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6.1
Hazard of naturally occurring radioactive material from Tunisian and Algerian Phosphorite

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In this study we investigate the radiological hazard of naturally occurring radioactive material in Tunisian and Algerian phosphorite province (Fig.1). In this province the phosphorites deposits are stratiform deposits and of sedimentary origin. The phosphorite beds occur in the Late Paleocene and Lower Eocene (Ypresian-Lutetian) in age (Sassi, 1984 et Zaïer, 1999). Twenty samples of phosphorite rocks were collected from the phosphorite mines. Activity concentrations in all the samples were measured by alpha spectrometry and gamma spectrometry.

Alpha spectrometry analyses (Fig.2) show that the specific activity values of $^{238}$U, $^{234}$U and $^{230}$U in the samples of Tunisian phosphorite were 327±7 (321–327), 326.81±6 (325.7–331.39) and 14.5±0.72 (13.9–15) Bq kg$^{-1}$, respectively. Specific activity concentrations measured by gamma spectrometry in the samples of the Tunisian and Algerian phosphorite show a little difference. Specific activity concentration levels of $^{40}$K; $^{226}$Ra, $^{232}$Th, $^{235}$U and $^{238}$U in the phosphorite samples from Tunisia were respectively 71.10±3.8, 391.54±9.39, 60.38±3.74, 12.72±0.54 and 527,42±49.57 Bq kg$^{-1}$ and Algeria were 15.72±1.73, 989.65±12.52, 12.08±1.2, 47.5±1.52 and 1148.787.3 Bq kg$^{-1}$, respectively.

The measured value of specific activity of $^{232}$Th and $^{40}$K in the Tunisian phosphorite samples is relatively higher than that in the samples of Algerian phosphorite. The measured concentration of uranium in the Tunisian phosphorite (527±49) Bq kg$^{-1}$ is lesser than in Algerian phosphorite. The measured concentration of uranium 238 in the Tunisian phosphorite samples was (527-1315±65) Bq kg$^{-1}$ which is higher than its maximum background value of 110 Bq kg$^{-1}$ in soils of the various countries of the world (M. Tufail et al., 2006). Different geological origins of phosphorites deposits are the main reason for the large spread in worldwide specific activities. Present study reveals that phosphate deposits contain natural radioactivity considerably higher than background level.

REFERENCES
6.2

The active Pont Bourquin landslide (Les Diablerets, VD): a combined geophysical, hydrogeological and ground-based remote sensing survey

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First important movements of the Pont Bourquin landslide were observed in 2004. Three years later, heavy rainfall triggered an earth and debris flow with a volume of about 11’000 m³ which was cutting the cantonal road between the villages Les Diablerets and Gstaad. Recently, successive events of debris slides-earth flows and mud flows with small volumes were triggered and reached again the edge of the road.

The 250 m long Pont Bourquin landslide is located in the Western Prealps of Switzerland in a tectonically complex zone and affects mainly black shale, cornieule rocks, flysch and moraine material. Since 2008, a combined ground-based remote sensing, geophysical and hydrogeological survey of the landslide is carried out with the aim to (1) quantify its movements, (2) define the origin of the groundwater in the sliding mass and (3) create an overall conceptual model of the landslide.

Regularly, TLS (Terrestrial Laser Scanning), Differential GNSS (Digital Global Navigation Satellite System) as well as Total Station measurements are performed. Several Seismic Refraction and ERT (Electric Resistivity Tomography) profiles were made along and across the landslide. Periodically, groundwater from boreholes and springs is sampled and chemically analyzed and groundwater tables are monitored in several piezometers between 2 and 5 m depth.

The main slip surface of the landslide is localized at about 10 m depth. Important movements occur also along shallower secondary slip surfaces. In a time period of three months, a 20 m-displacement could be measured in the middle part of the landslide. Water is playing an important role for the triggering of the landslide: on one hand, meteoric water is ponding on the low permeable landslide mass and in large extensional cracks and on the other hand, water is flowing along numerous fractures in the black shale and extruding at perennial springs on the landslide.

