EUROCORES Scheme: TOPO-EUROPE

TIMESCALES OF SEDIMENT DYNAMICS, CLIMATE AND TOPOGRAPHIC CHANGE IN MOUNTAIN LANDSCAPES (SedyMONT)

Collaborative Research Project CRP

Description of the CRP

a) State-of-the-art

It has been recognised that climate plays an important role in modulating fluvial and hillslopes erosion rates and imprints the mountain landscape (e.g., Molnar, 2004; Huntington et al., 2006). However, the response of topography to changes in the climate is complex and depends on many factors such as the magnitude and rate of the change and its effects on sediment production, local storage, and dynamic transport, all of which are strongly scale dependent. Understanding the magnitudes and timescales of change, reconciling geological process rates with present day short term rates of change, are fundamental to understanding the topographic evolution of mountain landscapes. The combination of datasets in these fields will allow a more accurate determination of which components in landscape forming processes have adapted to ongoing climate change, and to what extent. This is the main focus of SedyMONT.

The identification of the effects of climate variability and climate change on mountain landscapes relies on the detection of trends (or lack thereof) in instrumental records of hydroclimatic variables (air temperature, precipitation and streamflow) and of hydromorphologic properities of a landscape (surface erosion and sediment flux, channel network, hillslope-channel connectivity). The morphometry of a landscape integrates the influence of variables driving sediment transport over timescales of thousands of years. If consistent changes are observed in measurements of hydroclimatic variables, these should also be reflected to some extent in morphometric properties of watersheds. Whereas instrumental records have documented clear trends in the hydroclimatic variables in Europe during the last 30-40 years (e.g., Beniston et al., 1994; Brunetti et al., 2001; Frei & Schär, 2001; Schmidli et al., 2002; Birsan et al., 2005; and others), little is known about how the landscapes may have responded to these changes. For instance, although it was found that winter and spring runoff in the Swiss Alps has increased due to warmer temperatures and augmented icemelt (Birsan et al., 2005), we do not know whether the hydromorphologic properties and sediment discharge in the Alpine landscape have also changed in response to these trends.

Detection and analysis of landscape and sediment discharge changes are much more difficult to achieve because the response of a landscape to external forcing depends on a variety of processes and process interactions that have operated over a large range of temporal and spatial scales (Brunsden & Thornes, 1979; Harvey, 2001; Schrott et al., 2003; Korup & Schlunegger, 2007). Nevertheless, Vanacker et al. (2007) recently presented an example where the landscape’s vulnerability to external forcing was successfully quantified. The authors used long-term (thousands of years) process rates as criteria and compared them with data on short-term rates and their variability. Within this framework, the short-term changes within a landscape can be quantified using remote sensing datasets of various sources (e.g., Fruneau et al., 1996; Schwab et al., 2007a, b) and field-based investigations (e.g., Schürch et al., 2006; McArdell et al., 2007). The comparison of both sets of information – one addressing the long-term effects on the landscape and the other estimating the short-term changes – yields a more balanced appreciation of the impact of environmental changes (or human impact) on mountain landscapes. This is the strategy with which we propose to detect and analyse modifications in the landscape in response to ongoing global climate change.

b) CRP aims & objectives

Understanding the timescales and controls of sediment dynamics are a prerequisite if we aim to predict the landscape response to changes in temperature, precipitation and runoff. This requires identification of sediment sources and sinks and the mechanisms and rates of sediment transfer at sites in different environments. In SedyMONT we propose to address this topic on the basis of (i) historical records and field monitoring, (ii) morphometric and geologic histories, (iii) a conceptual modelling framework, and (iv) information on past and present climate variability and scenarios of future climate change.

The main objectives of SedyMONT are to

- understand the timescales and mechanisms of sediment production and transfer and to identify their effects in selected European mountain landscapes,

- document changes in process rates over different timescales (millennium to modern) from various historical sources, including monitoring conducted during the project,
- analyze how the inheritance of the landscape (e.g., due to the influence of previous glaciations) has affected process rates,
- investigate how landscape connectivity affects sediment transfer rates and residence times,
- develop a conceptual modelling framework to understand the transfer of sediment from sources to sinks (including the estimation of sediment residence times),
- analyse the frequency and magnitude of precipitation events in the study areas from observed data and regional climate model (RCM) based future climate scenarios,
- develop time series and chronologies of erosion, sediment yield and landscape change in the study basins.

