as glacier surging, jökulhlaups, and other flood-related events.

Thorough knowledge of the total sediment transport in vital for all hydropower evaluations, whether it concerns their environmental impact studies, evaluations of their efficiency and/or design. Hence, in relation to enhanced interest in hydropower development in recent years, major sediment sampling campaigns have been initiated in several rivers in East, South, and North Iceland during the last five years. In these specific campaigns, more complete sediment analysis has been carried out than in most other rivers, with frequent sampling and supplementary sampling methods. These methods include e.g. detailed suspended sediment sampling at various depths in several profiles across the river channel to evaluate the dispersion of suspended sediment within the watercolumn. Such analyses have been performed in the rivers Jökulsá á Dal, Jökulsá á Fjöllum, Skaftá, and Þjórsá with interesting results, which show well the distribution of sediment throughout the water and how suspended sediment of diverse grain size behaves differently within the watercolumn (e.g. Gunnarsson et al., 2001; Harðardóttir and Gunnarsson, 2002; Harðardóttir and Þorláksdóttir 2002a, 2003).

The greatest expansion of the sediment monitoring program at the Hydrological Service has, however, been in the field of bedload monitoring. Bedload sampling was inititally carried out at 14 locations in 1982 to 1984, but the sampling was sporadic and only few samples were taken at each place (Svanur Pálsson, 2000). Based on this initial sampling and a successful bedload study in the river Kráká in North Iceland by Þorkelsdóttir (1999), the first extensive bedload sampling program started in river Jökulsá á Dal in 2000 and has been evolving ever since. From 2000 to 2003, over 1600 bedload samples have been taken with a Helley-Smith sediment sampler at 11 sites, including several locations on the rivers mentioned above, and in rivers Hólmsá, Jökulsá í Fljótsdal, and Kreppa. The results of the bedload studies supplement the studies of suspended sediment in these rivers so that the total sediment transport can be evaluated.

With the extensive campaigns in effect today and the additional suspended samples from other locations, a substantial part of the country is monitored for suspended sediment discharge. Large regions are, however, not studied, mainly due to small number of harnessable rivers. Expansion of the sediment monitoring program to these regions, which at present mainly include West and North Iceland, is one of the tasks in future development of the sediment monitoring network. Similarly, expansion of the bedload sampling network to cover both as many types of rivers and the regional differences within the country will hopefully play an important role in future development of the network. However, due to complicated processes, such as glacier surges, jökulhlaups, and other flood phenomena, that affect sediment discharge in Icelandic rivers on the time scale from days to years, the value of long-time monitoring of rivers cannot be underestimated.

In addition to give an introduction of how the sediment monitoring network at the Hydrological Service has developed through the years, we will show some results of the different suspended and bedload studies that have been carried out over the last decade.

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Fluvio-aeolian interactions within the Northern Volcanic Zone (NVZ) sedimentary system, NE Iceland

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Iceland is one of the few regions in the world, where the mid-oceanic plate boundary has reached the sea level. The Northern Volcanic Zone (NVZ) to the north of Vatnajökull ice cap forms a distinctive landscape with lava flow fields and volcanoes of Quaternary age. Vast deposits of gravel, aeolian sand and loess blanket the practically unvegetated landscape (Thórarinsson 1961). At the margins of this degraded region, advancing fronts of wind-blown sediment destroy the surrounding vegetation cover, threatening pasturelands and human settlements (Arnalds 2000; Käyhkö et al. 2002). The key questions with regard to sedimentary processes and the overall land degradation in the area include the problem of sediment provenance, characterisation of the magnitude and mode of transport processes, the potential triggering mechanisms and the age of erosion, and the prospective measures for stopping the degradation. We review current understanding of the types of land cover occupying the region, the spatial extent, processes and the provenance of various sedimentary deposits, and discuss implications for future studies.

Spatial character of the sediment cover: Subglacial eruptions in Vatnajökull have accounted for several jökulhlaups (glacial outburst floods) in the region. These events and aeolian processes have had a considerable impact on the landscape evolution of Ódáðahraun sub-region of the NVZ. Based on Landsat TM satellite data and field studies of an area , three land cover categories dominate in the region (Käyhkö et al. 2001; Alho 2003): (a) barren sediment cover (39.0%); (b) lava cover (34.8%); and (c) vegetated areas (25.1%). Satellite image interpretation revealed several major aeolian sedimentary bodies, such as elongated SSW-NNE oriented aeolian sand stretches in the western half of the study area (Käyhkö et al. 2001).

Sedimentary processes: The sedimentary processes in the region are a complex mixture of fluvial and aeolian activity. On a long time scale, a continuous flow of sediment moves from the Vatnajökull margin towards the north by two main processes: 1) a gradual process, where meltwaters gradually build up the proglacial alluvium, from where the dominantly south-westerly winds transport the sand-size fraction across the lava fields towards the north, and 2) catastrophic processes in conjunction with glacial burst floods, where infrequent jökulhlaups bring about large amounts of sediment and drop the load where the competence suddenly decreases (Käyhkö et al. 2001).This combination results in a punctuated process that operates on various time scales and is hence difficult to model. In the Askja region near the margin of Vatnajökull, active aeolian sandsheets cover an area of 270 km² (Mountney & Russell in press). The sandsheet can be divided into a deflationary upwind part, an accumulating central part and a downwind part that is currently subject to aeolian bypass with only localised accumulation occurring in topographic hollows between basaltic lava fields. The distribution of landforms across the sandsheet reflects a regional aeolian sediment budget that is controlled by dynamic interactions between glacial, ice-margin fluvial, aeolian and volcaniclastic processes under the influence of a distinctive climatic regime. The distinctive jökulhlaup-related sediment cover (8%) along the Jökulsá á Fjöllum course (Alho 2003), the hydraulic models and the sedimentary evidence (Alho et al. submitted) demonstrate the magnitude of the past catastrophic jökulhlaup events.

Sediment provenance: Geochemical fingerprinting with XRF and textural analyses on surface sediments reveal some spatial trends in the sedimentary properties.

Due to mixing during the transportation process and simultaneous chemical weathering (palagonisation), the signals are somewhat diverse. Therefore, we have so far not been able to unravel the question of sediment provenance in different parts of the region. Rather than actual provenance, the geochemical signals seem to represent local conditions, the length of the period of subaerial exposure and the mixing of sediments during the transport process.

Implications for future research: Research in NVZ seeks to establish a semi-quantitative model for fluvio-aeolian sedimentary processes, including the gradual glaciofluvial input of sediment on a seasonal time scale, the catastrophic events related to jökulhlaups, and the subsequent aeolian processes, which take place across the area. Correlation and combination of different time scales, spatial extents and processes will aid our understanding of the total sedimentary system in the NVZ. This, again, will have important applications in land management and restoration in Iceland (Arnalds 1987).

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Assessment of subsurface lithology in periglacial environments using geophysical techniques

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Geophysical methods are particularly suitable for geomorphological investigations since the knowledge of structure, layering and composition of the subsurface at different scales are key parameters for geomorphological problems. In alpine subarctic environments the permafrost distribution can be a further important parameter influencing the periglacial morphodynamics. Various geophysical techniques have been used to study permafrost and characterise areas of permanently frozen ground for many years. Since geoelectrical methods are most suitable for investigating the subsurface with distinct contrasts in conductivity and resistivity, respectively, DC resistivity soundings constitute one of the traditional geophysical methods which have been applied in permafrost research to confirm and characterise mountain permafrost.

In general, a single geophysical method can lead to ambiguous results concerning the detection and characterisation of the subsurface lithology; hence, the combination of at least two methods is recommendable. Among the different geophysical techniques which are standardly applied, resistivity surveys constitute the most multifunctional method for research in glacial and periglacial environments since a comprehensive characterisation of the subsurface lithology can be obtained and additionally also a differentiation of ice types (between sedimentary ice and congelation ice) is enabled. In spite of some limitations of data interpretation two-dimensional resistivity tomography is considered as the most multifunctional method and could be first choice for geomorphologists working in mountain environments if only one single method can be applied.

During recent years advances have been achieved in using the traditional methods but with more powerful, state of the art instruments and modern data processing algorithms (two-dimensional surveys and data processing). The focus of this contribution lies on two-dimensional electrical resistivity tomography (electrical resistivity imaging) being one of those modern geophysical survey methods which have been used for various environmental studies for some years. The increase of application of modern geophysical methods also in geomorphology is due to the fact that geophysical methods are comparatively fast and non-destructive compared to conventional drilling and information of the whole survey area can be obtained rather than only results from the drilling sites. Furthermore, the more effective data acquisition enabled new fields of application.

The basic principle for the successful application of geoelectrical methods in geomorphology/quaternary geology is based on the varying electrical conductivity of minerals, solid bedrock, sediments, air and water and consequently their varying electrical resistivity. The resistivity of rock for example depends on water saturation, chemical properties of pore water, structure of pore volume and temperature. The large range of resistivity values for most materials is due to varying water content.

The measured apparent resistivities may be used to build up a vertical contoured section showing the lateral and vertical variation of resistivity over the section. The conventional method of plotting the results for the interpretation is the so called pseudosection, which gives an approximate image of the subsurface resistivity distribution. The shape of the contours depend on the array geometry and the subsurface resistivity. The arrays most commonly used for 2-D resistivity surveys are the so called Wenner, Wenner-Schlumberger and Dipole-Dipole configurations. Knowing the resistivities of different material types, it is possible to convert the resistivity image into an image of the subsurface consisting of different materials. However, as a consequence of overlapping resistivity values of different materials the information might be non-unique.

The inversion software tries to reduce the difference between the calculated and measured apparent resistivity values by adjusting the resistivity of the model blocks. A measure of this difference is given by the root-mean-square error (RMS). However, the best model from a geomorphological or geological perspective might not be the one with the lowest possible RMS. Thus, it is essential to perform the interpretation with consideration of the local geomorphological setting. This enables unrealistic images of the subsurface structure to be excluded. A further advantage of the 2-D inversion software is the possibility to incorporate topography in the inversion, which is an important factor for surveys on geomorphological features in mountain terrain.

The assessment of sediment thickness might be difficult depending on the subsurface resistivity distribution; in some cases only a semi-quantitative interpretation can be derived. Several examples of 2D resistivity imaging on geomorphological features with and without permafrost are shown of which some examples appear to be easily interpretable and some are more difficult surveys. On the latter, more challenging resistivity surveys the limits of interpretation of resistivity imaging surveys are discussed.

The significance of modern geophysical methods such as two-dimensional resistivity tomography for geomorphological studies is beyond controversy, if the limits of data interpretation are considered. At present 2-D surveys are the best compromise for efficiently obtaining survey results, although 3-D resistivity surveys are already possible. The resulting pseudosections yield - depending on the array geometry and chosen spacing - to detailed images of the subsurface. Choice of the appropriate electrode configuration for a field survey has to be determined from case to case. Special characteristics of the different array geometries should be considered, above all the investigation depth and the sensitivity of the array to vertical and horizontal changes in the subsurface resistivity distribution. In difficult cases and to avoid ambiguous results two-dimensional electrical resistivity surveys should be used in conjunction with other geophysical techniques such as refraction seismics or ground penetrating radar surveys as they provide complementary information about the subsurface.

Partial reactivation of an alpine rock glacier: response to Little Ice Age climatic change?

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Moderate climatic changes in alpine environments can induce modification in altitudinal limits. But activation thresholds are not the same for various periglacaial processes. Therefore many periglacial feature offer different responses to climatic imput variations.

Alpine rock glaciers were developed during the deglaciation stages of Wurm period or during the Late-glacial sequence. It results from both abundant debris accumulation and interstital ice feeding.
Therefore bloc tongue movment can be activated either by an important block input from the headwall, or from modification in intersticial ice budget.

The Chanrouge rock glacier is located in the Vanoise (northern Franch Alps) between 2700 and 2400 m, in a gentle sloping valley, on the northern slope of the calcareous Aiguille des Corneillers (3055 m).

The lower part is divided into two lobes, that do not show any signs of actual surface movement. The development of this double feature can be related to different rock failure providing large bloc supply probably associated to headwall permafrost destabilisation. The secondary lobe is diverted into a 30 m deep meltwater channel cut into cellular dolomite; this implies that the block tongue was emplaced later than the retreat of a local glacier lobe in the higher valley.

The upper part of the rock tongue offers evidence of present day permafrost activity above 2550 m (that corresponds to the limit established by W. Haeberli in the northern Alps). Surface ridge movement features are obvious.

A small divergent lobe is seen at 2500 m; it progrades perpendicularly to the main rock tongue. It seems to result from local reactivation, but rock movement should have been empeded and diverted by the main rock accumulation. This partial mobilisation can respond to an increase of snow feeding or to a change of intersticial ice plasticity. In this case, climatic imput variation was able to change slightly the altitudinal limit of internal permafrost movment, but was not sufficient to set movement to the whole feature.

It could be to related to the Little Ice Age, but the lack of organic deposit cannot support any dating. Indirect dating from historic pollution trace deposits is in progress.

Recent paraglacial slope deformation in Kongsfjorden area, West Spitsbergen (Svalbard)

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Since the end of the Little Ice Age, some parts of West Spitsbergen are experiencing a transition from a landscape dominated by glacial and periglacial processes to one in which paraglacial response is predominant (Mercier, 2001, 2002 ; Laffly and Mercier, 2002), like other glacier margins all over the world (Ballantyne, 2002). The paraglacial concept was first introduced by Ryder (1971a, b) and formalised by Church and Ryder (1972) as "nonglacial processes that are directly conditioned by glaciation" and they identified a "paraglacial period" as the time interval over which paraglacial processes operate. Recently, Ballantyne (2002) proposed a new and largest definition of paraglacial concept "nonglacial earth-surface processes, sediment accumulation, landforms, landsystems and landscapes that are directly conditioned by glaciation and deglaciation". Effectively, in the Kongsfjorden area (79°N, 12°E), glaciers retreated from their Little Ice Age maxima, and deformations affected both rock slopes and sediment-mantled slopes.

1 – Study area

Field investigations were carried out in the Kongsfjorden area, on the Brøgger Peninsula and surrounding, NW Spitsbergen, Svalbard. The study area is mountainous and supports a number of valley glaciers. Mass balance investigations on the local glaciers indicate a negative net balance since the end of the Little Ice Age (Lefauconnier *et al.*, 1999). Small glaciers (around 8 km^2 in area) have been retreating throughout the 20th century, more than a kilometre from their Little Ice age maxima in length and more than one hundred meters in high. Our approach combines geomorphological field observations with data obtained from aerial photography.

2 – Paraglacial adjustment of rock slopes

Rock mass response to stress redistribution is strongly conditioned by lithology and structure, in particular by joint density, orientation and inclination of discontinuities (Ballantyne, 2002). In the Kongsfjorden area, metamorphic rocks presented progressive rock-mass deformation with modified profiles, gravitational creep. The rates of rockwall retreat due to stress release in areas of recent deglaciation averaged 0.72 m.ky-1, compared with only 0.008-0.22 m.ky-1 resulting from freeze-thaw effects on rockwalls not affected by recent glacier advances (André, 1997).

3 – Paraglacial modification of sediment-mantled slopes

On the lateral moraine, like on the Colletthøgda slope, Kongsbreen glacier has retreated more than 1 200 meters between 1970 and 1990 and 900 meters between 1990 and 1996. The active (major?) processes reworking sediments are debris flows. On the site, 224 gullies were observed (gully density is 20 per 100 m). Process occurs each "summer" and is not dependent on extreme events but on the spatial distribution of ice inside the sediment-mantled. Rapid melting ice-core produced both slumping and translational sliding. Transfers of saturated sediments generate small alluvial fans. Paraglacial dynamic modified slope profiles (reduction in gradient from a mean angle of 37° to a mean angle of 15°). Rapidly, full sequence of paraglacial slope modification (gully incision-stabilisation) may occur within two decades on this site.

Conclusion

Some parts of West Spitsbergen, especially slopes in the Kongsfjorden area, experience very rapidly paraglacial adjustment of rock slopes and reworking of sediment-mantled slopes. Finally, in time scale, paraglacial dynamic on slopes presented the main input of sediment fluxes in the system after deglaciation.

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Permafrost Coasts of the Arctic

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The coastal zone is the interface through which land-ocean exchanges in the Arctic are mediated. Arctic coasts are highly variable, can be stable or extremely dynamic, and their dynamics are a function of environmental forcing (wind, waves, sea-level changes, sea-ice etc.) on the one hand and coastal morphology and geology on the other hand (Figure 1).