Due to its fast and continuous movements, the Pont Bourquin landslide represents a significant example for natural hazards processes in the Alps.

REFERENCE
6.3
Seismic signal analysis of rockslide events in the Swiss Alps

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Seismic recordings from regional networks may be used to identify and locate rockslide events, and can provide unique information on event characteristics that could otherwise only be established by eye witnesses. Here we analyze the seismic signals from 20 large rockslide events that occurred in the Swiss and French Alps during the last twenty years. Rockslide seismic signals have a typical ‘cigar’ shape characterized by an emergent onset and slowly decaying tail. The majority of seismic energy is contained in frequencies below $\sim$4 Hz, and near the source, the signal generally cannot be separated into different wave types. Five seismic metrics were used to quantify differences between rockslide seismograms: seismic duration, peak amplitude of the seismic velocity envelope (ePGV), average ground velocity (AGV), rise time (RT) from event onset to ePGV, and the area of the seismic velocity envelope (EA). Three seismic metrics (EA, AGV, ePGV) exhibited loglog attenuation behavior, RT exhibited semilog attenuation behavior and duration did not show any clear attenuation with distance. For comparison between events, each seismic metric was extrapolated to a common distance of 30 km; for duration the value at the nearest station was used. Event potential energy correlated well with seismic duration and ePGV, and rock/ice avalanches could be identified by unusually low ePGV. Event volume correlated with seismic duration and EA, and rock collapses could be identified by unusually low EA. Analyzing six events that occurred from the same slope with similar runout, the correlation of ePGV and event volume was better than that for all events, indicating that runout path has an important effect on ePGV. For these six events, a plot of EA versus duration showed that rockslides with more than one sub-event lie far from the fitted curve. We also attempted to match seismic waveform features to event dynamics as observed in video footage. A high amplitude signal on one horizontal component may indicate the time at which the moving mass was deflected in its runout path. An event with an initial free-fall phase exhibited an early-time high frequency signal on the vertical component, possibly resulting from impact of the rock mass on the ground.
Debris flow occurrence in mountain torrents seems to have increased over the last few years - most likely due to glacier retreat and permafrost melting in high Alpine regions [Lemke et al. (2007), IPCC report]. Additional debris material is available, which serves as starting material for catastrophic debris flow events after heavy rainfalls or snow melting. As a result, it is increasingly important to better understand the physical mechanisms governing initiation, motion and settlement of debris flows. Numerical models (such as RAMMS (RApid Mass MovementS [Christen et al., 2010])) are used to study the dynamics and are valuable tools for hazard assessment and mitigation in inhabited Alpine regions.

Experimental and naturally-triggered debris flows indicate that entrainment and deposition processes as well as the interaction between solid material and interstitial fluid are central to understanding the dynamics of debris flows (Brian). Yet, there are only a few models in use and most of them incorporate one-phase friction relations to describe the flow behavior. It is well-known that debris flows are mixed solid-fluid (two-phase) flows. Disadvantageous is that such models often use empirically derived friction coefficients. Two-phase flow models would allow the description of the interaction between solid and fluid material by treating the phases separately but in a coupled manner. Using an adequate energy description in such models would be a major step forward in properly describing flow height, flow velocity, runout distance as well as entrainment (bulking) and deposition processes.

For the project “Hazard mapping in Mattertain (VS): Data acquisition and numerical modeling of debris flows” we placed instruments in one of the mountain torrents (Dorfbach, Randa, VS) including devices to measure front velocity and flow depths and a video camera provides visual information of an event. The newly gained data combined with existing data from Dorfbach and other locations in the Swiss Alps can be used to investigate entrainment and deposition processes along the channel. The new knowledge on the dynamics helps to optimize the existing numerical debris flow model.