The routing of sediment and the rate of landscape change are controlled by the landscape's inheritance and transience. This is the case because these instrinsic variables potentially scale long-term denduation rates and the landscape's susceptibility to high-magnitude climatic perturbations. This issue is particularly acute for most of the mountainous topographies of Europe as they were substantially overprinted during the Last Glacial Maximum. In this context, it is relevant to operate with quantitative information about the connectivity between the various landscape architectural elements, and the limits for the routing of sediment. Specifically, the transfer of sediment and the related landscape change is more efficient if sediment production sites are directly connected with the sediment transfer system. The process rates then either depend on the production rates of sediment (supply-limited sediment flux), and/or the capacity of the routing system to transport sediment (transport-limited sediment flux). In summary, we anticipate that the vulnerability of mountainous drainage basins to external forcing strongly depends on the landscape's inheritance and transience, landscape connectivity, and the nature and magnitude of the rate-limiting process.

The conceptual numerical model will be used to build up an intuitive understanding of how the transfer of sediment from sources to sinks can be expected to vary spatially and temporally in natural catchments where processes and rates (and processes interactions) may vary considerably. The coupled model of hydrological regime and sediment transport will be applied using variable scenarios of climate change and intrinsic properties of the landscape. Specifically, we will explore possible controls on the time required for catchment areas to respond to changes in external forces (response time), and we will test to what extent and at which temporal and spatial scales the landscapes record these changes. The numerical model is anticipated to provide the conceptural framework to interpret the field-based datasets.

c) Strategy and work plan

Site selection

According to the scopes of the project, sites are selected based on their monitoring history, covering a range of representative mountainous settings across Europe spanning the whole range of processes and process interactions. Each site will be analyzed for time series and chronologies of landscape change, flux change, climate change and for sediment sources.

The seleted regions are

- Central Alps of Switzerland (Illgraben, 10 km^2 large). This case is representative for a catchment where the **transport capacity of debris flow processes** has been the fundamenal control for sediment discharge and landscape change. The Illgraben will serve as **key site** because of extensive monitoring history.
- Northern flysch Alpine border of Switzerland (Rotenbach and Erlenbach, 2 km^2 large each). This region will serve as a case where sediment discharge has been driven by **coupled effects of landsliding, debris flows and fluvial processes.**
- Southern Alps of Italy. This part of the Alps will be used to illustrate how **glacial inheritance of an Alpine-type landscape** has controlled the magnitude and frequency of sediment transfer processes in general and debris flows in particular.
- Northern Apennines of Italy (Reno drainage basin*).* The Reno system will provide an example where sediment discharge and landscape change has been controlled by **bedrock with different erodibilities.**
- Eastern Alps of Austria (Forefild of Pasterze glacier). This site will present a situation where sediment discharge and landscape change has been controlled by **modern glacial and permafrost conditions** and changes thereof.
- Nordfjord of western Norway (Erdalen and Bødalen catchment). These sites yield information about how the **landscape's inheritance of the Last Glacial Maximum** has influenced the source-to-sink processes in a **typical fjord-valley system**.

Data collection, survey strategy and methods

Each site will be analyzed in detail for the hillslope and channel dynamics, the geologic and geomorphic inheritance, the hydromorphologic properties, and the spatial and temporal variability of sediment discharge. The project participants will address these issue in distinct topical groups (see below). We will complile the data in a central online database developed in a uniform format to facilitate data exchange. The challenge lies in the integration of data from various sources (and thus with contrasting resolution) that will be collected with different tools. The selection of the methodologies will depend on the geological and geomorphic boundary conditions given by each research site.

Hillslope and channel dynamics

Detection of landscape changes in relation to hillslope and channel dynamics will be accomplished using various techniques of **remote sensing**. Aerial photographs are available for all test sites and will be analyzed for temporal changes of the landscape during the last 50 years. This technology was successfully used to quantify the temporal variations of sediment yields in the Swiss Alps (Schwab et al., 2007a). For instance, it will be important to explore whether the aerial extent of landslides or other portions of the landscape susceptible to erosion have changed through time. In addition, aerial photographs will be used to analyse connectivity between various segments of the landscape. Other relevant information are historial documents of landuse and landform changes including historical maps. We will also quantify in-situ erosion rates and changes in the cross-sectional geometries of feeding channels for selected sites. This will be achieved by the analysis of stereo panoramas taken with an **image assisted total station** and **terrestrial laser scanners**, which provide unique techniques in the field of quantitative geomorphology. Similarly, **GPS** data will deliver information about variablities in slip rates of landslides. These data, although short in terms of time span of observation, will be important as they improve our understanding of how floods of various magnitudes alter the cross-sectional geometries of channels (Hartshorn et al., 2002), the longitudinal profiles of mountain streams (Milzow et al., 2006), and the morphometry of hillslopes (Schürch et al., 2006; Schwab et al., 2007b). Will need this information if the aim is to provide scenarios of landscape change to modification in the hydroclimatic regime.