Coastal processes in the Arctic are strongly controlled by Arctic-specific phenomena. During the winter season, comprising 7-8 months, a thick and extensive sea-ice cover protects the coastline from hydrodynamic forcing. During the open water season, mainly after break-up in spring, the sea-ice is an important transport agent for sediments originating from coastal erosion.

Vast areas of the Arctic mainland are characterized by the occurrence of frozen ground (permafrost). In the coastal region the permafrost deposits, which can be frozen down to a depths of 1000 m, are in direct contact with relatively warm and saline sea-water. In the geological past, during periods of lower sea-level, the shallow Arctic shelf seas (mainly the Siberian shelf seas) have been dry and permafrost could be formed, which today, after flooding of the shelves, still exists as submarine permafrost. The coastal region is the transition zone between onshore and offshore (submarine) permafrost and the degradation of permafrost, which can be connected with the release of permafrost-bond greenhouse gases, is concentrated in this zone.

During the short, ice-free period the unlithified ice-rich, permafrost-dominated coastlines are rapidly eroded (at rates of several meters per year). Figure 2 shows an examples from the Siberian Laptev Sea. Coastal retreat results in land and habitat loss and, thus, affects biological and human systems. Therefore, in some regions geotechnical measures for coastal protection have to be taken. The material released through coastal erosion (sediment and organic carbon) is transported to the Arctic Ocean via currents and sea-ice and its contribution plays an important role in the material budget of the Arctic Ocean - in some shelf seas coastal erosion fluxes exceed the river input.

Arctic Coastal Dynamics (ACD) is a multi-disciplinary, multi-national project of the International Arctic Science Committee (IASC) and the International Permafrost Association (IPA). The overall objective is to improve our understanding of circum-Arctic coastal dynamics as a function of environmental forcing, coastal geology and permafrost and morphodynamic behavior. In particular, ACD aims to:

- establish the rates and magnitudes of erosion and accumulation of Arctic coasts and to estimate the amount of sediments and organic carbon derived from coastal erosion;
-develop a network of long-term monitoring sites including local community-based observational sites;
- refine and apply an Arctic coastal classification (includes ground-ice, permafrost, geology, etc.) in digital form (GIS format) and produce a series of thematic and derived maps (e.g. coastal classification, ground-ice, sensitivity etc.);
- compile, analyze and apply existing information on relevant environmental forcing parameters (e.g. wind speed, sea-level, fetch, sea ice etc.);
- identify and undertake focused research on critical processes;
- develop empirical models to assess the sensitivity of Arctic coasts to environmental variability and human impacts.

Further information can be found at the ACD internet page: http://www.awi-potsdam.de/www-pot/geo/acd.html.

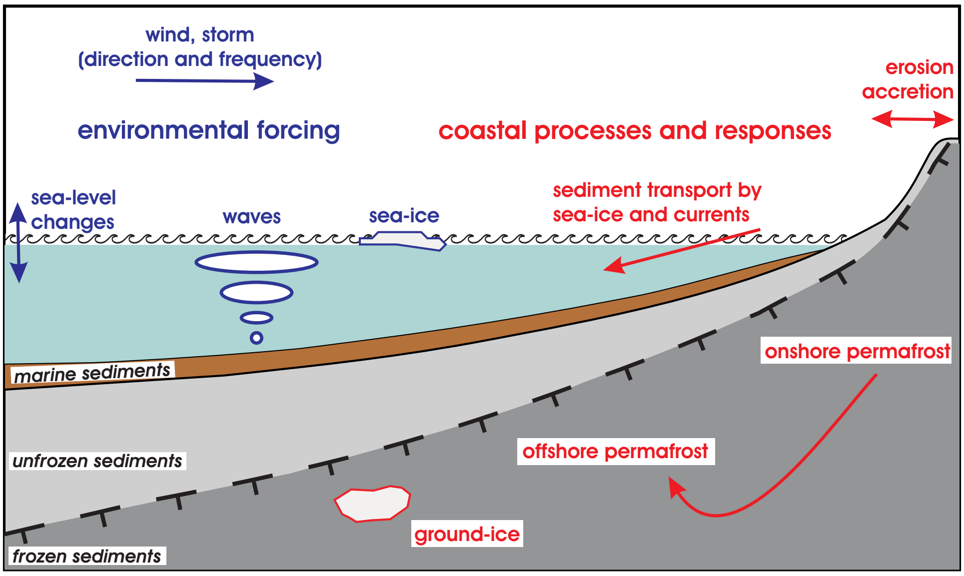

Figure 1. Arctic coastal dynamics as a function of environmental forcing and coastal morphology and geology. Arctic phenomena, i.e. sea-ice and permafrost, are of specific importance (see text).

Figure 2. Coastal section of the island Muostakh in the SE Laptev Sea (Siberian Arctic). The coastal cliff, which is ca. 15 m high and composed of frozen, ice-rich deposits (so-called Ice Complex), is rapidly eroded. The coastal retreat rates are several meters per year and most probably the island will be completed destroyed within the next 50 years.

Jökulhlaups impacts within the Jökulsá á Fjöllum system, NE Iceland: implications for sediment transfer

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The combination of glacial and volcanic activity in Iceland produces some of the world's largest glacial and fluvial sediment fluxes. Relatively frequent jökulhlaups are believed to be the dominant sediment transport agent in southern Iceland, accounting for most of the sediment stored within the vast *sandar* of southern Iceland. By contrast, much less is known about processes and rates of sediment transfer from the northern margin of Vatnajökull to the Denmark Strait. We review current understanding of the source, magnitude, frequency and impact, of jökulhlaups in the Jökulsá á Fjöllum river, northeast Iceland. Secondly, we discuss implications of current knowledge of jökulhlaup impacts for an understanding of sediment flux within the Jökulsá á Fjöllum river system.

Jökulhlaup source: Björnsson (2002) and Björnsson & Einarsson (1990) suggested that volcanic activity in the Bárðarbunga subglacial caldera may be the source of the flows that created the Jökulsá á Fjöllum canyons. Tómasson (1973) suggested Kverkfjöll, Grímsvötn or Bárðarbunga calderas or even from an ice-dammed lake to the south of Kverkfjöll as a possible source. Tómasson (2002) and Waitt (2002) however favoured Bárðarbunga as a source of volcanically triggered jökulhlaups. Björnsson (2002), Käyhkö et al. (2002), Carrivick et al. (In press, submitted), and Marren et al. (Submitted) identify Kverkfjöll as an additional jökulhlaup source.

Magnitude & frequency: Tómasson (1973, 2002) and Waitt (2002) reconstructed peak palaeo-jökulhlaup discharges in the Jökulsá á Fjöllum of 0.2–1.0 x 10^6 m^3s^{-1}. Käyhkö et al. (2002) and Alho (2003) used satellite remote sensing to map large-scale patterns of jökulhlaup erosion and deposition within the Jökulsá á Fjöllum. Alho et al. (submitted) used step backwater modelling techniques to reconstruct a peak discharge of 1.0 x 10^6 m^3s^{-1} from the upper reaches of the Jökulsá á Fjöllum. Russell et al. (2000) and Carrivick et al. (2002, in press, submitted) suggest that at least two jökulhlaups with peak discharges of ~10^5 m^3s^{-1} drained the flanks of Kverkfjöll during the Holocene. Some of the jökulhlaups with peak discharges of 10^4 m^3s^{-1} noted in the 15th, 17th and 18th centuries (Thórarinsson, 1950; Ísaksson, 1985) may be the equivalent of at least 6 jökulhlaups of possible historical age which drained from the snout of Kverkjökull (Marren et al., submitted).

Jökulhlaup impact and sediment flux: Geomorphological evidence of jökulhlaups comprises large tracts of scoured 'scabland' topography, bedrock gorges, streamlined erosional hills, boulder fields, large bars & bedforms. Large-scale jökulhlaup hydraulics and patterns of erosion and deposition within the Jökulsá á Fjöllum are strongly controlled by bedrock topography (Alho *et al.* submitted). The upper-middle reaches of the Jökulsá á Fjöllum contain a number of major basins which acted as sediment traps, providing a record of multiple high magnitude jökulhlaups. Conversely, reduced aerial extent of backwater ponding during smaller jökulhlaups resulted in reduced storage potential and the ability to transport sediment more efficiently through the system.

The magnitude and frequency regime of jökulhlaups in the Jökulsá á Fjöllum exerts a major control on the availability of sediment for transport in terms of the time required for 're-stocking'. Complexity of jökulhlaup channel topography increases the potential for lower magnitude jökulhlaups to rework deposits associated with larger floods. Active rifting processes and inundation of jökulhlaup channels and deposits by subaerial lava flows alters between- and possibly within-event flood channel morphology as well as increasing the long term preservation potential of jökulhlaup deposits. Jökulhlaups also provide a major source of sediment to the aeolian system (Käyhkö et al., 2002). Major fluvio-aeolian interactions have already been identified in the Jökulsá á Fjöllum (Käyhkö et al., 2002; Mountney & Russell, in press).

Outlook for future research: On-going research in the Jökulsá á Fjöllum seeks to establish a Holocene jökulhlaup chronology, allowing reconstruction of jökulhlaup magnitude and frequency regime. Correlation of proximal and distal jökulhlaup evidence will aid our understanding of jökulhlaup sediment flux in the Jökulsá á Fjöllum. In order to assess the impact of jökulhlaups as agents of sediment transfer we also require information about the role of non-jökulhlaup flows such as diurnal, seasonal and surge-related flows.

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Analysing denudative slope processes by combining process measurements with mapping and dating techniques and a GIS based integration of biological and geomorphological data – first results from Latnjavagge, Swedish Lapland

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This investigation is part of a monitoring programme which was initiated in the year 1999 in the Latnjavagge drainage basin (9 km²; 950 – 1440 m a.s.l.; 68°20`N, 18°30`E) in arctic-oceanic northernmost Swedish Lapland. The major monitoring programme in Latnjavagge aims at the quantification of the present-day sediment budget in this periglacial fluvial system. The intensity and spatio-temporal variability of the relevant denudative slope processes have been analysed by combining direct process measurements with mapping and dating techniques. Direct process measurements include the analysis of rockfall and boulder fall activity, the connected retreat of rockwalls and rock ledges and the analysis of creep and solifluction rates. Instrumentations and measurements have been conducted at several slope test sites within Latnjavagge showing differences in aspect, steepness, snow cover duration, ground frost, soil moisture, granulometric features of the regolith/debris, and vegetation cover. Mapping has included detailed geomorphological and vegetational mapping of the west- and east facing slope systems in Latnjavagge. Geomorphological data is analysed in combination with biological data using GIS as a tool. By integrating plant ecology with process geomorphology the interactions between vegetation cover and slope processes have been investigated. Aerial photographs and field investigations have been used to find process traces. Recurrence intervals of rapid process events have been estimated by mapping the spatial frequency of process traces and by dating these former process events using lichenometry and dating of pioneer plants colonising the bare ground after debris flows and slides. The denudative importance of discontinuous process events like ground avalanches, bebris flows and boulder falls has been estimated by mapping and quantifying the volumes and masses of material accumulated during these process events. Rockfall and boulder fall activity have been monitored since 1999 at several selected slope test sites using nets for collecting rockfall debris, painted rock wall areas, counting, morphometric analysis and lichenometric dating of boulders and a detailed photo documentation. Creep movements and solifluction have been measured by using painted stone lines (creep at talus cones), steel rod lines, and plastic tracers for depth-integrated measurements of moving rates (solifluction lobes and sheets). Altogether, the intensity of present-day slope processes in this arctic-oceanic periglacial environment is low. The low intensity of denudative slope processes, especially the low frequency of debris flows and slides, is to a large extent due to the very stable vegetation cover and the closed rhizosphere which are developed below 1300 m a.s.l. in the entire Latnjavagge catchment area. During former debris flow and slide events only smaller amounts of material were transported over only shorter distances. Avalanche activity is restricted to the steep east facing valley slope west of lake Latnjajaure. Solifluction and creep is characterised by only shallow and very slow movements of material. The most important slope processes regarding annual mass transfers [t m yr^{-1}] are rockfalls and boulder falls. Because of the altogether low process intensities in this periglacial environment longer monitoring periods (ca.

10 yr) are necessary to achieve reliable quantification of the process rates, mass transfers and the present-day sediment budget.

The combination of direct process measurements with mapping and dating techniques and the GIS based integration of biological and geomorphological data appear to be useful for the analysis of slope process intensities in this kind of environment.

Quantification of alpine rockwall retreat by aid of georadar and geoelectric measurements

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In several study areas in the Northern Alps, total thickness and structure of alpine talus accumulations were investigated by means of various geophysical techniques, mainly georadar (GPR) and 2D-geoelectrics (ERT). The results point to rates of backweathering of the dolostone rockwalls of 200 to 400 mm/10³a. It is very likely that a core of late-glacial or even LGM moraine material contributes to the total talus thicknesses. GPR turned out to be a powerful tool for the determination of debris volumes. Supporting geoelectric and seismic investigations are advisable to validate the results and to facilitate the interpretation.

Introduction

The quantification of stored material in sediment sinks is an important contribution to understanding regional sediment balances. Furthermore, the quantity of loose debris in alpine catchment areas represents a fundamental factor for risk assessment.

In many alpine cirques, where fluvial erosion is negligible, talus accumulations are archives for the quantity and temporal distribution of debris production. However, the time span to which the total amount of weathered material is related, has to be carefully examined.

The aim of the study is to check the application and the limitations of geophysical methods, as well as to provide an estimation of rockwall retreat rates by measuring the total volume of debris accumulated on the slopes.

Study areas and methods

The areas of investigation are spread over different geological units and altitudes of the Northern Alps. The preliminary results presented here were obtained in the Tegelberg area in the northernmost range of the Alps (47°34'N, 10°47'E) and in the Parzinn area in the Lechtaler Alps (47°15'N, 10°36'E). The predominant rock type in both areas is Hauptdolomit, a mostly well-bedded, intensely fractured dolostone that frequently stands out for extensive talus accumulations underneath the brittle rockwalls. The rock outcrops in the Tegelberg area are located in a small cirque at an elevation of 1600 - 1800 m a.s.l., while the Parzinn area ranges from 1900 - 2600 m, with rockwalls of up to 400 m height.

In both areas, a total of 12 GPR and 6 ERT measurements were carried out. Additional GPR, ERT and seismic measurements will be carried out in spring and summer 2004. In the Tegelberg area, drillings are planned for May 2004.

General results and efficiancy of the methods

The propagation velocities of the radar waves were determined from WARR (wide angle reflection and refraction) measurements. The velocities range from 0.10 to 0.125 m/ns in most of the debris bodies (Table 1). Specific velocity determinations in moraine and in bedrock are still to be carried out.

The electrical resistivity is highest in unconsolidated, loose debris (Table 2). In consolidated debris and/or debris with a higher portion of fine material, the resistivity is much lower. However, there is a broad overlapping between the possible values of debris and bedrock. This means that a distinction is difficult without the application of further techniques. The moraine material in the Parzinn area stands out for much lower resistivity (Table 2).

Table 1: Propagation velocities of GPR waves

Location	material	velocity (m/ns)
gravel pit (test)	gravel	0.09
	loose heap of debris	0.16 - 0.18
Tegelberg	debris, grass-covered	0.105
Parzinn	Loose debris	0.10 - 0.11
Dammkar	Loose debris	0.10
Zugspitze	Loose debris	0.125

Table 2: Electrical resistivity of various substrates

Material	resistivity (Ωm)
Debris (coarse, loose)	8000 - >20000
Debris (consolidated)	6000 - 15000
Debris (fine or veg.covered)	2000 - 8000
Debris (fluvially reassorted)	1000 - 4000
Moraine (veget.covered, Egesen)	500 - 3000
Bedrock (dolostone)	5000 - 10000

In all of the areas (a total of approx. 25 GPR profiles), the radar reflection patterns of talus material were characterized by distinct, surface-parallel lines (Fig. 1 and 3). Part of these lines are connected with intensive, repeated wave arrivals and are not subject to geological structures. However, many of the reflectors are limited to certain areas of the cones and hit other lines discordantly. Therefore, these features probably witness internal structures (interbedding of finer and coarser layers).

