WP 6 – Action 6.2 – State of the art report

Hazards related to permafrost and to permafrost degradation

Citation reference

Schoeneich P., Dall'Amico M., Deline P., Zischg A., eds (2011). *Hazards related to permafrost and to permafrost degradation*. PermaNET project, state-of-the-art report 6.2. On-line publication ISBN 978-2-903095-59-8.

Downladable on: www.permanet-alpinespace.eu

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Project reference

European Territorial Cooperation, Alpine Space Programme

Project PermaNET – Long term monitoring network for permafrost, 2008-2011.

ADRA - Association pour la diffusion de la recherche alpine

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ISBN 978-2-903095-59-8

2.
Permafrost and debris-flows

Citation reference

Zischg A., Curtaz M., Galuppo A., Lang K., Mayr V., Riedl C., Schoeneich P. (2011). Chapter 2: Permafrost and debris-flows. In Schoeneich P. et al. (eds): *Hazards related to permafrost and to permafrost degradation*. PermaNET project, state-of-the-art report 6.2. On-line publication ISBN 978-2-903095-59-8, p. 29-66.

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Content

Summary fo decision makers

Debris flows are rapid gravity induced mass movements that consist of sediment saturated with water. A debris flow event is the results of a combination of many triggering factors, and the isolation of the influence of permafrost to the debris flow event against the other triggering factors is difficult. For many debris flows that originated at altitudes above 2500 m, the influence of permafrost could be proven or is supposed.

Torrential systems can be classified into two main categories:

- Transport capacity limited torrents: in such torrents, a sufficient debris supply is always available. Debris flows are limited by the amount of available water and its transport capacity. Only an increase of water availability can lead to an increase in debris flows.
- Debris limited torrents: in such torrents, the transport capacity of debris flows exceeds the debris supply. Debris flows are limited by the amount of available debris.

Thus the influence of permafrost on debris flow intensity or frequency will strongly depend on the type of control driving the torrential system.

The way permafrost and permafrost degradation may influence debris supply to torrential systems can be classified as follows :

- Debris supply by rockwalls, either directly in the channel or indirectly through talus.
- Debris supply by rock-glaciers or other permafrost creep processes : by a rockglacier front overhanging catchment, rockglacier destabilization (« surging rockglacier ») or even collapse.
- The melting of intersticial ice will lead to a loss of cohesion of the previously frozen debris, which will become available for mobilization by surface processes.
- The melting of ice lenses leading to sliding of debris cover, or to the settling of loose debris, that will be prone to facilitated remobilization. The ice lenses are not necessary of permafrost origin, and the same will happen with buried glacier ice or firn.

Permafrost can influence the water supply, either by limiting infiltration or by providing additionnal water volumes :

- The active layer of the permafrost is often saturated in summertime because of the characteristics of the permafrost table as acquiclude.
- A special attention has to be payed to thermokarst (ice of permafrost or other origin) and especially to the formation of thermokarst lakes : these will eventually drain, possibly forming outburst floods.

It has to be noticed that in torrent catchments developping below the permafrost zone, debris flow activity may decrease with climate warming, due ot a decrease of debris supply due decreasing frost/thaw cycle intensity and frequency.

Strategies for the prevention of permafrost related debris flow activity changes were developped. In a first step, an overlay of catchments to the permafrost distribution map allows an indentification of potential cases. The identification of creeping debris bodies on orthophotos permits an estimation of the debris potential. In potentially dangerous zones, a visual field inspection and, if possible, ground temperature and BTS mesurements campaigns can provide evidences of the presence of permafrost.

1. Introduction

This report is part of the state-of-the-art report about the linkages between permafrost and natural hazards. This report has been elaborated within work package 6 “Permafrost and natural hazards” of the Alpine Space 2007-2013 project “PermaNET – Long-term permafrost monitoring network”. The aim of this report is to provide a basis for the formulation of recommendations for the consideration of permafrost in hazard assessment. The report has been written by the working group of WP6 in common.