Inheritance

Detailed **geologic and geomorphic mapping** will yield important information about the nature of the bedrock underlying the landscape, and the inheritance caused by glacial erosion/deposition during the Last Glacial Maximum. Further important information will be extracted from aerial photographs and geologic/geomorphic literature. The maps will be complemented by **provenance tracing** yielding information about the sources of the sediment. This is important if the aim is to interpret how the geological inheritance has affected sediment discharge. The provenance analysis also includes the delineation of potential sedimentary sinks. This information will be gained by petrographic studies of bedloads in channels (e.g., clast counting method, and/or tracing of heavy minerals, Schlunegger et al., 1993), and by detailed anlysis of aerial photographs (e.g., Schwab et al., 2007a) and mapping in the field (e.g., Schwab et al., 2007b).

Hydromorphologic properties

Quantitative data about the hydromorphometric properties of a landscape is relevant if the aim is to understand source-to-sink relationships. The required information are steepness and concavities of channels and hillslopes, and connectivities between the various portions of a watershed. This information can be readily extrated from DEMs using **GIS analyses** tools (e.g., Schneider et al., 2007; Korup & Schlunegger, 2007). These data can then be interpreted in terms of the geomorphic architecture of landscapes, and the connectiviy between the relevant architectural elements. Within this framework, assessements of process rates over shorter timescales will yield information about the variabilities in space and time, and about potential trends (Schlunegger & Schneider, 2005). An important contribution in this context will be provided by the development of **a conceptual modelling framework** to understand the transfer of sediment from sources to sinks (including the estimation of sediment residence times). This framework will be based on the impulse-response (linear or nonlinear) concept for interpreting fluxes between different components of the sediment transfer system in a transient state. Already a simple linear two-component (hillslope-channel) impulse-response model has been shown to satisfactorily explain sediment transfer in a large Australian basin (Lu et al., 2005; 2006). The SedyMONT model will expand this approach to include spatially distributed storage and transfer of sediment, time-variant connectivity between components, and a framework for analysing uncertainty.

Sediment discharge

Sediment discharge data will be established by measuring present-day **sediment budgets** at the outlet of watersheds and/or **cosmogenic nuclides** (CNs) on river-borne quartz minerals. These tools allow the calibration of sediment yields for time scales ranging from hundreds to thousands of years. In particular, the cosmogenic nuclides record the path of sediment particles from weathering to transport over geomorphic time scales (e.g., von Blanckenburg, 2005; Kober et al., 2007; Norton et al., 2007). We propose to assess modern and palaeo-denudation rates by measuring concentrations of the radionuclide ^{10}Be for river-borne sands, and possibly for medium-grained sand deposited in the post-glacial terraces. Samples for CN analyses will be collected over the whole range of spatial scales within the analyzed watersheds to measure in detail the scale-denudation relationships. Data on variabilities and magnitudes of short-term sediment discharge will be collected using **geophysical tools** installed at the test sites (e.g., force plate at the outlet of the Illgraben, McArdell et al., 2007), or based on sediment budget calculations for sediment traps behind retention dams. Subsurface data from stratigraphic recorders (**georadar, seismic refraction survey**) calibrated with geochronometers (e.g., ^{14}C ages) will illuminate the dynamic response of sedimentary sinks in response to variations in sediment discharge. In addition to standard methods for monitoring bedload transport additional innovative techniques like **shock sensors** and **biofilm analyses** will be applied to analyse channel stability/mobility and bedload. In summary, the detection of changes and trends of surface erosion and sediment flux will be used to investigate present-day variabilities in sediment discharge and information on average sediment discharge for longer time intervals (possibly a few thousands of years) (Vannacker et al, 2005; 2007).

d) Bibliography

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e) Milestones and deliverables

The project will deliver

- process-based comprehension of the sites,

- understanding of process rates and magnitude-frequency relations across scales,
- reconstructed time series and chronologies of erosion and sediment transport in the study basins,
- methods to assess the effects of geomorphic connectivity,
- quantification of in-situ erosion rates in channels, and
- methods to predict topographic response to climate change.