The debris - rock interface is characterized by an fading of the debris reflections rather than by a single distinct reflector. This is probably due to the rather low dielectrical contrasts between dry rock and dry debris. These results were obtained in all areas of investigation and are definitely not related to a lack of transmitted energy. Partly, the unsharp boundary line renders it difficult to clearly define the bedrock surface. In or slightly below the depth of the supposed bedrock surface, hyperbolic reflection patterns (usually connected with single reflectors like large boulders) were frequently observed. These patterns are due to outcropping edges of Hauptdolomit layers buried by debris.

Structure and thickness of the debris bodies

The boundary between debris and moraine material is usually characterized by a considerable contrast of the electrical and dielectrical properties. In the radargram of Fig. 1, the interface is clearly recognizable as a diagonal bunch of lines.

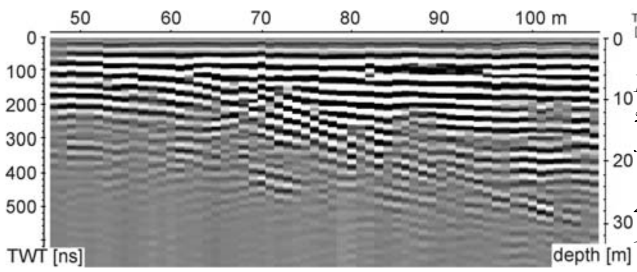

Fig. 1: Part of the radargram "Dremel 1" (25 MHz), Parzinn area. The profile stretched from the Egesen moraine ridge (left) upslope on an extensive talus cone (right.). Note that from a profile distance of 60 m, the surface rises with an angle of 30° to 35°.

Fig. 2 shows the sharp resistivity contrast at the glacial deposits / debris interface (white dashed line). The very loose surface layer of the talus contrasts to the better consolidated or finer debris below. However, in greater depths it is unclear whether the areas of medium resistivities (5000 - 10000 Ωm) are related to bedrock or to dry, consolidated debris.

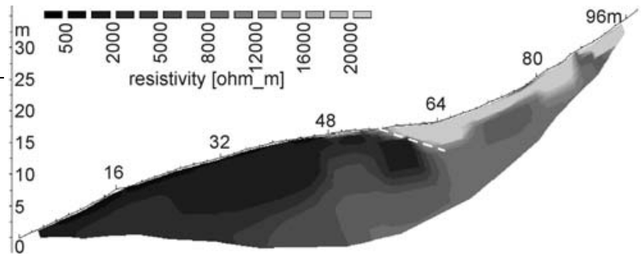

Fig. 2: ERT section "Dremel 1", Parzinn area. The profile was situated parallel to the radargram (Fig. 1)

At the Tegelberg site, a talus thickness of 13 to 16 m was established, which equals to a rockwall retreat rate of 600 mm/10^3a. Taking only the uppermost (probably Holocene) layer of the talus into consideration, the weathering rate decreases to 200 mm/10^3a, which is in the order of magnitude of recent rockfall measurements (SASS, submitted).

In the Parzinn area, talus thicknesses of up to 44 m were measured. However, the profile "Dremel 4" (Fig. 3) and other profiles give evidence for a core of moraine material under the debris. The loose talus material with the characteristic, striped radar facies can be clearly distinguished from a deeper zone with more irregular reflection patterns. The spatial connection to the moraine ridge at the surface leads to the assumption that the debris cone is underlain by late-glacial moraine sediments. The bedrock surface follows way deeper. Further reflectors within the moraine material possibly indicate at least two phases of moraine deposition.

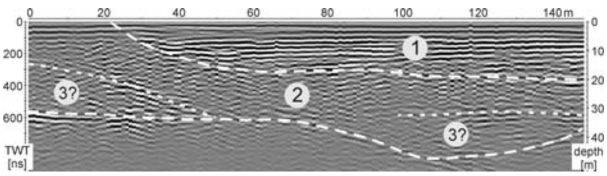

Fig. 3: Radargramm of a part of the talus cone "Dremel4", Parzinn. Starting point (0m) on Egesen moraine ridge (horizontal), start of the loose debris at 20m profile distance (inclined 30-35°).
1: loose debris (Holocene);
2: late-glacial moraine material;
3?: possibly late-glacial or LGM basal moraine.

The quantification of the upper layer of the talus again leads to a backweathering rate of 200 to 400 mm/10^3a. Similar results were obtained by HOFFMANN & SCHROTT (2002).

Preliminary conclusions

By aid of GPR, a very high penetration depth of more than 40 m was achieved. The cross-check with geoelectric measurements renders it possible to calculate reflectivities and thus contribute to a more sophisticated data interpretation.

The assumed core of moraine material under the talus slopes is concurrent to the calculation methods of MAISCH et al. (1999), according to which the late-glacial cirque glaciers of the northern Alps must have been mostly "sedimentary based". Using seismic refraction, however, it is not always possible to differentiate bedrock from glacial deposits (HOFFMANN & SCHROTT, 2002). Thus, GPR might turn out to be a powerful tool for the investigation of talus accumulations.

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Monitoring of a large landslide in the Almenningar area, N-Iceland

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The presented project is part of an ongoing study of a large landslide in the Almenningar area, N-Iceland. Inside the landslide area, large bodies of landslide material show signs of constant movement, which might have been active for a long time. The aim of the current investigation is to find the origin and control factors of the landslide activity in the Almenningar area, but the main focus is finding the reason for the constant movement in parts of the landslide material.

The Almenningar area is located in the outermost part on the eastern side of the Skagafjörður fjord. The investigated area is about 5-6 km long, from the farm Hraun in the south and north to the Skriðnavík cove. The area is characterised by a north-south oriented coastline with up to 80 m high sea cliffs. Above the coastline two glacially eroded, east-west oriented valleys occur, separated by up to 500-600 m high mountains. The mountain sides are covered by thick landslide material, often reaching down to the present shoreline. At least six large landslides have been observed in the area. The largest of those are located in the southernmost and northernmost parts. The main and only whole year road to the town of Siglufjörður leads through the landslide area.

Since 1977 the Icelandic road authority has carried out measurements of the moving bodies of debris in the Almenningar area. Since the road was constructed in the area, more than 40 years ago, extensive damages have occurred on the road, often causing hazardous conditions.

The bedrock in the area is from the Tertiary period, about 10-15 million years old. It is mainly build up of jointed basaltic lava flows, usually separated with relative thin sedimentary horizons. The lava pile in the area is generally dipping about 7-10° towards the west and southwest, but local dip can be up to 22° in the same direction.

In the year 2003 extensive geomorphologic mapping was carried out in the area. At least six large landslides were observed. Three of those landslides did not show any indications of movement, but the other three showed that a constant movement has occurred, probably over long periods of time.

The main research focus has been on the northernmost landslide, the Tjarnardalir landslide. In the last few years severe damage has occurred on the part of the road located there, often causing hazardous conditions. The Tjarnardalir landslide is originated from the western side of the Mánarfjall Mountain. The scar of the landslide is about 800 m long from north to south and about 850 m long from east to west. The mean width of the slide is around 1400 m and mean length about 1550 m. The total volume of the slide is estimated at least 110,000,000 m^3. The front of the landslide reaches the present coast, forming up to 60 m high coastal cliffs that show clear indications of extensive coastal erosion. The frontal part of the landslide can be divided into two areas. The southern one, reaching from the Kóngsnef cliff, south to the Kvígildi Mountain, is characterized by a 450-500 m wide and 250-300 m long slide scar. The road is situated inside the scar, about 100-250 m from the coastline, which forms about 20-30 m high sea cliffs. In this area measurements show westward movement with mean rate up to 60 cm/year. The northern side, from the Kóngsnef cliff north to the Skriðnavík cove, is characterized by up to 60 m high steep coastal cliff. In this part the road is situated 20-50 m from the cliff edge, at about 80 m height. A steep 30-40 m high slope is located above the road. The costal erosion in this part of the landslide is extensive, and the slope below the road shows clear signs of slide movement. Several large U-shaped failures have formed in the road itself. Measurements in this area show westward movement with mean rate up to 26 cm/year.

Further studies in this area will mainly be focused on the stratigraphical record. It is important to know which types of sediments underlie the landslide material and find out if some sliding planes occur that can explain the movement. It is also important to understand the triggering factors for these movements. It is known that the main sliding movement occurs from April to June, i.e. during the snow-melt period and from August to October, i.e. during the autumn rain period. It is also known that extensive costal erosion occurs, but its role for the sliding movement is not fully understood.

Sediment budgets of two small catchments in the Bavarian Alps, Germany

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These investigations were carried out in two small catchments (Reintal, Lahnenwiesgraben) in the German Alps near Garmisch-Partenkirchen, Bavaria. Both catchments have drainage areas of about 17 square kilometres, which facilitates quantitative comparisons between the basins relating to runoff and sediment production. The studies are part of an ongoing comprehensive research project on sediment cascades in Alpine geosystems. Our research focuses on fluvial sediment (transport, mobility, and functional connections). Recording stations are installed at each of the catchment outlets. They log water level, electrical conductivity, and turbidity. The stations are equipped with automatic water samplers for regular and event related sampling. Parameters analyzed in the samples are suspended sediment concentration and grain size as well as the concentration and ion composition of the dissolved load. At selected discharge stages bedload was collected with a Helley-Smith sampler.

The Reintal is drained by the Partnach river, its catchment is lithologically dominated by massive limestones (Wettersteinkalk), which are subject to karstification processes (underground drainage, caves, karst hollows). The Lahnenwiesgraben is underlain by mixed lithologies including limestones but also easily erodible rocks (mudstones, moraine deposits with high quantities of fine-grained material). The Partnach River has a discontinuous profile, interrupted by rockfall induced sediment storage basins (small lakes, alluvial plains). These intervening sediment sinks result in a reduction in the output of solid load and sediment throughput in the upper and central part of the system. Thus the system is disconnected and uncoupled. Discontinuities in the Lahnenwiegraben are only caused by man-made river training with bed load retaining check dams, which are filled by fluvial sediments. Thus the Lahnenwiesgraben has the character of a coupled system.

Runoff is highly variable in the Lahnenwiesgraben reacting directly and sensitively to rainfall input. The flood hydrographs show short lag times and steep rising and falling limbs (Fig. 1). The Partnach is a buffered system (buffering caused by karst hydrology and the storage systems). Runoff peaks are less steep with a broader base (Fig. 1). Only one flood hydrograph in August 2002 had an extremely steep rising limb resulting from a storm event, which covered the area directly upstream of the gaging station. The different runoff characteristics of the catchments have important consequences for sediment transport dynamics. They make the two catchments interesting natural experimental sites for comparing sediment transport attributes in coupled and uncoupled systems as well as in buffered and non buffered fluvial systems.

The regular way to calculate annual load and the load of individual flow classes is by using the flow duration curve and the rating curves for the individual sediment components. This was, however, not possible for all components on the same level of reliability, which has to be considered in the evaluation of the results.

There was no highly significant correlation between concentration of total dissolved solids (TDS) and discharge in both catchments because of the small variation of the dependent variable (TDS). Data for dissolved load were derived from the close relationship between elecrical conductivity and TDS, which was found on a continuous monitoring basis at the measuring stations. In small mountainous catchments the correlation between suspended sediment concentration (SSC) and discharge is generally rather poor. In the Reintal, however, the calculation of SSC was possible with a polynomial rating curve. In the Lahnenwiesgraben the calculation of SSC had to be made with event specific rating curves, separated for the limbs of the hydrograph, or with interpolation for sampling intervals. It was interesting to note that there is a close correlation (r=0,8606, n= 50) between the peak discharges of individual events and the total suspended sediment load during the event.

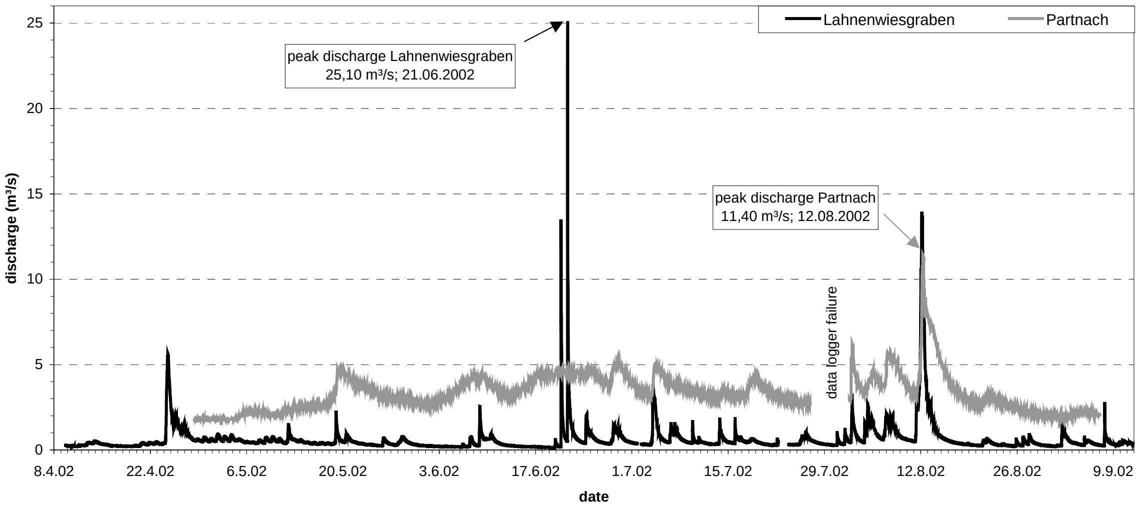

Figure 1. Hydrographs of the alpine rivers Lahnenwiesgraben and Partnach in the 2002 obeservation period (log interval 15 minutes).

The relation between discharge and Helley-Smith bedload sampling is highly significant (>99%) for the Lahnenwiesgraben. But the rating curve is problematical, as manual measurements are not possible at discharges above 9 $m^3 s^{-1}$. There was no highly significant (only 90%) relationship between discharge and bedload transport in the Partnach. In the disconnected system of the Partnach dissolved load output is dominant. Solid load output accounted for less than 10% of total sediment export in 2001, but for more than 25% in 2002, when peak discharges were higher. In the connected system of the Lahnenwiesgraben with throughput of solid load, SSL and bedload output are much more important with more than 70% of total load in 2001 and more than 90% in 2002.

Effective discharge is defined as the flow or flow class which performs most work in terms of sediment transport. Effective discharge may be calculated separately for the different types of sediment transport (dissolved load, suspended load, bedload) and also, in an integrated approach, for the total load. Both approaches will be discussed in the presentation. In the Partnach effective dicharge is found in low flow classes (less than 5 $m^3 s^{-1}$), in the Lahnenwiesgraben at discharges of more than 15 $m^3 s^{-1}$.

Significance of mineral / organic components in the sediment flux from upland catchments

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Upland and mountain environments in the UK can be broadly divided between areas of steep relief, dominated by mineral sediment systems, and more subdued moorland areas which have an extensive cover of blanket peat. Generally speaking sediment flux from such environments is low by European standards primarily because of low relative relief and temperate maritime periglacial climate. However, low sediment yields do not mean there are no problems with sediment flux. Many areas are actively eroding and local extreme events can have major impacts. The aim of this paper is to present results from several upland sediment budgets studies carried out in both mineral-dominated and organic- dominated upland catchments in the UK in order to illustrate five main points:

1) Basic geological, topographic, hydrological and vegetation controls govern landscape development at the regional scale and the same factors which contribute to the gross geomorphology also govern sediment flux.
2) The range and intensity of geomorphic processes operating in mineral and organic-dominated catchments is significantly different.
3) The physical properties of peat ('organic sediment') have important implications for sediment flux and transport dynamics.
4) The efficiency of slope –channel coupling differs between catchments where mineral soils dominate and catchments where peat soils dominate.
5) When comparing sediment budgets from mineral-dominated and organic- dominated upland catchments volumetric sediment budgets (m^3) have advantages over mass (t) budgets.