We present 2D numerical simulations in a 3D terrain (Dorfbach, Randa, VS) using RAMMS. The model is based on the 2D shallow water equations and incorporates the Voellmy friction relation. We performed simulations for different scenarios in order to assess different flow paths and deposition areas, which may have disastrous consequences for the population in the Mattertain, VS. The ability to incorporate mitigation structures helps to evaluate the dimensions and the position of such structures in order to protect the populated areas. On the basis of these results we show weaknesses of the used Voellmy model.

Comparison with natural events show that the reproduction of flow heights, runout distances as well as local deposition of material causing channel blockage are problematic. The development of a more realistic two-phase flow model may improve the results concerning runout and deposition processes.

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6.5
Climate warming and stability of hanging glaciers: lessons from the 1895 Altels break-off

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The Altels hanging glacier broke off on September 11, 1895. The ice volume of this catastrophic rupture was estimated to 4.10 cubic meters, which made this collapse the largest ever observed in the Alps. However, the causes of such a collapse are not entirely clear. Based on former works, we reanalyzed this break-off with help of a new numerical model. This model, initially developed by Faillettaz et al. (2010) for gravity-driven instabilities, was applied to this glacier. It takes into account the progressive maturation of a heterogeneous mass towards a gravity-driven instability, characterized by the competition between frictional sliding and tension cracking. We use an array of slider blocks on an inclined (and curved) basal surface, which interact via elastic-brittle springs. A realistic state- and rate-dependent friction law established in the laboratory is used for the block-bed interaction. We model evolution of the inner material properties of the mass and its progressive damage eventually leading to failure, by means of a laboratory-based stress corrosion law governing the rupture of the springs.

It appears that such a break-off could only happen when the basal friction at the bedrock is reduced in a restricted area, possibly induced by a storage of infiltrated water within the glacier. This result seems to be confirmed by the exceptional hot summer preceding the collapse.

Moreover, a two-step behavior could be evidenced: (i) A first calm regime, without visible changes, its duration depending on the rate of basal change. (ii) An unstable regime with a rapid increase of basal motion within few days. As a consequence, a crown crevasse opens few days later (which was observed) and the final instability occurs. This means that the destabilization process of a hanging glacier due to a progressive warming of the ice/bed interface towards a temperate regime will occur without easily visible signs until few days prior to the collapse.

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6.6
Thermal effects on seasonal variability of deformation rate at the Randa rock slope instability, Valais

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Following two catastrophic rockslides in 1991 at Randa, Switzerland, a new retrogressive instability has been observed in the area of the crown and northern margin incorporating 4 - 7.5 million m³ of fractured crystalline rock.

Geodetic measurements reveal a constant long-term displacement rate of more than 20 mm/yr. In 2000, a multi-component monitoring system was installed, including borehole inclinometers, extensometers in boreholes and at the ground surface, piezometric pressure sensors, and temperature sensors. Five years of continuous inclinometer data measured across an active discontinuity at 68 m depth reveal that the deformation rate abruptly increases as soon as the ground surface temperature drops below 0 °C in fall, and then decreases slowly after snowmelt in spring. Piezometer data in 50 and 120 m deep boreholes show that the regional groundwater table is low throughout the year, which is not unusual for the highly fractured rock mass and ridge topography of the test site.
Nevertheless, temporary perched water bodies are observed and local pore pressures are expected to reach a maximum after snowmelt. Therefore, observed annual changes in the deformation time series are contradictory to seasonal velocity variations reported for most large mass movements, where acceleration usually occurs after the onset of snowmelt.

The records from fiber optic strain sensors installed in August 2008 and monthly geodetic surveys conducted in 2008/09 confirm the temporal behavior observed in in-place inclinometer data. We hypothesize that stress changes induced by near surface thermal contraction and expansion of rock play a key role in forcing movements along active discontinuities at depth and in propagation of fractures, while pore pressure effects are of lesser importance.

The mechanisms by which thermo-elastic stresses may drive rock slope deformation are explored with numerical models applying both continuum and discontinuum approaches. The discontinuum models indicate that thermally-induced stress changes at depth can lead to permanent displacement along critically stressed fractures.