The collected and ellaborated data will be made accessible to the public by a central online database on a devoted project webpage. Because the project is explicitely designed to analyze how representative European topographies have changed in the last decades, we will produce a quantitative database for predicting how the landscape will respond to ongoing warming.

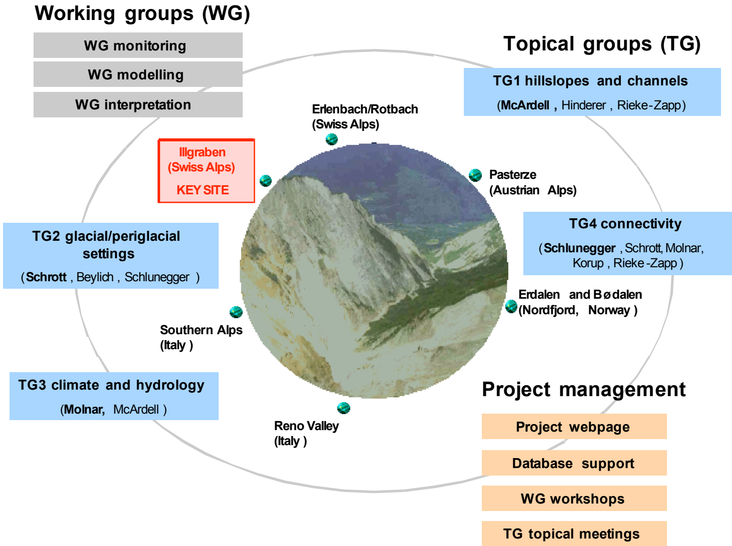
A major deliverable of the project will be in higher education. The Individual Projects will be funding PhD students who will be encouraged to work in an interdisciplinary fashion and build their own networking within the CRP and between CRPs. Regular within-CRP workshops for the funded PhD students will be organized to foster the education component of the project.

Description of the collaboration

a) SedyMONT group setup and management

SedyMONT consists of 6 individual projects (IPs) and 3 associated projects (APs). The research goals will be achieved by three general working groups in which all project partners participate (WG monitoring, modelling, interpretation) and four topical working groups (TG hillslopes and channels, glacial/periglacial settings, climate and hydrology, connectivity) in which the project participants are divided based on their expertise and research interest (see Figure and Table).

Collaboration within SedyMONT will be fostered through joint workshops of the WG interpretation, modelling and monitoring, and topical meetings of individual TGs. During WG workshops, the general research needs relevant to the SedyMONT scopes and objectives will be discussed, and required research efforts be identified. The details of the research programs for each site that result from workshops of the working groups (WGs) will be coordinated by the topical working groups (TGs) that desing and discuss research tasks of the individual projects guided by principal investigators (PIs) and associated partners (APs). This organization ensures that individual tasks at each sites will be strongly coordinated within the scopes of SedyMONT, and that results will become accessible to the whole SedyMONT group.



Individual Projects (PI name)	Collaborators	Project Title	Topical Groups 1	2	3	4
IP1: Schlunegger (Uni Bern) Project Leader	McArdell (WSL Birmensdorf), Rieke-Zapp (Uni Bern)	Assessment of timescales of sediment discharge in selected sites of the Swiss Alps (Illgraben, Rotenbach, Erlenbach)	x		x	x
IP2: Schrott (Uni Salzburg)		Sediment budget for a glacier forefield (Pasterze, Upper Tauern, Austria) – quantification and temporal variability. A contribution to climate change research in high mountain environments	x	x		x
IP3: Beylich (NTNY Trondheim)		Erdalen and Bødalen site project (Nordfjord, western Norway): Holocene, sub-recent and present-day source-to-sink-fluxes in a valley-fjord system		x		x
IP4: Molnar (ETH Zurich)	Burlando (ETH Zurich), Korup (WSL Birmensdorf)	Analysis and modelling framework for sediment production and yield in mountain basins under climate change	x		x	
IP5: Reiterer (TU Vienna)	Kahmen (TU Vienna)	Analysis of short term in-situ erosion rates by image-based measurement systems (ASTIRI)	x		x	

IP6: Hinderer (TU Darmstadt)	Hornung, Bieg (TU Darmstadt), Schlunegger (Uni Bern)	High resolution 3D architectural analysis and chronology of the Illgraben fan	x			x
Associated Projects (AP name)	**Collaborators**	**Project Title**				
			1	**2**	**3**	**4**
AP1: Picotti (Uni Bologna)	Berti, Simoni (Uni Bologna)	Sediment transfer processes in glaciated and unglaciated landscapes (Southern Alps and Northern Apennines)		x		x
AP2: Densmore (Durham Uni)	Schlunegger (Uni Bern), McArdell (WSL Birmensdorf)	Sediment dynamics and evolution of the Illgraben fan	x		x	
AP3: Tecklenburg (FH Oldenburg)	Luhmann (FH Oldenburg)		x		x	