In order to highlight these points two main sediment budgets studies are considered from two small headwater catchments in Northern England. These are Rough Sike in the North Pennines (54º 40'N, 02º 23'W, 540 m.a.s.l., 83 ha) and Iron Crag in the Northern Lake District (54º 41'N, 03º 05'W, 500 m.a.s.l., 2.5 ha). Rough Sike is a blanket peat catchment in the North Pennines with a sediment yield of 44 t km^2 a^{-1}. Results demonstrate that fluvial suspended sediment flux is controlled to a large degree by channel processes. Gully erosion rates are high but coupling between the slopes and channels is poor and therefore the role of hillslope sediment supply to catchment output is reduced. Consequently contemporary sediment export from the catchment is controlled primarily by in channel processes. The Iron Crag catchment is a small torrent system with an annual sediment yield of approximately 1916 t km^2 a^{-1}. The majority of eroded sediment is supplied to an alluvial fan at the base of the system, which acted primarily as a sediment sink. Channel (70 %) and bank (25 %) sources dominate sediment supply, and surface processes and rockfall on the hillslopes (5 %) provide only a minor contribution. Temporal variations in yield display seasonal trends and responses to individual storm events. Freeze-thaw cycle frequency and rainfall characteristics are shown to be important factors controlling sediment delivery.

The implications of this paper are much wider than the UK context illustrated here because in many upland and mountain catchments where there is a dominance of mineral or organic component in the material flux similar considerations need to be heeded when comparing sediment budget results.

Science Meeting Poster Presentations

Sediment fluxes from creep processes at Jomfrunut, southern Norway

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Based on velocity measurements of surface and subsurface creep, sediment flux due to solifluction and ploughing boulder activity were estimated in a mid-alpine site in southern Norway (Finse, UTM185198). The results of the study indicate a geomorphic work performed by solifluction of approximately 9 $MJkm^{-2}a^{-1}$. The results obtained by this study imply that sediment flux rates by solifluction under favourable conditions may be comparable to or exceed those of rapid mass movement obtained in more alpine environments.

Sediment sources and spatio-temporal variability of fluvial sediment transfers in arctic-oceanic Latnjavagge, Swedish Lapland

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This study is part of a monitoring programme which was initiated in the arctic-oceanic Latnjavagge drainage basin (ca 9 km²; 950 – 1440 m a.s.l.; 68°20`N, 18°30`E) in northernmost Swedish Lapland in the year 1999. Over a period of four years the relevant denudative processes have been monitored and quantified.

The mean annual mechanical fluvial denudation rate measured at the inlet of lake Latnjajaure (situated within Latnjavagge close to the catchment outlet) is 2.3 t km^{-2} yr^{-1} (Table 1). More than 90% of the total annual sediment load is transported in a few days during snowmelt generated runoff peaks (Table 2). The major reason for this behaviour is restricted sediment availability. High-magnitude runoff events are necessary to break up channel pavements which is exposing fines. Essential is that snowmelt generated runoff peaks are much more efficient than rainfall generated runoff peaks (Table 2). The snowmelt generated runoff peaks are especially efficient in the early season when ground frost is still present in larger areas of the Latnjavagge valley, preventing infiltration of snowmelt and rain water. The concentrated surface flow in creeks causes the mobilisation of debris creek pavements and the connected exposition of fines. Compared to this situation, saturation overland flow induced by heavy rainfall later in the summer season (after melting of ground frost) does not cause significant mechanical fluvial denudation which is mainly due to the very stable vegetation cover and the closed rhizosphere which are developed below 1300 m a.s.l. in the entire Latnjavagge catchment area. Also piping which occurs frequently at the slope systems and with high intensity during heavy rainfalls in the later summer season does not cause significantly higher suspended sediment concentrations in the surface water. Mobilized channel pavements exposing fines during snowmelt generated runoff peaks are the most important sediment source for the fluvial system in Latnjavagge. Other relevant sediment sources are ice patches and ice fields and material which is mobilized by slush flows. Local disturbances of the vegetation cover and rhizosphere caused by direct human impacts like extensive reindeer grazing, some hiking tourism and field research at the Latnjajaure Field Station, situated in Latnjavagge, are of minor importance. The stable slope systems are characterized by a low frequency of debris flows and slides.

Altogether, the intensity of fluvial sediment transfers – also compared with other arctic periglacial environments - is very low in Latnjavagge. The steepness of channels, the pattern of ice patches and ice fields within the catchment area, and the location of areas showing a significant slushflow activity are the main controlling factors for the spatial variability of mechanical fluvial denudation within the drainage basin. The lakes within Latnjavagge, especially lake Latnjajaure (0.73 km²), are significant sediment traps. Mechanical fluvial denudation is slightly lower than chemical denudation and is – regarding annual mass transfers [t m yr^{-1}] – the second most relevant denudational process in this arctic-oceanic periglacial environment.

Table 1. Rates of mechanical fluvial denudation in Latnjavagge, arctic-oceanic Swedish Lapland.

Field season	***Catchment***	**Precipitation [mm]**	**Discharge [mm]**	**Yield of suspended solids [kg/km^2]**
26.05.2000 - 31.08.2000	*Latnjavagge*	226	754	291
	Outlet Lake		734	211
	Inlet Lake		790	2587
	Subcatchm. A		422	134
	Subcatchm. B		735	360
	Subcatchm. C		629	1027
	Subcatchm. D		747	5157
29.05. 2001 – 18.08.2001	*Latnjavagge*	264	748	1259
	Outlet Lake		754	252
	Inlet Lake		757	2257
	Subcatchm. A		472	206
	Subcatchm. B		675	516
	Subcatchm.C		674	1136
	Subcatchm. D		784	3909
28.05.2002 - 31.08.2002	*Latnjavagge*	158	648	674
	Outlet Lake		650	202
	Inlet Lake		654	2046
Annual denudation rates [kg/km^{2}yr]	*Latnjavagge*		733	762
	Outlet Lake			227
	Inlet Lake			2294
	Subcatchm. A			279
	Subcatchm. B			462
	Subcatchm. C			1217
	Subcatchm. D			4361

Table 2. Snowmelt generated and rainfall generated runoff peaks and sediment transport during runoff peaks in Latnjavagge, arctic-oceanic Swedish Lapland.

Field season	**Runoff peak no.**	**Reason for runoff peak**	**Total yield during peak [kg/km^2]**	**% of total denudation *annual mean (2294 kg/km^{2}yr) / during this campaign***	**Total runoff during peak [mm]**	**% of mean annual runoff (733 mm)**	**C max during peak [mg/l]**	**C mean during peak [mg/l]**	**% of total denudation *annual mean (2294 kg/km^{2}yr) / during this campaign***
2000	1	Snow melt	1864	81 / 72	163	22	43.40	11.44	
	2	Snow melt	412	18 / 16	211	29	6.75	1.95	
	3	*Rain*	*113*	*5 / 4*	*66*	*9*	*2.20*	*1.71*	**104 / 92**
2001	1	Snow melt	2064	90 / 91	388	53	16.20	5.32	**90 / 91**
2002	1	Snow melt	1820	79 / 89	334	46	18.23	5.45	
	2	*Rain*	*49*	*2 / 2*	*31*	*4*	*1.80*	*1.58*	**81 / 91**

The effect of long-term temperature enhancement on potential denitrification across different subarctic-alpine plant communities

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Introduction

Climate change is expected to alter the nitrogen availability and soil carbon dynamics and, as a consequence, affect plant community composition and production and thereby ecosystem gas fluxes rates. The International Tundra Experiment (ITEX) was established at Latnjajaure Field Station (LFS), in northern Swedish Lapland, in 1993 and gives a great opportunity to investigate the long-term effect of climatic warming on the soil ecosystem. The Open Top Chambers (OTCs) used within ITEX are located in five different plant communities, which covers both heaths and meadows and the gradient from dry to moist plant communities, and increases the soil surface temperature by approximately 1.5°C (Marion *et al.* 1997).

In this recently started study we are adopting the results from the ITEX study and try to relate them to the soil processes and properties such as potential nitrification and denitrification, soil organic matter, C:N ratio and ecosystem respiration. Thus, we make an effort to amalgamate plant community changes with changes in the subarctic-alpine soil ecosystem. Here we present the results on potential denitrification and some general soil variables; in June 2004 we also have the intention to present studies on potential nitrification and C:N ratio.

Methodology

The Open Top Chambers (OTCs) used in this study are located in four different plant communities (dry heath, dry meadow, mesic meadow and moist meadow). The plant communities were "point-framed" in august 1994. Soil sampling took place in August 2003. To analyse the potential denitrification we used an anaerobic incubation technique, based on acetylene inhibition technique (Klemedtsson *et al.* 1977), resulting in N_2O as the only end product, which is then analysed by gas chromatography. We also analysed soil water content, soil organic matter and pH.

The multivariate statistic analysis of the plant communities was made with CANOCO 4.5. The result of the Detrended Correspondence Analysis (DCA), length of gradient (of the first axis) = 4.469, shows that there is a unimodal response and we used the multivariate method Correspondence Analysis (CA) for our data (Jongman *et al.* 1995). The soil properties were analysed statistically in a nested ANOVA using StatView 5.0.1 and Super-ANOVA 1.11. Transformation of the data was necessary for potential denitrification and soil organic matter that were log-transformed.

Results & discussion

The eigenvalues of the first two CA axes are 0.747 and 0.454, respectively, and are explaining 49.8 % of the variance, of which 31.0 % is explained of the first axis. The ordination diagram of the CA (Fig. 1) shows that the plant communities are differentiated from each other in four distinct plant communities.

The plant communities are also showing significant differences in potential denitrification ($P=0.009$) as well as in soil water content ($P=0.001$), soil organic matter ($P<0.001$) and pH_{KCl} ($P<0.001$). The highest values of potential denitrification and soil organic matter are found in the dry meadow while the dry heath, not surprisingly, has the lowest values. The dry meadow, which has the highest denitrification activity, is dominated and distinguished by *Dryas octopetala* that has a large root biomass that could influence the activity of the denitrifying bacteria. Symbiotic dinitrogen-fixing bacteria have been found in

D. octopetala (Mattias Zielke pers. comm.) that also may contribute to the higher denitrification activity in the dry meadow. The major difference in the dominating plant species abundance between the plant communities seems to have a regulatory effect on the soil ecosystem.

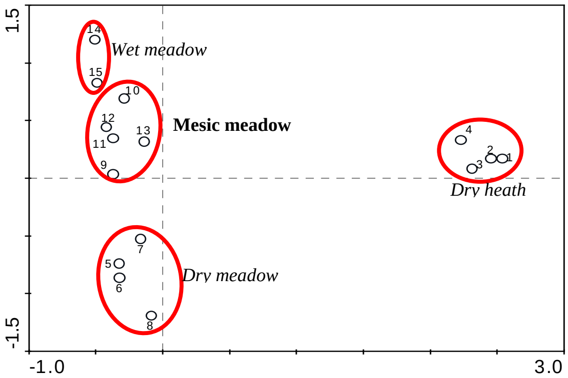

Figure 1. Correspondence Analysis (CA) performed on plant abundances in the canopy. The eigenvalues of the first two CA axes are 0.747 and 0.454, respectively.

There seems to be a slight increase, illustrated in Fig. 2, in potential denitrification due to the temperature enhancement, although, there is no significant effect. The non-significant effect was most likely due to the large spatial variability in denitrification potential within the plant communities. It was however not possible to conduct a more intense sampling procedure of the soil within the OTCs without destroying them for further use. There is also non-significant effect on the other soil properties except in the dry meadow where the soil water content decreased in the OTC ($P = 0.037$).

The results indicate that the plant composition has a larger influence then the 1.5°C soil surface temperature enhancement on the activity of the denitrifying bacteria.

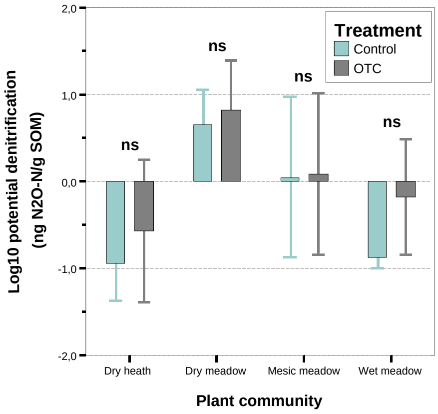

Figure 2. The potential denitrification (ng N_2O-N/g SOM), log-transformed, split by plant community and temperature treatment. ns (= non-significant) are referring to the temperature treatment.

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Glacier Outburst Floods (jökulhlaups) from Kverkfjöll, Iceland: flood routeways, flow characteristics and sedimentary impacts

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Jökulhlaups are known to have drained along the Jökulsá á Fjöllum during the Holocene (e.g. Thórarinsson, 1950; Sæmundsson, 1973; Tómasson, 1973; Waitt, 2002) but little is known about their number, age, source and flow characteristics. This study documents detailed geomorphological and sedimentological evidence for jökulhlaups that have drained through the proglacial area of Kverkfjallarani, part of the fissure swarm associated with the Kverkfjöll Volcanic System. Jökulhlaups have routed through Kverkfjallarani from the glaciated Kverkfjöll volcano and thence into the Jökulsá á Fjöllum. Jökulhlaups inundated the Kverkfjallarani valleys to an extent and depth where each valley became a channel (Carrivick et al., 2004).

Erosional evidence of jökulhlaups within Kverkfjallarani includes gorges, cataracts, spillways, subaerial lava steps and valley-wide scoured surfaces. Depositional evidence includes wash limits, boulder bars, cataract-fill deposits, terraces, slackwater deposits and outwash fans (Carrivick et al., 2004). Some of these landforms have been documented previously in association with jökulhlaups. However, subaerial lava surfaces that have been scoured of the upper clinker, gorges within pillow-hyaloclastite ridges, gorges between pillow-hyaloclastite ridges and subaerial lava flows, subaerial lava lobe steps, cataract-hollow boulder mounds and boulder run-ups are previously undocumented landforms. These landforms may therefore be diagnostic of jökulhlaups within an active volcanic rifting landscape. The spatial distribution and characteristics of these landforms and sediments suggests that there have been at least three jökulhlaups through Kverkfjallarani and that they originated from either of the calderas of the Kverkfjöll volcano.

The routing and hydraulics of the Kverkfjallarani jökulhlaups were very strongly influenced by topographic and geological properties of the routeways. Together with other inter-event processes, these factors also controlled the quantity and nature of sediment supply to a jökulhlaup. Sediment supply from glacial moraine, weathered pillow-lava slope material and pre-existing valley-fill sediments was initially abundant but quickly became exhausted. Present day valley-fill and slackwater sediments consequently reflect initially hyperconcentrated flows that became more fluidal. Increasing discharge and decreasing sediment availability resulted in a decline of sediment load and thus progressively increased flow energies to a threshold above which bedrock erosion ensued. Basalt lava became stripped, scoured and plucked. Plucking was particularly effective due to the characteristic vertical cooling joints of subaerial basalt lava and created a feedback loop as flow energies were exacerbated over a plucked step. Thus cataracts and gorges were formed, particularly at the margins of subaerial lava lobes, in areas of flow constriction and/or immediately upslope of a zone of increased channel gradient. Some plucked boulders became deposited in imbricated clusters.

Jökulhlaups through Kverkfjallarani clearly had a very short flow duration, because sedimentary cover over the bedrock is discontinuous, sediments contain typically structureless units, boulder clusters have no dominant obstacle clast and gorges are generally box-shaped. Imbricated boulder clusters and sedimentary units show that jökulhlaups were probably fluidal, turbulent and supercritical over large areas of the anastomosing channel bed. The assemblage of erosional and depositional evidence suggests that a Kverkfjallarani jökulhlaups had highly variable hydraulic properties, both spatially and temporally. Hydraulic variability was caused by topographic expansion and contraction of channels, a steep gradient and geological properties including subglacial and subaerial lava and tectonic faults that run across and along valleys.

This research continues, with the aim of quantifying spatial and temporal variations in flow characteristics. Flow reconstructions are achieved within a high-resolution 2D model and is validated against the above field data (Carrivick, this volume).
Increased understanding of the relationship between flood characteristics and impacts gained from this research can be used for hazard identification and mitigation on flanks of other glaciated volcanoes and within similar volcanic, glacial and semi-arid environments.

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Palaeohydraulics of a glacier outburst flood (jökulhlaup) from Kverkfjöll, Iceland

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Holocene jökulhlaups from Kverkfjöll volcano probably had a peak discharge ~1-2 x 105 m^3s^{-2} (Carrivick et al., 2004a) and inundated an anastomosing complex of valleys (Waitt, 2002; Carrivick et al., 2004b). However, hydraulic characteristics of those jökulhlaups have only tentatively been suggested (Carrivick et al., 2004a; 2004b,). This study therefore aims to quantify spatial and temporal variations in the hydraulics of jökulhlaups from Kverkfjöll.