6.7
Detailed characterisation of thinnest lake sediment deposits using scanning electron microscopy.

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Detailed characterisation of the sediments is in many limnogeological research questions of particular importance. One example is the distinction between background and event sediments. Within the FloodAlp! project, flood-related event deposits in numerous lakes in the alpine realm are studied. Hundreds of such layers can occur in the Holocene sediment record of alpine lakes ranging from less than a millimetre to several tens of centimetres in thickness. The specific characterisation of these deposits and the distinction between flood deposits, mass movement-related event-deposits and typical varve deposits (e.g. authigenic carbonate layers) is of crucial importance.

The characterisation of layers thicker than a few millimetre can be achieved by standard chemical, physical and mineralogical analyses, such as smear slides, thin sections, oxygen and carbon-isotope analyses, C/N ratio, total organic carbon (TOC) and inorganic carbon content (IC). In addition, the mineralogical composition as well as the grain size pattern, shape and texture of detrital grains within these event deposits are essential properties of the sediment layers that can mostly be obtained by optical microscopy of thin sections or smear-slide analyses. However, grain size and structures of fine-grained sediment layers thinner than a few millimetres, cannot be analysed due to the limited resolution of the optical microscope.

To analyse such thin and fine-grained event layers, we are using a low vacuum scanning electron microscope (ESEM) in combination with an energy dispersive x-ray analyses system (EDX). Although these techniques are well known since decades, only the recent development of EDX detectors with increased active surfaces allow recording elemental maps within a few minutes and thus enable an elemental mapping of larger areas. The combined information of the backscattered electrons (BSE) and the x-ray maps allow a mineralogical and textural characterization of millimetre to submillimetre-scaled event layers. With our current experimental setup, we are able to map sediment intervals over several millimetres in thickness continuously, which allows us for example to establish grain size distributions within individual layers.

First results from millimetres to submillimetre-scaled event-layer analyses demonstrate the potential of our approach. Sediment cores of four lakes in the northern Alps (Hinterer Schwendisee, Fälensee, Klöntalersee and Canovasee) were analysed. Thinnest flood-related event deposit could be characterized in detail and distinguished from background sedimentation as well as from mass-movement deposits, all results that could to date, at this scale, not be achieved by optical methods only. Detrital minerals are clearly detectable and upward fining gradation within the flood layers can be observed. In a few cases, an erosional base of the turbidite can be documented.

Our approach allowed us to characterise flood records of millimetres to centimetres thickness in more detail than it would have been possible with an optical microscope. The results demonstrate the high potential of this method as it increases the spatial and thus the temporal resolution of event deposits.
6.8

Movements characterization along open back crack affecting Turtle Mountain, Alberta, Canada

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Turtle Mountain is located in the Foothills in southwest Alberta, Canada and is formed by highly fractured Paleozoic carbonates rocks and Mesozoic clastic rocks. This area is mainly affected by two major geological structures that are the Turtle Mountain anticline and the Turtle Mountain thrust. This site became famous after a 30 M m³ rock avalanche of massive limestone and dolostone affecting the eastern mountainside of Turtle Mountain on April 1903. This resulted in the burying of the Frank village and more than 70 casualties. However, portions of the Mountain are still unstable and some of them are currently monitored (Froese et al. 2009).

The structural features of Turtle Mountain were investigated in order to understand the potential origin of the fractures, the present day scar morphology and to identify the most important failure mechanisms (Langenberg et al. 2007; Jaboyedoff et al. 2008; Pedrazzini et al. in press; Humair et al. 2010).

This study focused on the investigation of the open back cracks that are affecting the crown area of Turtle Mountain, between North and Third Peak (Fig. 1 and 2). The analyses are based on high resolution DEM, orthophoto, aerial photogrammetric, and manual field estimation analysis. The results are compared with extensometers values of displacement. Each method attempts to provide information on the displacement vectors and on the opening of the moving rock compartments measured on the open back cracks.