Debris flows are rapid gravity induced mass movements that consist of sediment saturated with water. Debris flows have a high content of sediment material and therefore a high density. The front of a debris flow could flow with velocities up to 60 km/h. Because of the high energy, debris flows could cause severe damages to houses and infrastructures.

While recent progress in measurement technologies and modelling has significantly improved our understanding of the relationship between permafrost and rock face stability (e.g. Harris et al. 2009), the role of permafrost and permafrost degradation in the initiation of debris flows is not well-known yet. Debris flows are highly complex geomorphic processes. The initiation is depending on a variety of factors, ranging from topographical characteristics, the precipitation, the characterisation of the sediment, the variable state of the soil and sediment such as saturation etc. A debris flow event is the results of a combination of many triggering factors, and the isolation of the influence of permafrost to the debris flow event against the other triggering factors is difficult. Therefore, the understanding of the influence of permafrost and especially of the permafrost degradation to the probability of occurrence and the intensity of debris flows is still lacking of completeness (Rebetez et al., 1997; Zimmermann et al., 1997; Jomelli et al., 2004; Jomelli et al., 2007, Sattler et al 2008).

In general, the increase of air temperatures is affecting the hydraulic and geotechnical properties of perennially frozen debris cones or slopes. But, the reaction of ground ice in sediment and scree slopes is only indirect and supposed to a time-lag. It depends on the topographical conditions, on the structure of the surface and of the soil material, on the interaction with the snow cover or avalanche deposits and on the ice content itself. High ice content retards the thawing process by the uptake of latent heat (Noetzli et al., 2007). Complex interrelationships such as these let permafrost in superficial sediments respond merely slowly to climate forcing, i.e. within decades to centuries (cf. Haeberli, 1992).

The influence of permafrost on the activity of debris flows is only partly considerated within the elaboration of the hazard maps. Only the guidelines for hazard zone mapping of the Autonomous Province of Bolzano are prescribing the consideration of permafrost in the elaboration of hazard zone maps.

2. Typology and involved processes

Permafrost can influence debris flow activity in different ways, mainly by increasing the debris supply to the torrential system, but also by influencing the water concentration time and availability. But the efficiency of permafrost influence will depend on the functioning mode of the torrential system.

Controls on debris flow intensity and frequency

Various classifications of torrential systems exist. One of the most useful is based on the limiting factors of debris flow formation, and distinguishes two main categories:

- Transport capacity limited torrents: in such torrents, a sufficient debris supply is always available. Debris flows are limited by the amount of available water and its transport capacity. Every time the precipitation and runoff exceed a given threshold, a debris flow will form, but it will be limited in size and will not evacuate all the available debris. In these cases, an increase of debris supply or availability will have no significant influence neither on intensity nor on frequency of debris flows, that are totally controlled by precipitation and runoff. On the contrary, an increase of the water supply through additional meltwater, drainage of water bodies (thermokarst lakes, « water pockets », …) will allow an increase of debris flow intensity, as there is no debris limitation.
- Debris limited torrents: in such torrents, the transport capacity of debris flows exceeds the debris supply. Debris flows are limited by the amount of available debris. Debris flows will form only if the stock of available debris has been rebuilt since the last event. In these cases, an increase of the debris supply or availability can significantly increase both the frequency and intensity of debris flows. Especially very large debris flows may be expected. On the contrary, an increase of the water supply will not influence the debris flow intensity or frequency, unless the debris supply is increased too.

Thus the influence of permafrost on debris flow intensity or frequency will strongly depend on the type of control driving the torrential system.

Permafrost and debris supply

The way permafrost and permafrost degradation may influence debris supply to torrential systems can be classified as follows:

- Debris supply by rockwalls, either directly in the channel or indirectly through talus:
    - below permafrost belt : the probable evolution can be either a decrease or an increase, depending on the altitude of the rockwalls relative to the range of maximum frost/thaw cycle intensity and frequency ;
    - above permafrost limit: the probable evolution will be an increase due to deeper melting of active layer. For more detail see chapter on rockfalls.
- Debris supply by rock-glaciers or other permafrost creep processes:
    - rockglacier front overhanging catchment: the hazard is in most cases already present since a long time. The importance of debris supply will vary with creep velocities. In case of an acceleration of the rockglacier, this will lead to an increase of debris supply ;
    - rockglacier destabilization (« surging rockglacier »): such cases can cause a strong increase of debris supply. For more on rockglacier behaviour, wee chapter on rockglaciers.