Palaeohydraulic reconstructions were achieved, mainly by using a high-resolution 2D model named SOBEK, which routes a user-specified hydrograph over a DEM. A DEM with 10m-horizontal and sub-metre vertical resolution was derived from digital stereo aerial photographs and ground control points, which were obtained by DGPS survey. The SOBEK model was best fitted to field evidence of inundation and flow depth, by varying fluid density, surface roughness, hydrograph shape and peak discharge. Additionally, independent reconstructions of the Kverkfjallarani jökulhlaup were made by the palaeocompetence and slope-area methods. The palaeocompetence method empirically relates the size of fluvially-transported boulders to flow velocity, shear stress and stream power. The slope-area method computes flow velocity through a cross-section, using knowledge of cross-sectional geometry, channel gradient, channel roughness and flow stage.

The best-fit SOBEK model had a linear-rise to peak hydrograph with a peak (unit) discharge of 200,000 m^3s^{-1}, a fluid density of 1500kgm^{-3} and the channels had a Manning's roughness of 0.05. This jökulhlaup routed through Kverkfjallarani in 3.5 hours with a mean flow front velocity of 1.6ms^{-1}, although at higher stage local velocities reached up to 15ms^{-1}. Higher stage flow depths typically ranged from 2-4m with maximum depths of 6-7m. Shear stresses calculated by SOBEK were highly varied ranging from 100 - 7500Nm^{-2}. Similarly, unit stream powers ranged from ~2000 to >50,000 Wm^{-2} with an average value of 8500 Wm^{-2}.

Palaeocompetence calculations suggest that flow depths were typically 1.7m and that flow velocities were 2.4 - 9.4ms^{-1}. Shear stresses implied by palaeocompetence calculations were 35 – 1076 Nm^{-2} and stream powers were 16 – 8097 Wm^{-2}. Slope-area calculations suggest that jökulhlaup flow velocities ranged from 6-20 ms^{-1} and decreased with distance downstream. Cross-sectional discharges along Hraundalur ranged from 30,000 to 115,000 m^3s^{-1} and attenuated rapidly downstream. Slope-area calculations of shear stress and stream power were rather more uniform, averaging ~1500 Nm^{-2} and 25,000 Wm^{-2} respectively. Additionally, slope-area reconstructions indicate that jökulhlaups along Hraundalur were largely supercritical and that the channel roughness ranged between 0.03 and 0.06.

The lower palaeocompetence results indicate that jökulhlaups through Kverkfjallarani were coarse sediment supply-limited. Inconsistently high slope-area values of hydraulics in tributary valley gorges indicate that these gorges were probably not bank-full. In general, Kverkfjallarani jökulhlaup hydraulics reflect the strong modification of flow by topographic and geological controls. Steep valley gradients produced fast and shallow flows, whilst rapidly expanding and contracting channels created hydraulically-ponded zones, localised deeper and accelerated flows and consequently hydraulic jumps.

A hyperconcentrated flow routed along a relatively narrow and steep channel (gradient typically 0.02-0.04) allowed a Kverkfjallarani jökulhlaup to generate bed shear stresses and stream powers comparable to those of the Missoula, Bonneville and Altai floods, which are the largest known terrestrial outburst floods. This is despite the fact that flow depths and discharges in Kverkfjallarani were orders of magnitude less than those of the Missoula, Bonneville and Altai floods. This explains the ability of the Kverkfjallarani jökulhlaups to achieve geomorphic work of a similar nature to that of the other larger outburst floods.

Palaeohydraulic reconstructions from a 2D hydrodynamic model allow spatial and temporal variations in flow hydraulics to be related to flood geomorphology and sedimentology. These relationships provide quantitative estimates of erosional and depositional thresholds and hence of landscape evolution due to jökulhlaups. Knowledge of jökulhlaup hydraulics and flow behaviour has additional implications for hazard analysis and mitigation. These palaeohydraulic reconstructions will therefore be of interest for applications within similar glacial, volcanic and semi-arid landscapes and upon the flanks of other glaciated volcanoes for example.

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The June 10^{th}-12^{th}, 1999 snowmelt triggered debris flows in the Gleiðarhjalli area, north-western Iceland

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The aim of this presentation is to emphasise the role of rapid snowmelt as a relevant debris-flow triggering factor, and to analyse the geomorphic impact of the June 1999 event through landform creation, sedimentological analysis and suspended sediments quantification.

Regional environment

Located in north-western Iceland, on the western shore of the Skutulsfjörður fjord (66°03' N and 23°10' W), Gleiðarhjalli is a 1500 m long and 400-500 m wide bench in the eastern side of the Eyrarfjall mountain, 700 m in elevation, at 450-500 m a.s.l.

The Gleiðarhjalli surface is covered with extensive boulder fields, where rocks up to 30-40 metric tons dominate, inherited from glacial periods. High latitude vegetation growths on finer sediments. Upstream the bench, a 150-200 m high cliff wall with a talus apron forms the highest part of the Eyrarfjall mountain. Downstream, slopes are steep, with an average gradient from 25° to 35°, and are covered by talus in the lower parts; the upper parts are terminating into cliffs which are cut into numerous gullies.

The bedrock is of Miocene age (14-16 m.y.), and mostly made up of sub-aerial erupted basaltic lava flows, usually separated by lithified sedimentary horizons. The lava beds dip towards the south-east.

The climate is subpolar oceanic, and very changeable weather with frequent temperature and precipitation excess characterise the area.

Debris-flow forms are widespread on the slope below Gleiðarhjalli, where a total of 26 individual channels is counted, all of them acting as temporary brooks, draining the area.

Debris-flow triggering factors

The debris-flow triggering factors are triple: debris availability, steep slopes and specific weather conditions that lead to the debris-flow release.

- Debris availability consists in a huge stock of cohesionless material, up to 20-35 m thick at the edge; this debris mantle is easily subjected to internal stress, mainly caused by high runoff on the impermeable basaltic bedrock.
- Steep slopes, downslope Gleiðarhjalli bench, are prone to encourage the mass movements.
- In late May 1999, a snowstorm occurred and the air temperatures at sea level were low: 60 mm of snow fell and the temperatures remained lower than + 8°C at sea-level. The consequence was an heavy and wet snow accumulation in the mountains. In early June 1999, only small amounts of precipitation were recorded and the air temperature increased slowly until June 7th, when the wind picks up and shifts to south-east. From June 8th, the air temperature suddenly rose to + 17.5°C, in strong southerly wind, starting an intensive snowmelt period in the mountains. From June 10th to June 12th, debris flows release constantly.

The first two conditions are always gathered together in the Gleiðarhjalli area, but the weather conditions in late spring 1999 were more seldom and were of outstanding importance in the event triggering.

Debris-flow release

The general process of the debris-flow release could be schematised as follows in the specific setting of a steep mountainside broken by a large bench covered with thick debris: the rapid thaw of the snow cover in the mountains results in the seepage of melt water into the debris mantle that covers Gleiðarhjalli, and consequently leads to runoff on the impermeable basalt. At the edge of the bench, the subsurface runoff reappears and generates rotational slides, as the front is undermined from its foundations. The mass of debris changes into debris flows while running down.

The debris-flow progress can be divided in three phases than are easily witnessed from downslope:

- During the first phase, the observer notices an increasing turbidity in melt water streams, due to collapsed sediments from the front of Gleiðarh1alli bench, and consequently to an increasing load of sediment in stream flows.
- During the second phase, rolling stones and rockfall occur, because of major undermining and minor slides in the front of Gleiðarhjalli debris mantle: the larger boulders roll down while finer sediments are discharged via the brook.
- Finally, during the third phase, mixture of debris and water, i.e. debris flows, run down in a thunder noise, following preexisting gullies and brooks.

Each phase could last for several hours before the release of the first pulse, as the process needs time to engage, but the three phases followed in less than twenty minutes between two successive pulses in the same debris-flow channel.

Geomorphic impact

From Gleiðarhjalli, six debris flows were triggered on June 10th-12th, 1999, some of them involving up to 10 pulses. All debris flows were investigated at the time of the event. Although greatly variable in size, topographic changes were obvious during the event, through erosional and depositional landforms. Thus, typical landforms were created, from up to downstream:

- the geomorphic efficiency of debris flows is very high in the upper part, despite its short length (50-70 m). The channel depth reach 5 m in larger debris flows, but the minimal depth is in order of 1 m for smaller debris flows. Subtracting the depth measured before the event from the one measured just after, the dissection caused by the June 1999 event may reach 2 m. The channel bottom is lined with numerous large boulders and smaller material abandoned by the last pulse.
- The erosive and accumulative median part, which is the most important due to its length (250-370 m), is large from 5 to 15 m. The asymmetric cross-section is a characteristic of this part, because of the overflowing of the mass of debris to one side of the channel or another, while running downslope. The dissection is far lower than in the previous part, and do not exceed 2 m in the case of larger debris flows, the June 1999 event being responsible of only 0.2 to 0.7 m.
- The accumulative lower part is the wider one (up to 70 m) for most of the debris flows, except for the smaller ones, where it can be summed up in two thin and elongated deposits. Uneven and asymmetric levées border the narrow channel that only slightly dissect the slope surface.

The deposit volume estimated from the six debris flows ranged from 70 to 3000 m^3 (debris flow no.1: 3000 m^3; debris flow no. 2: 70 m^3; debris flow no. 3: 120 m^3; debris flow no. 4: 1000 m^3; debris flow no. 5: 800 m^3; debris flow no. 6: 800 m^3). With a catchment area of 4.5 km^2, and almost 6000 m^3 of material, the average denudation was calculated to be 1.3 mm.

Sedimentological analysis of the debris-flow material was done with samples taken in the main axis of four debris-flow channels, in order to characterise the finer material. The asymmetry index Skewness is in all cases positive, underlining that coarse sediments dominate within the deposits. Sorting is characterised through Krumbein index, which is superior to 1 and Trask index, which is superior to 2. the results highlight the bad sorting of the deposited material, that was already suggested by the elongated shape of the sedimentological curves. Moreover, fine material (< 0.063 mm) represents from 10 to 25 % of the deposits, pointing out that the structure of the debris flows is supported with fine sediments that allow the motion of the flow.

Finally, samplings of suspended sediment in debris-flow channel no. 4 during the year 1999 underlines the high load of sediment in water running during the highest debris-flow activity period:

- on June 7th, when the thaw is told to be normal, only 0.1 g/l of suspended sediment is collected;
- on June 10th, at 16:00, just after the first rockfall from the edge of Gleiðarhjalli, the load of running water is multiplied by 10 as almost 1 g/l is measured in the turbid water;
- on June 11th, at 10:00, 46.1 g/l is sampled, just half an hour after the first pulse;
- on June 11th, at 16:30, the sample made just few minutes after the debris flow indicates that the load of suspended sediment in the channel reach 249.3 g/l.

Overall, the June 10th-12th, 1999 debris-flow event were extremely efficient from a geomorphological point of view, transferring about 6000 m^3 of sediment, creating new landforms through erosive and accumulative processes and deepening or widening the previous ones. The specificity of this event remains in its triggering factor, which was mainly rapid snowmelt. This snowmelt debris-flow release were often diminished in literature, but represent almost 50 % of triggering factors in the Westfjords of Iceland.

Application of radionuclide techniques for evaluation of sediment redistribution

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Determination of sediment redistribution rate and its temporal and spatial variations is the key question for understanding landscape development within undisturbed and intensively disturbed areas. Dynamic of relief within temperate environments is controlled by slope and fluvial processes, which are seriously intensified in cases of disturbance of vegetation cover. Monitoring of different processes activity is the best way for understanding their dynamics. However the essential limitations of monitoring approach are expensiveness and necessity for long observation periods. Quantitative assessment can be made only in cases of sediment dating or evaluation of redistribution of different markers. Natural and artificial radionuclides are one of the best markers, which can be used for evaluation of denudation and sedimentation rates.

Isotope ^{137}Cs (bomb-derived and Chernobyl-derived) is the most wide-used marker, which has been applied for assessment soil/sediment loss/gain in different environment. Special Handbook summarising experience of different scientific teams was published with support of IAEA in 2002. The ^{137}Cs allows to date sediment and measure sedimentation rates for 50 (bomb-derived) and 18 (Chernobyl-derived) year periods. Simultaneously it can be applied to evaluate sediment redistribution for these time intervals. Vast areas of the European North were contaminated by both bomb-derived and Chernobyl derived ^{137}Cs.

The $^{210}Pb_{ex}$ is a natural isotope, which has also been widely used to study sediment redistribution in different environments. It falls from the atmosphere mostly with precipitation and allows sediment dating for period of 100-120 years. As well as ^{137}Cs, it can be applied for evaluation of sediment redistribution. Combined use of both isotopes is a good tool for improved quantification of sediment redistribution dynamics.

Our approach to quantification of sediment redistribution is based on combined use of traditional geomorphological methods and radionuclide technique. The morphological elements within the studied basin are classified into three groups in terms of their role in sediment transport. There are essentially stable areas, eroding areas and depositional areas. Eroding and depositional areas may be further classified into geomorphic units with relatively uniform rates of erosion or deposition. The radionuclide sampling strategy is based on a geomorphologic structure of the study area and aimed to characterise each morphological unit. Area of each unit is measured simultaneously. Results of laboratory analysis of radionuclide concentrations in the samples taken from different geomorphic units are recalculated using calibration models into erosion or deposition rates. It is usually possible to determine erosion rates for two time intervals and depositional rates for at least three time intervals. As a result, quantitative relationship between eroded material and deposited sediment within studied basin can be established for a few time spans. Suggested approach can be used for relatively small catchments because of limitation in sample transportation and analysis.

Evaluation of long-term rates and patterns of overbank sediment deposition on the floodplains and assessment of sedimentation rates in lakes are the other tasks, which can be solved using radionuclide techniques. It is especially important to be determined for rivers draining periglacial areas, because floodplains and lakes are the main sediment sinks in such environments. This information can be further used for calibration of sediment budget models.

Uncertainties and advantages of radionuclide technique application are discussed. Several examples of successful application of ^{137}Cs and $^{210}Pb_{ex}$ at different sites within Russia are presented.

Sediment discharge in jökulhlaups in the Skaftá river, South Iceland

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Skaftá river in South Iceland is one of many Icelandic rivers subjected to frequent jökulhlaups (glacial outburst floods). The flood water originates from underneath the Skaftá cauldrons in Vatnajökull glacier, where a geothermal area melts the glacier ice and the water is stored until it is released in jökulhlaups (Björnsson 1977). Since 1955, at least 40 jökulhlaups of different size have been detected in river Skaftá with usually larger floods originating from the eastern cauldron. The average time period between jökulhlaups from each cauldron has been just over two years; however, the periodicity and the size of the jökulhlaups appears to have changed in recent years. This pattern changed following glacial surges in the outlet glaciers in western Vatnajökull in the early 1990s, but the most recent jökulhlaups have become more frequent and smaller, especially those from the eastern cauldron (Zóphóníasson 2002).

Water stage has been monitored at several locations in Skaftá during the last decades so the hydrograph during jökulhlaups is well known. However, although suspended sediment samples have been taken from one or more locations along the river during most of the jökulhlaups, too few samples were taken during most events to calculate suspended sediment discharge. The jökulhlaups in 1991, 1994, 1995, 2002 (two events), and 2003 (two events) are exceptions, but during these events the Hydrological Service took 269 suspended sediment samples from altogether five localities in Skaftá, as well as a few samples from Hverfisfljót and Djúpá rivers which were also affected by the largest jökulhlaups. In addition, Old (2000) monitored extensively two jökulhlaups in Skaftá in 1997.

In this paper results from sediment studies during the seven jökulhlaups will be introduced although special concentration will be on results from the 2002 events when extensive number of suspended (142) and bedload samples (315) was taken.

Great changes were seen in sediment load and grain size during the course of the two jökulhlaups in July and September 2002. Maximum discharge in these jökulhlaups, which originated from the western (July) and eastern (September) cauldrons, was around 700 m^3/s, whereas the total volume of the floodwater was about 160 Gl in both events. In the July jökulhlaup, the first sediment samples were taken about half a day after the flood initiated and the last samples were taken nine days later when the event had finished. Sampling started a bit later in the September jökulhlaup but the samples were well distributed throughout the event. In both jökulhlaups samples were taken from the upper (Sveinstindur) and lower (Ása-Eldvatn and Kirkjubæjarklaustur) reaches of the river.