Data exchange occurs through a central online database developed in a uniform format that will be made available for the project participants during the first two years, and to the public in a more advanced stage of the project. The challenge lies in the integration of data from various sources (and thus with contrasting resolution) that will be collected with different tools. This coordinated strategy of the data collection at each site (montoring), data validation (modelling) and process understanding (interpretation) will strengthen European landscape change prediction in response to ongoing climate change and climate variabilites.

SedyMONT is managed by an open **steering board** consisting currently of Fritz Schlunegger (University of Bern) who is Project Leader (PL), Peter Molnar (ETH Zurich) and Brian McArdell (WSL Birsmensdorf).

b) SedyMONT study site selection

Understanding the timescales and controls of sediment dynamics and predicting the landscape response to changes in regional temperature, precipitation and runoff requires the identification of sediment sources and sinks and the quantification of the mechanisms and rates of sediment transfer at sites in different environments. Accordingly, study sites are selected across Europe representing the whole range of geological/geomorphological and climatic boundary conditions (e.g., glacial inheritance and transience, supply and transport-limited sediment transfer). The sites are expected to have experienced a large variety of processes and process interactions (e.g., glacial erosion and permafrost hillslope creep, debris flows and fluvial processes, coupled/decoupled channelized-hillslope processes). Each site will be analyzed for time series and chronologies of landscape change, flux change, climate change and for sediment sources. The **Illgraben site** will serve as key site because of its extensive monitoring history, rich process understanding and available data.

c) Expertise and track record of SedyMONT partners

SedyMONT group partners are selected based on their expertise in monitoring, in the interpretation of processes and process interactions, and modelling. It is important that the scientific expertise of the SedyMONT group covers both the regional and topic aspects of sediment transfer in mountain settings, and that all scales from short-term in-situ processes to long-term landscape development and sediment transfer affecting whole watersheds are considered. Knowledge about the regional aspects of the key sites and about the sediment transfer mechanisms will be provided by McArdell together with Schlunegger, by PIs Schrott, Beylich, and APs Picotti, and Densmore. These researchers have also extended expertise in the monitoring of processes and landscape change for long-term processes operating at large scales (e.g., photogrammetry based change detection, sediment discharge). Expertise for the calibration of short-term changes of landscapes and quantification of in-situ erosion by channel incision or landsliding will be provided by Rieke-Zapp with PIs Schlunegger, Reiterer, and collaborators Luhmann/Tecklenburg. PI Hinderer will calibrate the stratigraphic response to variable sediment discharge on the Illgraben fan using geophysical tools (georadar). Finally, PI Molnar and partners Burlando and Korup are experts in the field of hydroclimate and hydromorphology. They will deliver the conceptual framework for data interpretation.

d) *European added value of the collaboration*

The variety of sites in different climatic and topographic environments across Europe will allow the investigation of different dominant processes, driving mechanisms and a wide range of process activity. The fact that various sites and environments will be studied in SedyMONT also means that a range of scientific expertise is required. In this sense SedyMONT will be a novel grouping of scientists in Europe across the traditional boundaries of geology, geomorphology, hydrology, climatology and geodesy, working at vastly different timescales, with potential to generate tremendous added value (together with EU funded climate modelling projects such as PRUDENCE and ENSEMBLES) on the effects of climate change on landscapes and ecosystems (Christensen et al., 2007).

Experts from the SEDIFLUX network (ESF project) predicted that climate change will cause major changes in Earth surface systems, especially in high latitude and high altitude regions (Beylich et al., 2006). SedyMONT will add to the state-of-the-art by combining information on geomorphological processes with predictions of climate change within a monitoring and modelling framework. Information transfer will be established with the Sedimentary Sources-to-Sink-Fluxes in Cold Environments (SEDIFLUX) network (**Beylich**), the IAG working group on Geomorphology and Earth System Science (GESS) (**Schrott**), the IAG working group on Sediment Budgets in Cold Environments (SEDIBUD) (**Beylich**), and the International Commission on Continental Erosion (ICCE) of the IAHS (**Molnar**). **Schlunegger** and **Densmore** are founding members of the European Surface Processes Group (ESPG).