Therefore, the aim is to confront the different methods in order to evaluate the relevance of any of them in such an investigation. The linkage between the global previous analysed structural pattern of discontinuities and the cracks geometry is performed. Indeed, most of the cracks show a “saw-teeth” geometry and are controlled by two or more pre-existing discontinuity sets (Fig. 3). An estimation of the cumulative displacement on the open cracks allows estimating the effect of stress release on the behaviour of the Turtle Mountain rock compartments. Depending on the orientation of the movements, different deformation zones are created. Moreover, based on the orientation, opening and persistence of the open cracks, an investigation of the volume of potentially unstable rock compartments is attempted.

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Figure 1: Main lineaments detected in different structural zones between North and Third Peak. From Pedrazzini et al. (in press).

Figure 2: View of the crown area affected by multiple open cracks.

Figure 3: Field example of the control of pre-existing fractures on the crack orientation and its displacement vector.
A remote sensing application for hazard analysis at Alp di Roscioro, Canton Tessin.

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An unstable rock slope located on the western flank of the lower Riviera valley, above the village of Preonzo (TI), was the focus of a study using a combination of helicopter acquired lidar/imagery and ground based radar interferometry. The rock slope instability, known as Alp di Roscioro, consists of a steep 200-300 metre high, largely inaccessible scarp that endangers an industrial complex at the foot of the slope. Since 1989 the instability has been monitored by Cantonal authorities, following the discovery of large tension cracks behind the main scarp (see Figure 1). In 2002, approximately 150K m$^3$ failed in the highly fractured southern section, with renewed activity taking place in northern section in 2010, resulting in a smaller failure of approximately 30K m$^3$. In an effort to better understand the hazard posed by the instability terrestrial and airborne remote sensing techniques were employed for improving our understanding of the geological disposition and the distribution and volume of unstable rockmass compartments.

A high resolution, lidar-based digital terrain model and images were acquired by helicopter using the scan2map-system developed at EPF Lausanne and operated by BSF Swissphoto. The special “handheld” setup of the mapping system enables a high operational flexibility and allowed to perform an oblique scan of the area of interest, thus guaranteeing high mapping accuracy also in the very steep scarp beneath the Alp. The resulting 3D model, that combines the Lidar data and the oblique imagery in one (see Figure 2), was used to construct a detailed geological model and identify important structures controlling the instability. Additionally, structural data was extracted from the HRDTM for analysis of kinematic mechanisms, the results of which indicated the importance of joint intersections forming wedges.

High precision, ground-based radar interferometry (GPRI) was used to delineate the boundaries of the moving rock mass and establish an activity profile for comparison with in situ crack meters installed along the main tension crack. Similar magnitudes of displacement between interferometry and crack meter results indicated that the unstable area moves as a coherent block. As a result, dominant, steeply dipping slope sub-parallel joints (K1) become activated in tension resulting in small scale failure (as evidenced from recent activity). Ongoing research is focused on further elucidating the failure mechanism, establishing accurate volumes for unstable compartments, and defining possible failure scenarios (i.e. run out analysis).
6.10

Investigating the seismic response of a large rock slope instability (Randa, VS)

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Several observations in the Matter valley of southern Switzerland attest to an important role of earthquake induced rock slope displacements, however owing to the long return period of large earthquakes in the area, co-seismic landslide hazards are not often fully appreciated. In this study, we investigate the seismic response of a large unstable rock mass above the village of Randa in Canton Valais. The site is the subject of numerous interdisciplinary investigations aimed to understand the internal structure and dynamic response of the roughly 5 million m³ of unstable material.

In this study, we employ ambient vibration measurements and fiber optic (FO) strain monitoring to measure the rock mass response to small nearby earthquakes. Notable amplification was observed within the unstable rock mass, with strong polarization in the direction of instability deformation. Results further highlight resonant frequencies of internal rockslide blocks, or effective compartments with similar behavior, which help us understand the rockslide internal and deformation structure.