In July, suspended sediment load increased substantially with discharge, although it started to decrease before the highest discharge values were reached; understandable as the highest discharge peak was amplified by precipitation. Sediment load increased again to about 7000 kg/s little less than four days after the flood started, and about 18 hours after earthquake tremors were reported at the Skaftá cauldrons. The time lag between the tremors and the peak in sediment load fits well with the travel time of water from the cauldrons to the main sampling site of Sveinstindur. Hence, it is plausible that mechanism causing the tremor is responsible for mobilization of sediment of different origin or sorting, which is reflected by a change in grain size distribution. During the start of the second peak in suspended load, grain size distribution of the sediment changed substantially with a rapid increase of the fine silt fraction (0.002–0.02 mm) and a corresponding peak in conductivity. The discharge or sediment data do, however, not determine the cause of the tremors, i.e. whether they are of volcanic origin or pressure boiling of groundwater as has been debated.

Similar change was seen in suspended sediment in the September jökulhlaup in 2002 although the timing of grain size changes was slightly different within the course of the jökulhlaup and did not correlate as well with peak sediment load. Difference was also seen in conductivity, which was substantially lower in September (320 μS/cm) than in July (500 μS/cm).

The data shows that although the total volume and the hydrographs of the two jökulhlaups are similar, the relationship between sediment load, conductivity, and grain size distribution differs between the two events.

Bedload transport was measured at Sveinstindur during both 2002 jökulhlaups and at Ása-Eldvatn in September. Based on the data gathered with these measurements and analogous measurement made during the summer of 2002, a preliminary bedload rating curve was created. The bedload constituent of the total sediment discharge was, however, small according to these data; less than 5%.

The environmental impact of glacier surges and these frequent jökulhlaups in the Skaftá river basin has been dramatic everywhere along the river channel from the glacier to the coast. Sediment is being deposited and remobilized for a long time following the jökulhlaups, causing great modifications of the channel. Hence, thorough understanding of the total sediment budget is crucial for all environmental studies in the basin, and in particular if plans to harness the river for hydroelectric purposes will take place.

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Quantification and visualisation of sediment bodies in a high alpine geosystem

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Sediment storage is a major component of sediment flux systems. In high alpine environments sediment is mainly stored in sediment bodies created by gravitative, periglacial and glacial processes. Processes and storage bodies are often coupled in cascading systems. Information on volume and thickness of sediment storage elements in alpine regions is often based on estimations only. Few localised studies quantified sediment volumes using geophysical methods.

I present here the conception of a study on location, characteristics and volume of sediment bodies in the Turtmann valley, Switzerland. The Turtmann valley is a meso scale catchment (app. 125 km²) located in the valaisianne Alps. This glacierized valley contains 15 hanging valleys of various sizes located at altitudes between 2300 and 2600 m. Maximum altitudes in the Turtmann valley reach 4153 m at the Bishorn peak. Sediment storage types in the Turtmann valley include a great number of periglacial landforms; especially rock glaciers are very frequent.

In a first approach sediment bodies will be mapped and classified using geomorphological mapping, interpretation of high-resolution HRSC – air photos and geomorphometrical analysis of high-resolution DEM data. Classification is based on surface structure, sediment type, location, and geometry. Based on this classification the sediment bodies will be related to their formative processes. Minimum values for sediment thickness and volume will be assessed from DEM analysis. In the field geophysical surveys, refraction seismics as well as 2-D DC resistivity tomography, will be applied to different storage types in several parts of the Turtmann valley to gain information about sediment thickness. The geophysical data will then be used to calculate volumes and to construct 3-dimensional sediment bodies. By analysing (1) the sediment storage type, (2) the location, (3) the geomorphometrical characteristics of the source area of sediment production, and (4) the calculated volumes of the test sites, a general model will be developed to calculate volumes of all sediment bodies in the valley.

This study focuses at the understanding of the role of sediment storage in high alpine geosystems with strong impact of periglacial processes. To visualise the storage bodies in the sediment flux system of the Turtmann valley I intend to create a 3-dimensional map, combining information of the geomorphological mapping with volumes of the 3-dimensional sediment bodies.

The 1995 Sölvadalur debris slide in Central North Iceland

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The 1995 Sölvadalur debris slide occurred on the western side of the Sölvadalur valley. This valley is one of the southernmost valleys of the Eyjafjörður fjord and valley system, in central northern Iceland. The debris slide was initiated when a part of an old rockslide fell down the mountain side about 0.5 km south of the farm Þormóðsstaðir in the innermost part of the Sölvadalur valley. The mountain on the western side of the Sölvadalur valley is about 700 - 900 m high and is composed of numerous individual basaltic lava flows of late Tertiary age, separated by volcanoclastic sedimentary horizons of variable thickness. The bedrock has been subjected to geothermal alteration which has caused formation of secondary minerals, mostly zeolites in the basaltic lava flows. In tephra rich layers, found in about 50 m thick volcanoclastic sedimentary horizon in the upper part of the mountain the geothermal alteration has caused formation of clay rich minerals. In early Holocene times, sliding movement along this sedimentary horizon appears to have initiated the old rockslide in the mountain above Þormóðsstaðir.

The 1995 debris slide occurred at the end of an intensive snowmelt period in central northern Iceland following a cold winter characterized by heavy snowfall. The first snow of the winter 1994-1995 fell early on unfrozen ground. No snowmelt occurred during the winter and the ground remained unfrozen below a thick snow cover. When the intensive snowmelt started in June, showing air temperatures between 15-20° C and fairly strong southerly winds, the melt-water percolated directly into the ground which soon became saturated. In the central part of northern Iceland most of the snow, except further inland, melted between the 9th and the 14th of June, causing a major flooding of rivers and a sudden rise in the ground water level, followed by high debris-flow activity. In the Eyjafjörður area the debris-flow activity was highest in the Sölvadalur valley and along a 2.5 km long stretch of the western side of the valley, where about 20 debris-flows occurred on the 12th of June. These debris-flows originated in the soil covering the mountainside.

In late June most of the snow had melted in the lowlands and coastal areas in central northern Iceland. The groundwater level had subsided and the slopes had become more stable. A considerable numbers of snow patches were still in the process of rapid snowmelt high in the mountains, but the debris-flow hazard seemed to be over.

On June 29th a large snow patch was still melting rapidly in the uppermost part of the 900 m high mountain above the farm Þormóðsstaðir during a period with strong and warm southerly winds. Most of the melt water from the slope had been absorbed by an old rockslide, which formed a small hillock between 550-600 m in the mountain side above the farm. At around five o'clock in the afternoon a small stream of mud started to flow from the old rockslide, down into the gully in the valley below. About half an hour later a major part of the old rockslide collapsed and flowed down the slope and into the gully. It is estimated that the mass travelled at 40-45 km/h down the slope and the total volume of the slide material was around 600-800.000 m^3 most of which fell straight into the gully. The river dammed up for a short time after which a highly liquefied mudflow went down the Núpá tributary river and into Eyjafjarðará, the main river of the Eyjafjörður valley. It continued down the river course into the delta area, about 35 km downstream, where it reached the sea some hours later. The mudflow flowing down the river in Sölvadalur was a flood wave composed of mud and debris, where huge boulders and clusters of soil were seen floating in the dense liquid. In the gully in the Sölvadalur valley surprisingly little material was deposited and the flood wave caused very little erosion of the river course, leaving the vegetation cover on the gully sides virtually intact. Much more material was deposited in the river course of the Eyjafjardará river and in the delta area.

The falling debris slide eroded all soil cover and even some of the sediments in the slope below the old rockslide. The scar caused by the debris slide in the old rockslide showed that major part of the debris material originated there. Casts and boulders of clay-rich volcanogenic sediments were spread around the whole scar and down in the river course. Most signifying were huge casts of greasy and slippery green clay. The origin of the green clay is in a volcanoclastic sedimentary horizon in bedrock. The high clay content is due to geothermal alteration of an acid tephra layer which is a part of the sedimentary horizon.

The triggering factor for the debris slide was rapid snowmelt. The melt water coming from the top of the mountain percolated into the old rockslide which became saturated with water. The old rockslide absorbed huge volumes of water before it started to slide on the slippery green clay and in parts becoming liquefied. In the mountain side above it was clear that water had trickled out of the fissures connected to the old rockslide scar in the bedrock. Melt water had penetrated the porous bedrock of the mountain top and groundwater had flowed out of the mountain side along the sediment horizon that originally initiated the old rockslide.

The green clay appears to be essential in initiating both the debris slide of 1995 and the old rockslide. Originally it is an acid tephra horizon which has been geothermally altered into material very rich in clay minerals. This type of bedrock horizon is relatively common in the Tertiary lava pile of Iceland, and the same type of green clay rich material has been observed by the present authors in many rockslides in Northern Iceland.

Jökulhlaups as agents of glacial sediment transfer

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Glaciers and ice sheets erode, entrain, and deposit massive quantities of debris. Meltwater fluxes exert a fundamental control on ice dynamics and sediment transport budgets. Glacier outburst floods (jökulhlaups) are high meltwater fluxes, constituting high frequency, high magnitude events within many glacial systems. Using field evidence from Skeiðarárjökull Iceland, we examine the primary controls on sub-, en-, and proglacial sediment transfer by jökulhlaups.

Jökulhlaups produce significant glaciological and sedimentological impacts because they can simultaneously erode, deposit, and re-work sediment. Jökulhlaups that impose flood waves at the glacier bed can induce increased glacier sliding on a localised scale. Jökulhlaups can re-work and entrain huge volumes of sediment in sub- and englacial zones, thereby extending the recognisable impact of jökulhlaups from the proglacial to intraglacial environment. Most jökulhlaups transport sediment to proglacial sandar, and often directly to oceans. Proglacial jökulhlaup deposits form distinctive sedimentary assemblages, coupled with suites of high-energy erosional landforms.

Skeiðarárjökull and Skeiðarársandur, Iceland are the world's largest glacier and outwash plain subject to frequent and regular jökulhlaups, collectively providing an analogue for Quaternary ice sheet margins subject to high magnitude jökulhlaups. Comparatively little is however known about sub- or englacial jökulhlaup sediment transfer regimes. In this presentation, we (i) present evidence for jökulhlaup sediment entrainment within sub- and englacial locations, and jökulhlaup erosional and depositional impacts within subglacial sediments; (ii) identify glaciofluvial sedimentary characteristics diagnostic of fluvial accretion from hydraulically supercooled floodwater; and (iii) discuss the controls and characteristics of jökulhlaup erosion, transport, and deposition.

During the 1996 jökulhlaup, sediment rich floodwater issued from supraglacial fracture outlets. The initial sediment-laden appearance of supraglacial discharge is thought to have originated from fine-grained diamict, purged from the glacier bed at the front of a subglacial flood wave (Roberts *et al.*, 2001, 2002). At Skeiðarárjökull, intra-clasts contained within jökulhlaup fracture-fills and proximal proglacial outwash suggest wide spread mechanical erosion of subglacial sediment (Russell and Knudsen, 1999; Roberts *et al.*, 2001; Waller *et al.*, 2001). Englacial jökulhlaup deposits emplaced during the November 1996 jökulhlaup contain many rip-up clasts comprising sheared glacial diamicton and stratified glaciofluvial sediment (Roberts *et al.*, 2001; Waller *et al.*, 2001). Intra-clasts within englacial and ice proximal proglacial jökulhlaup deposits are diagnostic of subglacial mechanical excavation (Russell and Knudsen, 1999; Russell *et al.*, 2001; Roberts *et al.*, 2001). Russell and Knudsen (1999) suggested that the rip-up clasts were the product of mechanical excavation of the glacier bed by jökulhlaup waters. Frozen rip-up clasts composed of basal ice and diamicton indicate direct mechanical erosion of the glacier bed (Waller *et al.*, 2001).

The initially high sediment concentration of 1996 flood water (Snorrason *et al.*, 2002), coupled with the occurrence of copious numbers of intraclasts within rising-stage proglacial outwash, suggests that most excavation took place during the rising flow stage. Skeiðarárjökull is known to have advanced to its present position during the last millennium, providing ample opportunity for over-riding of former proglacial sediments. After the 1996 jökulhlaup, a slightly sinuous, 0.5 km wide trench extended 10 km up-glacier obliquely from the head of the Gígjukvísl ice-walled canyon. Smith *et al.* (2000) and Magilligan *et al.* (2002) estimate that 50-96 X 10^6 m^3 volume of sediment was deposited in the immediate proglacial area. At minimum, this is an equivalent volume to ten 10 km long, 50 m wide and 10 m deep subglacial channels. Major subglacial excavation of unconsolidated sediment is highly likely to have created or enhanced at least one major subglacial jökulhlaup channel or tunnel valley.

Scouring of unconsolidated sediment from beneath Skeiðarárjökull during the 1996 jökulhlaup is an outstanding example of the sediment scavenging-potential of subglacial floodwater (Russell and Knudsen, 1999, 2002). The 1996 jökulhlaup impacted most parts of the glacial & proglacial system, with super cooled jökulhlaup discharge being able to entrain large volumes of sediment to the glacier. It is clear that jökulhlaups have a tremendous ability to erode and transport large volumes of sediment from the glacial system to the proglacial and offshore sedimentary systems. In terms of geomorphological work, reflected by volumes of sediment transported, jökulhlaups are highly significant events which are responsible for the bulk of sediment within the vast sandar of Iceland.

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Sediment flux and lithofacies in Lake Baikal (Siberia, Russia): a spatial and temporal perspective

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Spatial and temporal variability in erosion and sedimentation rates of cold regions is highly sensitive to climatic modulation. Building up of snow/ice cover, development of permafrost and recession of discharge are factors that reduce erosion rate. These factors may also affect sediment flux that, in some occasions, has been observed to increase instead. These apparently contrasting situations may depend on several other factors such as time span, topographic and tectonic conditions. We present in this report a study of temporal variability in sediment flux of two sites in Lake Baikal over a time period of several million years. The location, tectonic setting, extreme thickness of the sedimentary column, unique bio-diversity and paleoclimate sensitivity made the lake an attractive target for a wide spectrum of investigations. The lake has three asymmetrical basins which are separated by fault-controlled blocks of the Buguldeika-Selenga Saddle and the Academician Ridge (Fig. 1).

The material used in this study includes samples collected from two boreholes (core BDP-98, 600 m deep and BDP-96, 200 m deep) at the Academician Ridge (53º4' N and 108º2' E at a water depth of about 333 m and 321 m, respectively) and one at the Buguldeika-Selenga Saddle (BDP-93, 52°3' N 106°1' E at a water depth of 354 m). Turbidites, large river deltas and isolated ridge and banks are the most common sediment facies in the lake. Sedimentation rate in these systems varies from a few centimeters per kyr to more than 30 cm kyr^{-1}. During the last 3 Myr the Buguldeika-Selenga Saddle and the Academician Ridge were dominated by hemipelagic sedimentation with a variable fluvial influence. Textural, mineralogical and geochemical parameters were used in the evaluation of sediment flux to the lake. Several analytical techniques were involved including laser based grain size analyzer, X-ray diffractometry, light and electron scanning microscopy, ICP-AES and ICP-MS and accelerator mass spectrometry (AMS). In order to avoid large internal variability in the studied material, we have sampled mainly silt-dominated sediment layers. A rhythmic structure made of diatomaceous ooze alternating with fine-grained siliclastic material is observed in the upper 100 m of all the three cores. This feature reflects low bio-productivity and high terrigenous supply during cold climate (glacial) and vice versa during warm climate (interglacial) periods. Sediment accumulation rate and flux vary between the two studied sites, being about 3-5 times faster at the southern one (Buguldeika-Selenga Saddle), which is more influenced by fluvial input compared to the Academician Ridge (Fig. 2).

The glacial-interglacial sedimentation pattern continues to a depth of about 110 m blf (meters below lake floor) (about 2.6 Myr) in the cores from the Academician Ridge. Below this depth, stable hemipelagic sedimentation can be traced to about 280 m blf. In the deep part of the BDP-98 core two other sedimentary facies, characterized by sedimentation rates faster than above, begin to dominate. Thus, the deltaic facies in the bottom of the core is preceded by transitional environment. The detrital mineral flux to the lake includes mainly plagioclase feldspar, quartz, K-feldspar, micas and chlorites. Diagenetic minerals are represented by calcium and iron carbonates as well as iron oxides, sulfides and phosphates. Particularly interesting are layers enriched in diagenetic vivianite ($Fe_3[PO_4]_2 \times 8H_2O$), siderite ($FeCO_3$) and nests of framboidal pyrite (FeS_2). Apart from the detrital components there are also variable amounts of biogenic particles such as diatom frustules and sponge spicules. These associations together with appearance of turbidites indicate interplay of climate, tectonics and diagenetic factors that affect sediment fluxes in the lake.

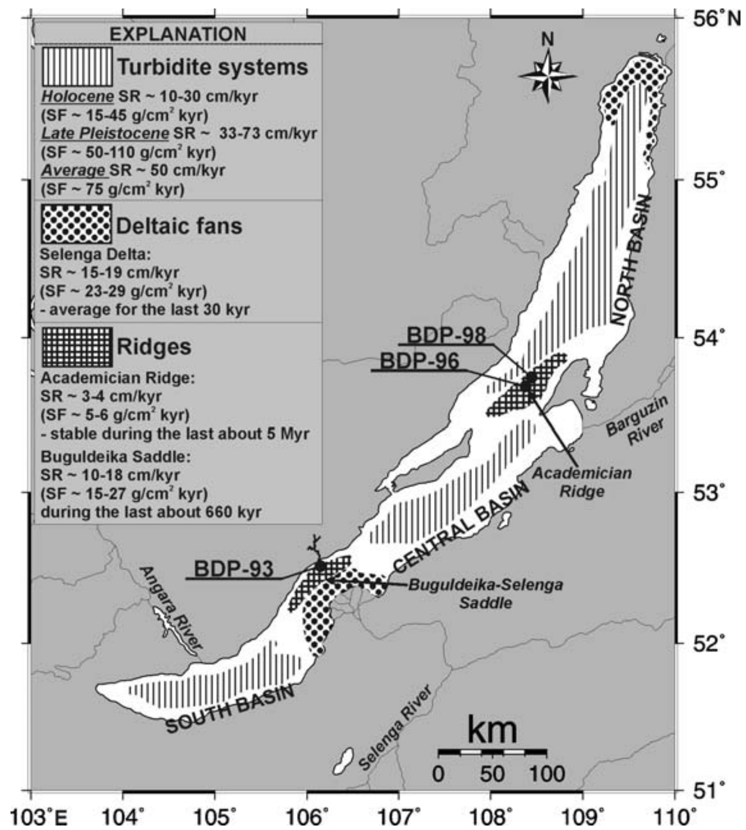

Fig. 1. Map of Lake Baikal showing location of studied sections, major depositional environments and lake basins. SR = sedimentation rate, SF = sediment flux.

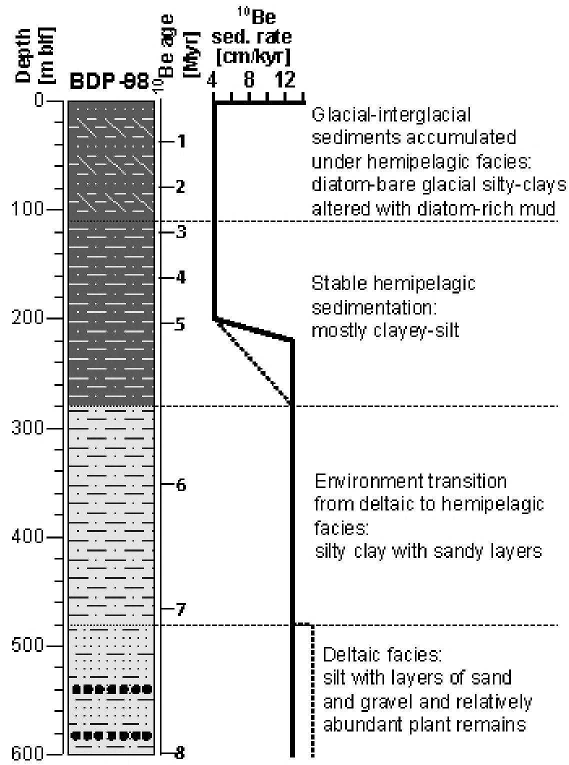

Fig. 2. Simplified lithology of the BDP-98 sediment core showing major sedimentary facies, ^{10}Be-based age and average sedimentation rates.

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Environmental controls and rates of rock weathering on sub-Antarctic Marion Island

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Marion Island lies at 46°S in the southern Indian Ocean, 2° north of the Antarctic Polar Front, and measures approximately 18km in diameter. The island is located in the belt of Westerlies, has a hyper-maritime periglacial climate and rises to 1231m in the interior mountains. Mean annual air temperature at sea level is 6°C and precipitation in the order of 2000mm pa falling on approximately 25 days for month. Two rock types are found. Pleistocene grey lavas form the base of the island. Angular lava blocks and clasts derived from outcrops and from fault scarps are widespead on the grey lava exposures. Block morphology follows cooling joint structures while fracturing and crack propagation appears to follow the basalt bonded discontinuities. The grey lavas are overlain by more recent, post Last Glacial (predominantly Holocene) vesicular black lavas and associated scoria cones. Clays are virtually absent on the island and chemical weathering appears limited although weathering rinds typically less than 2 mm thick are found on some grey lava surfaces.

Due to the high frost cycle frequencies and high moisture conditions, a perception exists of the sub-Antarctic islands being an ideal environment for active frost weathering. To date, weathering rates and detailed measurements of the environmental controls of weathering processes are absent for the islands, and very few data exist for the Antarctic region as a whole. Rock moisture and temperature conditions and weathering rates were monitored on the island as part of a South African National Antarctic Programme project spanning the period 1997 to present. These data include annual and short-duration monitoring of rock temperatures, detailed short-duration rock moisture fluctuations, and a three year monitoring period of mass loss from individual black and grey lava clasts located at different altitudes.

Grey lava temperatures monitored at sea level show few cycles crossing below the freezing point. Mean annual rock surface temperature is 7.7°C, with a maximum recorded range of -0.8° in winter to 24.0°C in summer. At 1000m a.s.l. rock surface temperatures range between –8.8°C and 30.0°C with a mean temperature of 1.8°C. Rock temperatures regularly exceeded air maximum temperatures, and the maximum air temperature recorded was 15.8°C with a mean annual of 0.8°C. In a one year period, rock temperatures experienced 200 cycles around 0°C and air 222. A Total of 85 cycles were measured across –3°C, somewhat fewer than the 136 air cycles, while 35 rock cycles exceeded 10hours or longer over the year.

Grey and black lava clast moisture content shows a high degree of variability on a diurnal basis and up to seven moisture cycles were measured within a 24hour period at sea level. On the annual cycle moisture contents are found to be higher in winter and lower in summer. Directional aspect of rock surfaces is found to be a significant control on the number of wetting and drying cycles where wind bearing rains (frontal activity) and desiccation by wind increase the amplitude and number of cycles. A high potential thus exists, particularly at altitude in the interior, for mechanical weathering processes to be operative.

Rock weathering rates, as determined by annual mass loss from small clasts (<400g), was measured over a three year period at four sites on the island on an altitudinal transect from the coast towards the interior. Mass loss from grey lava clasts is found to be 0.02% near sea level, increasing to 0.10% per year at 730m a.s.l. Black lava clasts yielded mean losses of up to 0.72% at sites, although no altitudinal trend in mass loss is evident. In the sea spray zone, grey and black lava clasts monitored over one year had mean losses of 0.30% and 0.41% respectively. Weathering rates are marginally inflated by the annual weighing procedure, determined to contribute approximately 0.01% to the measured grey lava clast mass losses, and 0.07% to the black lavas. Since none of the clasts showed visual signs of fracturing or flaking, mass loss appears at most to be on a granular scale and material removal is probably assisted by rainwash. Extrapolated values suggest black lava clasts can weather completely within 200 years and grey lava clasts within approximately 1000 years at high altitudes. These data have implications for the lifespan of periglacial landforms constituting small clasts, particularly those formed in the early Holocene. The chemical weathering component remains unknown.

Temperatures at altitude suggest a favourable environment for the freeze-thaw weathering process throughout the year, and in notably in winter when moisture contents remain high and temperatures are slightly depressed. However, the dynamic rock moisture and temperature environment are particularly favourable for mechanical weathering processes in general and the relative contribution of any freeze-thaw mechanism *per se* to mechanical weathering still requires assessment. Further, under these conditions and particularly where high rainfall causes rapid removal of weathered product the overall contribution of chemical weathering could be underestimated.

Hydrologic monitoring of supercooled discharge from Icelandic glaciers: hydrodynamic and sedimentary significance

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Debris entrainment and transport at the base of glaciers and ice sheets is important, as this is the zone where most sediment concentrates, forming a layer of debris-rich ice. This sediment-rich layer of ice strongly influences rates of glacier movement, erosion, sediment transport and deposition. Knowledge of glacial sediment entrainment processes is crucial for understanding glacier movement, sediment flux and the sedimentary record. Previous work has shown that if meltwater is displaced rapidly from beneath a glacier then hydraulic supercooling will result, allowing dynamic freezing of meltwater in zones of lower ice pressure. The efficiency of this process allows the partial freezing of sediment-laden meltwater to create sedimentary inclusions within glacier ice. Supercooling has been recognised as an active englacial sediment entrainment mechanism at glaciers in Alaska, and more recently at several temperate Icelandic glaciers.

We present short-period temperature measurements and field evidence of glaciohydraulic supercooling from Icelandic glaciers Skeiðarárjökull, Skaftafellsjökull and Svinafellsjökull. Fieldwork was carried out in July 2000, July 2001, March and July 2002 and March and July 2003. Two RBR TR-1050 temperature probes were used to record water temperatures in turbid artesian vents suspected of discharging supercooled meltwater. Field evidence of supercooling was recorded and vent locations were constrained using GPS techniques. The structure and sediment characteristics of frazil, anchor and basal ice were documented.

Turbid artesian vents were identified at a number of locations around the margins of Skaftafellsjökull and Skeiðarárjökull. Meltwater temperatures were consistently below atmospheric freezing point at many sites although not all monitored vents exhibited supercooled meltwater temperatures each time they were measured. Meltwater temperature measurements also confirm supercooling in Skeiðará during a small outburst flood from Grímsvötn subglacial lake.

Field evidence of supercooling is prolific at all three glaciers. Progressive accretion of supercooled meltwater creates sediment-laden ice exposures adjacent to active artesian vents and frazil ice aggregates containing copious sand and silt particles were repeatedly observed in meltwater outlets into which artesian vents discharged. At Skaftafellsjökull, vent-related upwellings sometimes occur several tens of metres upglacier from the snout. Field evidence of supercooling was also identified at nearby Svínafellsjökull during flood conditions.

Debris-rich basal ice exposures close to subglacial artesian vents are metres thick, and exhibit little evidence of tectonic thickening. Instead, the sections contain bedforms, coarse particle clusters and channel fills, representing grain-by-grain deposition from turbulent, high-energy flows. Observations also confirm that *in situ* melting of basal ice creates thick sedimentary sequences, as sediment structures present in the basal ice can be traced into ice-marginal ridges. Although this evidence seems persuasive, the link between supercooling, freeze-on of debris-laden meltwater and the development of thick sequences of basal ice remains a hypothesis to be rigorously tested.
Results obtained from this research demonstrate that supercooling occurs over a range of hydrological conditions and that the process does not operate continuously at all instrumented sites. It is clear that supercooling occurs during normal cycles of meltwater flow and during both comparatively small and high-magnitude jökulhlaups. Understanding controls on the efficacy and pervasiveness of hydraulic supercooling is important for ascertaining glacier sediment fluxes and for decoding the sedimentary record of modern and ancient glaciers and ice sheets. Debris entrained by

supercooling could account for large volumes of sediment deposited at former terrestrial glacier margins and the deposition of ice-rafted debris (IRD) in marine settings. For example, it has been speculated that rapid discharge of supercooled meltwater from the base of over-deepened ice sheet basins constitutes a plausible mechanism for entraining extensive amounts of sediment to the Laurentide Ice Sheet.

Further research is required i) to establish controls on temporal variations in supercooled meltwater signatures, especially in circumstances where measured meltwater temperatures are above atmospheric freezing point, despite the prevalence of frazil and anchor ice and ii) to identify diagnostic sedimentary sequences that result from *in situ* meltout of debris released from debris-rich ice exposures formed by the effects of supercooled discharge.

Rapid mass wasting of peat hillslopes under an extreme rainfall event – a sediment budget appraisal

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Rapid mass wasting of hillslopes in upland and mountain peatlands is most dramatic when large mass movements in the form of flow failures (bogflows) or shallow translational landslides (peat slides) involving loss of the entire blanket peat cover are triggered. Although peat mass movements are relatively common geomorphological events in UK and Irish uplands the causes and movement mechanisms are poorly understood. Most peat failures are triggered by high magnitude rainfall events, and impacts include damage to stream ecosystems, loss of high quality, protected blanket bog, and loss of property and infrastructure. Peat slope failures are becoming increasingly recognised as potentially damaging events in parts of the UK as well as Ireland, particularly as consequences of extreme weather events that are predicted to become more common as climate change progresses.

On 19 September 2003, an intense rainfall event lasting less than three hours caused around 35 landslides within an area of 3 km^2 on Dooncarton Mountain (260 m.a.s.l.), Co. Mayo, Ireland (54º16'N, 09º 50'W). Most of the landslides were peat slides, and these were unusual in that many failures slid along a surface within the peat, evident from the shiny, black and discontinuous thin veneer of peat left on the failure scars. Even some of the steeper slopes that failed (e.g. 30–40º) involved peat up to 0.5 m deep. Impacts on the local community included inundation of farmland, loss of livestock and farm machinery, damage to bridges and devastation of the Pollathomas graveyard. One house was destroyed and up to 50 families were affected by the landslides. The damage to property, infrastructure and livestock (mainly sheep) was initially estimated at c.10 million Euros.

The overall aim of this research is to determine the hydrogeomorphic conditions which produced these failures and assess the geomorphological impact in terms of local sediment budgets. Field measurements were undertaken to quantitatively assess the geomorphological impacts of the event in terms of sediment production and delivery; and the degree to which the hillslope failures are coupled with stream channels. This poster provides preliminary sediment budgets for the major slides within the study area. Slides vary in size from several hectares down to several 100 m^2. Runout distances at some sites stopped at the toe of slopes but in others the majority of failed peat was removed by stream transport. Slope angles at the point of failure ranged from 12 to 46º. Estimates of material loss and storage are provided for each of the major slide sites. Geomorphologically the events are of enormous significance because they represent the largest cluster of failures yet recorded (globally) in both spatial and temporal terms (occurring within two hours of one another, and over an area of only 3 km^2).

Field Excursions

The bedrock, landscape and climatic characteristics in Iceland

Bedrock

Iceland is a volcanic island located on the North Atlantic spreading ridge, which separates the North American and the Eurasian continental plates. The bedrock or the lava pile is composed of basaltic volcanic rocks and relatively thin sedimentary horizons. The lava pile of Iceland has been divided into three statigraphical units, based on age and appearance; the Tertiary series, the early Quaternary series and the late Quaternary series, and the lava fields of the volcanic zones.

The oldest bedrock (3-16 m.yr), the Tertiary series, occur in the eastern, central northern and western part of the island. It is mostly composed of jointed basaltic lava flows, erupted subaerially, individual flows varying in thickness from 2-30 m and usually separated by lithified sedimentary horizons varying in thickness from few centimeters up to tens of meters. Acid rocks and intrusions are found locally in buried central volcanoes, which also have been centers of tectonic activity. The Tertiary lava pile is intersected by basaltic dykes, most of which confined to dyke-swarms and old fault zones. The lava beds of the Tertiary series dip generally towards the center of island, towards the active volcanic zone in the center of Iceland.

The Early Quaternary series form a zone intermediate between the Tertiary basaltic areas and the active volcanic zone. In this zone, more variation occurs in the general bedrock composition. The main reason for this is the periodically coverage with glaciers during that time interval (3-0.7 m.yr). The lava pile from this time consists predominantly of sub-glacial volcanic material erupted during glacial periods, made of pillow lavas, various types of breccias and hyaloclastites. This material is commonly interstratified with extensive sub-aerial lava flows erupted during interglacial periods. Sediment horizons from this time are also much ticker than in the Tertiary, due to much more erosion and landscape formation connected with the glacial activity.