In May 2010, a $M_{L}$ 3.4 earthquake struck the area. Five km from the epicenter at Randa, we measured clear transient deformations up to 30 micrometers across surface tension cracks. Spectral peaks from the FO strain record match closely with ambient vibration measurements and new analysis of seismic data recorded during previous experiments. Comparing strain records from either side of one instrumented block, two spectral peaks at 3 and 5 Hz were apparent. 5 Hz energy was found to be exactly out of phase, indicating Eigen-mode block vibration, while 3 Hz energy was in phase, suggesting a resonant frequency of the larger unstable rock mass. 3 Hz resonance could be observed from other ambient vibration measurements distributed around the unstable rock mass, while 5 Hz peaks were visible only in the area of the instrumented crack.

The combined methodology offers a unique view into the rockslide structure, highlighting effective block assemblages and offering clues as to their size, which matches well with local geodetic displacement monitoring and structural characterization.
6.11

Representation problems of danger and “risks” maps

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Danger maps in Switzerland are represented with five levels of danger: white (no danger, or negligible danger), white-yellow (residual danger), yellow (low), blue (medium), and red (high). The zoning is performed on actual state, taking into account assessment measures (as long as they are considered as durable in terms of functionality and if there maintenance is guaranteed; projects cannot be integrated). These maps are then used for the land use planning and to establish protection measures. They are supposed to be checked “periodically” and updated “in case of important modification of the danger” (Lateltin, 1997). The yellow-white color is displayed for both very low occurrence/very high intensity hazards or very low danger remaining after protection measures. Thus, we identify two problems in this methodology:

• The difficulty to identify the initial state danger level and the risk of forgetting the danger (more or less willingly)
• The ambiguity of the yellow-white color

Our French neighbors have a different system. They draw their “hazard” maps (which correspond more or less with our danger maps) ignoring the existing protection measures (Besson et al. 1999; Garry & Graszk 1999). After the identification of areas with stake, they draw a regulatory zoning plan. This plan aims to classify the area into different constraints levels for the land use, regarding the level and type of danger, the existing protection measures or the possibility to build new ones and the stake. This technic offers two advantages:

• The preservation of the primary danger level
• The ability to perform openly an interests weighing

Thus, we propose to adapt the Swiss system with a new color code. The level of danger reduced by a safety measure could have the color of the original danger, with an overprinting representing the method of danger reduction and the color of the danger level considering the protection measures (fig. 1). This representation can be made whether by a point symbol or by a pattern including the symbol. As the representation of protection measures with pictograms is not easy to understand, the symbology should be tested with the assistance of psychologists. We assume that with this new symbology, the authorities and the public will be aware of the potential danger and of the reduction method and that the danger cannot then be forgotten anymore. Furthermore, the yellow-white color would only represent the very low occurrence/very high intensity hazards. This symbology would offer more tools to perform the interests weighing at the risk study level.

Figure 1. Examples of symbologies. The first image displays the danger map without protection measures. The second image displays the new map after the building of a dike with the “symbol” method. The third one is the same as the second one, but with the “pattern” method. In both case, the symbols takes the colour of the danger level considering the dike.

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6.12

Historical activity of the Saint-Barthélémy stream (VS) – old data, new look

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The Saint-Barthélémy stream drains a 12.5 km² catchment in the canton Valais, through three geological domains. Its steep course (avg. slope 20°) connects the Dents du Midi massif down to the Rhone valley, creating a massive debris fan of 130 * 10⁶ m³.

The first records of its activity are a great subject of debate, since the Bois Noir fan is one of the supposed location of the Tauredunum event, which caused a tsunami wave on the Lake Leman in 563 AD. The torrent is not mentioned in the archives before 1470. It has since produced series of debris flows once every century. With the arrival of natural sciences, and the increasing human activity in the Rhone valley, the mentions of the Saint-Barthélémy activity strongly increases in the XIXth century, with two majors crisis around 1835 and 1870.