The youngest bedrock, the Late Quaternary series (> 0.7 m.yr), consists of hyaloclastic volcanic ridges and table mountains erupted subglacially in glacial periods and interstadial glacially sculptured lava flows. It also consists of the postglacial lava fields of the active volcanic zone.

The landscape

The bedrock of Iceland has been sculptured by glacial, fluvial and marine erosion. The landscape characteristics are variable around the island and reflect the age of the bedrock and its composition.

The main topographical features in the Tertiary areas in the northwestern, central northern and eastern parts of the island are glacially eroded, U-shaped fjords and valleys cut into the extensive highlands plateaux. The fjord and valley sides are often steep, with an average height of up to 600-800 m. The upper parts of the slopes are often nearly vertical cliffs whereas the lower parts are covered with various glaciogenic sediments and talus material.

In Southern Iceland large glaciers and extensive sandur plains characterize the landscape in association with extensive mountains formed during the Quaternary period. Due to both glacial and marine erosion steep slopes and high cliffs up to 500 m have been cut into the mountains massive.

Hyaloclastics ridges and Table Mountains with steep slopes and extensive lava fields characterize the landscapes in the volcanic active zones in the central part of Iceland.

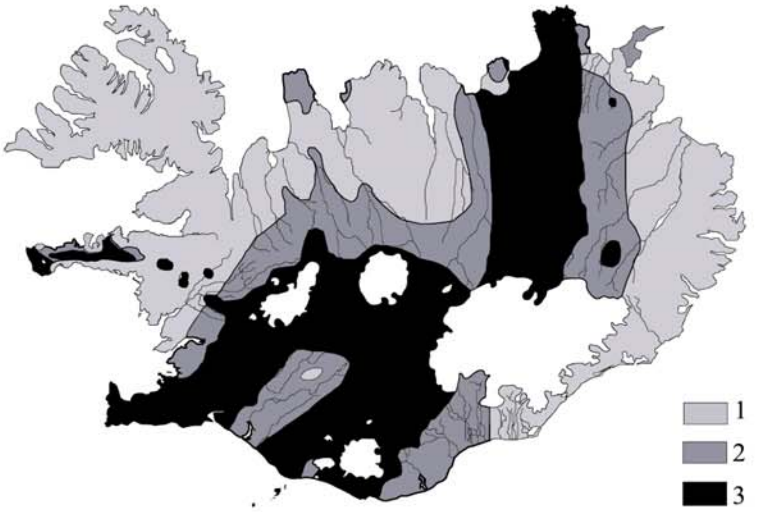
Climatic and soil characteristics in Iceland

Climate

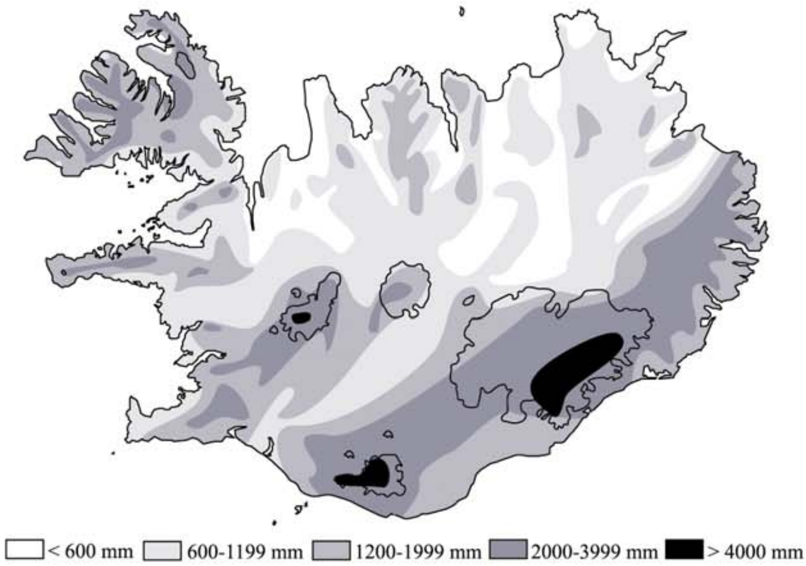
According to the Köppen-Geiger system Iceland is located at the junction between the temperate and the arctic climatic regions. The climate is categorized as cool temperate and maritime, with cool summers and mild winters. The weather in Iceland is constantly changing with high variation in precipitation and temperature. This is mainly due to the fact that Iceland is located near the main low-pressure pathway over the North Atlantic Ocean, The Icelandic Low. The mean annual temperature is higher in the southern part of the island than in the northern part, due to higher winter temperatures in the south. The mean annual precipitation is highest in the southern and southeastern parts of the island. This is mainly due to the fact that the prevailing winds producing precipitation are southerly and southeasterly lose their moisture over the southern highlands.

Soil

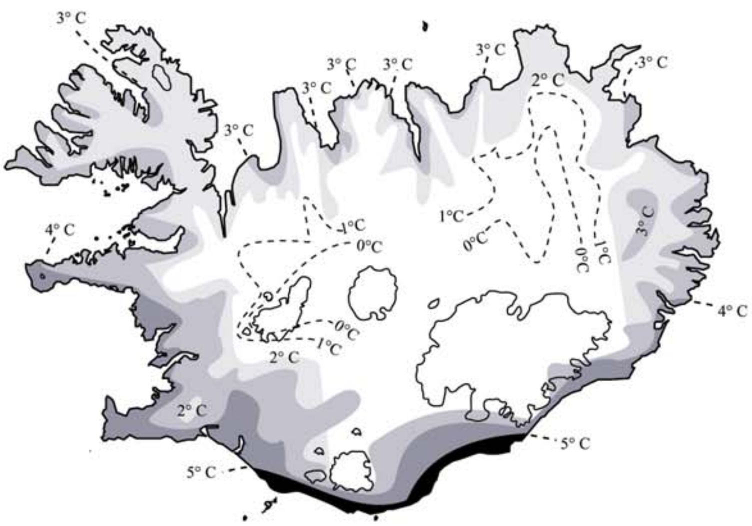
The slopes in the Tertiary basaltic areas in Iceland are usually covered by glacial till in the lower parts. The upper parts of these slopes are usually steep, terminating into cliffs. The areas are with till cover are often also covered by talus, colluviums and humus material with high permability. Due to the high permeability these soils are strongly influenced by frost action. The valley bottoms are usually dominated by fluvial and glaciofluvial deposits.



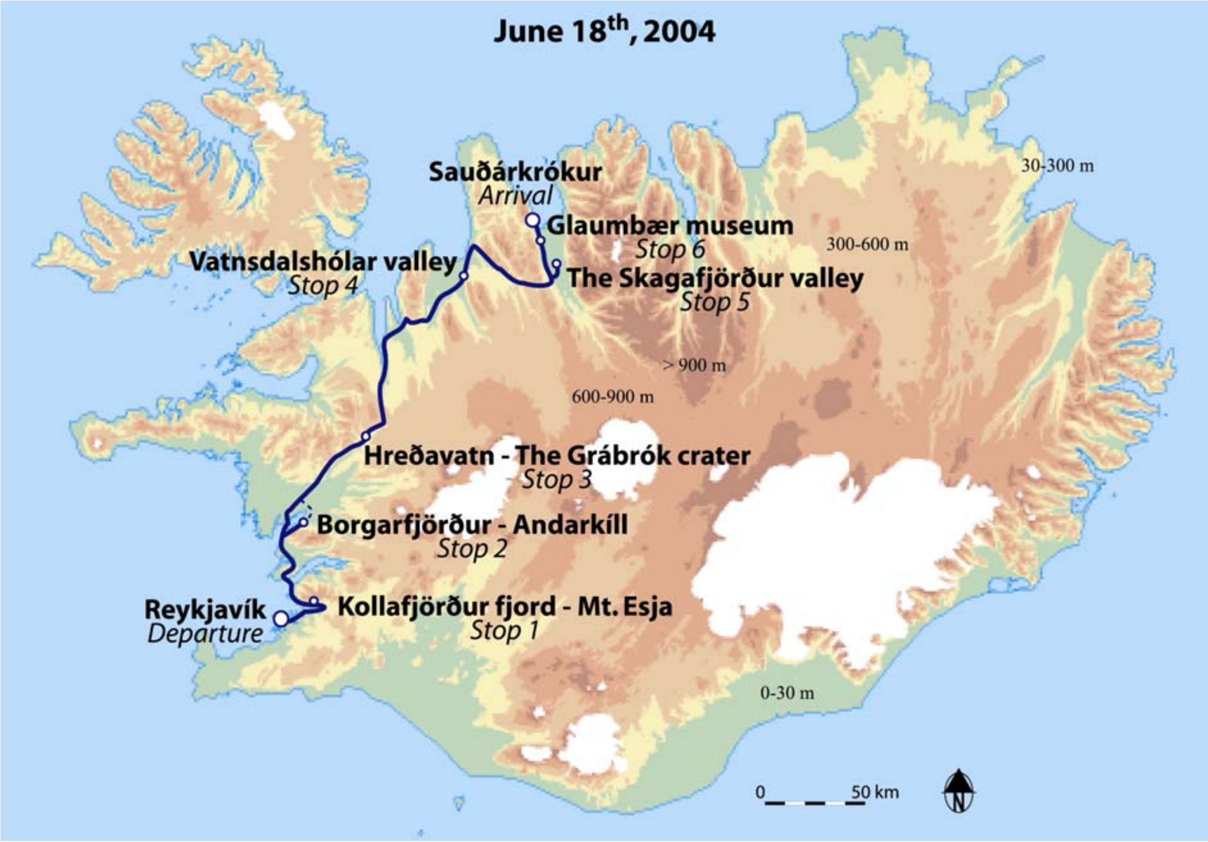
Simplified geological map of Iceland
1 - Basaltic Formations from Tertiary Period (Miocene-Pliocene) 2 - Plio-Pleistocene Formations
3 - Pleistocene and Holocene Formations (From Þ. Einarsson, 1994).



Mean annual precipitation in Iceland (From Þ. Einarsson, 1994)



Mean annual temperatures in Iceland (From Þ. Einarsson, 1994)


June 18th, 2004
Sauðárkrókur
Arrival
Glaumbær museum
Stop 6
Vatnsdalshólar valley
Stop 4
The Skagafjörður valley
Stop 5
30-300 m
300-600 m
> 900 m
600-900 m
Hreðavatn - The Grábrók crater
Stop 3
Borgarfjörður - Andarkíll
Stop 2
Reykjavík
Departure
Kollafjörður fjord - Mt. Esja
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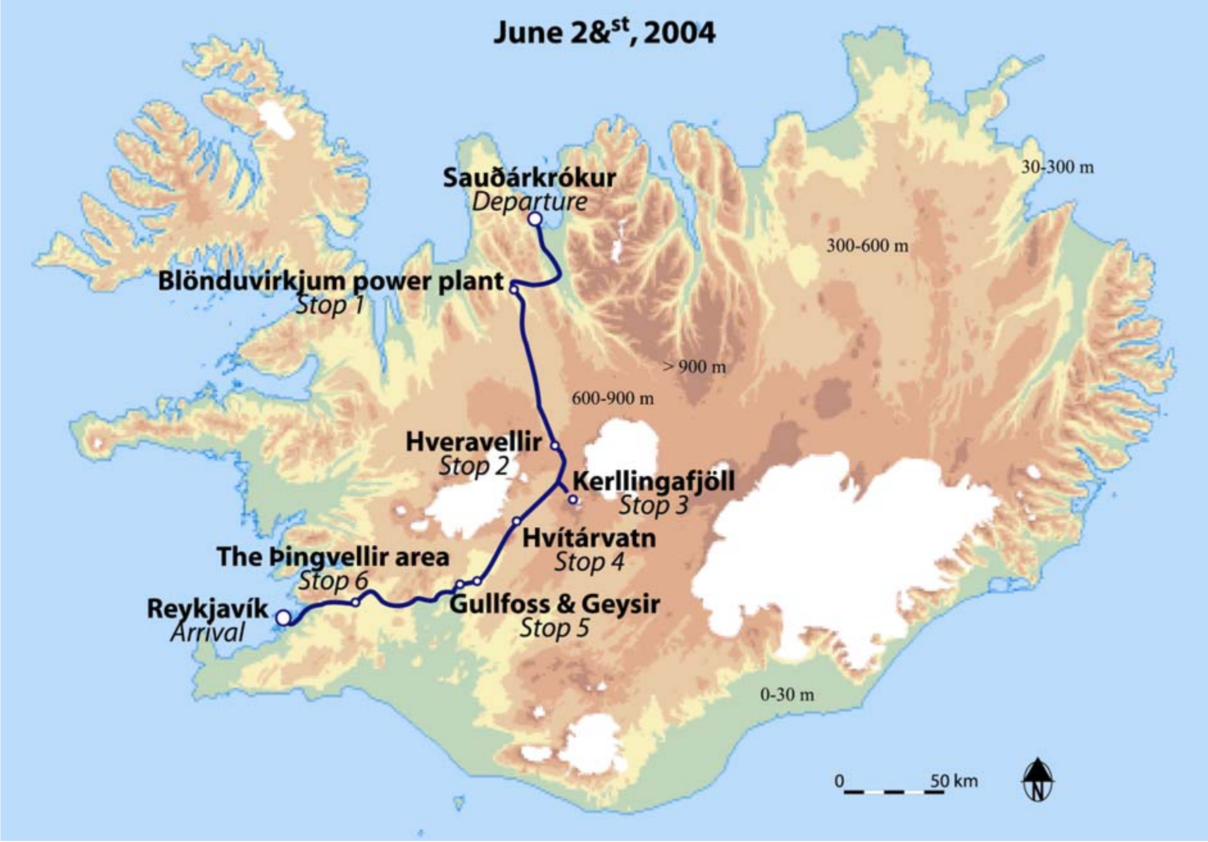
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Sauðárkrókur
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Blönduvirkjum power plant
Stop 1
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Hveravellir
Stop 2
Kerllingafjöll
Stop 3
Hvítárvatn
Stop 4
The Þingvellir area
Stop 6
Reykjavík
Arrival
Gullfoss & Geysir
Stop 5
0-30 m
0
50 km
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Friday 18th of June

Departure from Reykjavík at 8:30
During the trip to Sauðárkrókur we will take the main road, road no. 1, along the western side of Iceland.
Lunch packages will be distributed during the trip.
Estimated arrival in Sauðárkrókur at 18:00.

1. Stop
The Kollafjörður fjord - Mt. Esja
Slope processes, talus, landslides/rockslides

2. Stop
Borgarfjörður – Andarkíll
Sea-level changes, high strandlines from Bölling sub-stage, deglaciation history, slope processes, glacial geomorphology, composition of the Tertiary bedrock

3. Stop
Hreðavatn - The Grábrók crater
Holocene volcanic activity, volcanic zones and the continental drift, Tertiary bedrock

4. Stop
The Vatnsdalshólar rockslide, in the Vatnsdalur valley
Holocene rockslide and debris flow activity

5. Stop
The Skagafjörður valley
Tephra chronology – Holocene landscape development

6. Stop
The Skagafjörður valley
The Glaumbær museum. An old turf farmhouse from the 18th and 19th century Iceland. The oldest part of the farmhouse was built in the mid 1700´s and the youngest part between 1876 and 1879.

Monday 21st of June

Departure from Sauðárkrókur at 8:00.
On the way to Reykjavik we will take the highland road, Kjölur, between the Langjökull and Hofsjökull glaciers.
Lunch and dinner packages will be distributed during the trip.
Estimated arrival in Reykjavík around 20:00, possibly later.

1. Stop
The Blönduvirkjun power plant, in the Blöndudalur valley

2. Stop
Hveravellir geothermal area in the Kjölur area

3. Stop
The Kellingafjöll Mountains
Quaternary / Holocene landscape development

4. Stop
Hvítárvatn - Kjölur
Quaternary / Holocene landscape development

5. Stop
The Gullfoss waterfall and the Geysir geothermal area

6. Stop
The Þingvellir national park

Registered Participants (SEDIFLUX Members) of the First SEDIFLUX Science Meeting, Sauðárkrókur, Iceland, 18th –21st of June, 2004

A

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