The last crisis occurred between 1926 and 1930, with debris flows transporting an estimated volume of 106 m³. The instantaneous denudation rate during the crisis reached 12 mm/year. Contemporary denudation rates are ranging between 0.13 and 0.88 mm/year (Rudaz 2010). This last crisis is well documented in its chronology, by local testimonies, field visits during and after the crisis, and most importantly photographs. The behavior of this stream was already supposed to be in a pulse regime, a low background activity interrupted by strong crisis (Bardou & Jaboyedoff 2008).

Looking back on past crisis, it appears that in almost every case (1870 excepted), a rock avalanche occurred in the upper part of the catchment. Using the 1926 event as an exemple, the chronology of past crisis can be reconstructed.

The rock avalanche occurs in the steep upper gorge, and mixes with perenneal snow avalanche deposits, which lubricates the mass and allows a portion of it to reach the alluvial fan (august 1926) on an otherwise sunny day. The main volume of the rock avalanche is mobilized during intense storm precipitation (september and october 1926), forming massive debris flows, and erodes a quaternary deposit in the central part of the catchment. This activity slowly decreases as the original rock avalanche volume is exhausted. Following this crisis, the torrent was corrected by check dams in the central zone, but the main cause was not addressed. The upper cliffs and their failure are historically the source of sediment pulses and their corresponding risks.

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Fig. 1 debris flow damage in 1930, © André Kern, Usine de Lavey, Médiathèque Valais – Martigny

Fig. 2 upper gorge with rock avalanche (a) and resulting debris flow trace (b), B. Rudaz
Reconstruction of the Holocene flood history for assessing the future flood hazard in the Central Alps (FloodAlp project)

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Floods caused by extreme precipitation events represent a major natural hazard in the Alpine realm, involving enormous financial and social damage (e.g. Hilker et al. 2009). Current climate models predict even an increase in heavy precipitation in the future related to an intensification of the hydrological cycle in the context of global warming (Frei et al. 2006). In order to assess this flood hazard, knowledge about the natural variability of extreme flood events is required. Lacustrine sediment records allow the reconstruction of flood recurrence rates in the past, with the great advantage that their records reach beyond the time span covered by instrumental and historic data series.

The FloodAlp project aims to reconstruct the Holocene flood history of the Central Alps. We investigate 18 small lakes (0.01 to 3 km²) along a North-South Alpine transect from northeastern Switzerland to northern Italy covering a large range in altitude. This multi-archive approach eliminates only locally occurring events, like spatially limited thunderstorms, from the overall signal and gives evidence on the geographical distribution of the flood events. In addition, the wide altitude distribution provides information on the seasonality of the events because high-elevation lakes are, due to their ice cover in winter, only susceptible for summer/autumn rainfalls. Sedimentologically, our approach is based on the mobilisation of sediment material in the catchment during intense precipitation events and the subsequent transport of this material in the river waters to the next downstream lake. The high density of the water-sediment mixture reaching the lake leads to the formation of underflows and finally to the deposition of flood-turbidite layers on the flat basin floor. In the sediment cores, these flood layers are identified and mapped with a suite of visual, mineralogical, chemical and physical methods (Gilli et al. in press).

The flood records of the first six analysed lakes show a general trend from lower flood activity in the early and mid-Holocene to higher flood frequencies in the late Holocene (0-4 kyr). In addition, correlations to variations in the large-scale atmospheric circulation pattern as reconstructed from the GISP2 ice-core record have emerged (Mayewski et al. 2004). Furthermore, some lakes in the Northern Alps present a particularly enhanced flood activity during the last 2000 years. In these cases, land-use changes leading to more easily mobilised sediment material could play an important role, indicated by the conspicuous thickness of the deposits especially during the last millennium. The extension of our flood archive with further lacustrine records will refine these observations and interpretations and will give more evidence on the seasonal occurrence of the events.

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Figure 1: Map of Switzerland and surrounding regions displaying the studied lakes in the Northern and Southern Alps.