- rockglacier collapse: a collapse will bring a sudden supply of large volumes of loose debris, prone to a remobilization by debris flows. The collapse event itself could trigger a debris flow event.

- Permafrost melting:
  - the loss of internal ice as stabilising binding material in the course of active layer thickening and the consequent increased availability of erodible material;
  - the melting of interstitial ice will lead to a loss of cohesion of the previously frozen debris, which will become available for mobilization by surface processes. The development of enhanced and irregular pore spaces through incomplete thaw consolidation after permafrost melt influences the hydraulic conductivity and thus reduces the overall mechanical slope stability (Zimmermann and Haeberli, 1992). This could enhance significantly the debris availability. This process can concern rockglacier fronts (many known cases), but also frozen talus or debris cones, or any kind of frozen surficial deposits ;
  - the melting of ice lenses contained in permafrost can lead either to sliding of debris cover, or to the settling of loose debris, that will be prone to facilitated remobilization. The ice lenses are not necessary of permafrost origin, and the same will happen with buried glacier ice or firn.

Permafrost and water supply

Permafrost can influence the water supply, either by limiting infiltration or by providing additionnal water volumes:

- The active layer of the permafrost is often saturated in summertime because of the characteristics of the permafrost table as acquiclude. Therefore, the stability of these slopes is lower, the infiltration capacity is low, and the superficial discharge is high. The permafrost table can act as a slide horizon for landslides in the active layer.

- Thermokarst (ice of permafrost or other origin):
  - weakening of ice/debris dams can lead to draining of lakes and hence to lake outburst floods ;
  - formation of thermokarst lakes : these will in turn increase ice melt and eventually drain, possibly forming outburst floods.

- The melting of ice lenses with dimensions of more than a few cubicmeters leads to the formation of caves within the sediment. In case of extreme precipitation events, these caves can be filled with water and lead to the explosion of parts of the slopes when the water pockets are void abruptly because of the water pressure.

3. Case studies

This chapter describes some debris flow events started in permafrost zones or which were affected or influenced (partially) by permafrost. The case studies have been collected and compiled by the project partners of PermaNET. The aim of this collection is to extend the single observations in each region to a broader view.

3.1 France

Haute Savoie departement

A systematic inventory of torrential basins potentially affected by permafrost related hazards has been achieved for the Haute Savoie departement in France in 2008, in collaboration with the RTM service (Garcia 2008).

The study consisted:

- On the one hand to inventorise all events where presence of ice has been observed or assumed in the debris flow formation zone ;
- On the other hand a screening approach: all catchments developing into the potential permafrost belt, according to the map of potential permafrost distribution (Bodin et al. 2008) have been selected. The presence of surficial deposits displaying flow patterns was then investigated on orthophotos. Only the catchments showing significant debris potential in the permafrost belt were finally retained in a shortlist and underwent a geomorphological mapping on orthophoto.

Finally, 10 catchments with potential permafrost related hazards were identified and classified in three hazard classes. Three examples with recent events or high hazard potential will be described in the following.

Derochoir – Torrent des Arandellys – Les Houches

Latitude	45.8661
Longitude	06.8086
Elevation [m a.s.l.]	1000 to 3600
Slope	75 %
Aspect	N
Type of feature	Rockglacier
Evidence of permafrost	Creeping of rockglacier, observation of ice (end of 19th century)
Occurence of debris flows	Yes / no
Type of torrent	Transport limited
Influence on debris supply	Hanging rockglacier front
Influence on water supply	none
Area of catchment	4.7 km2
Length of torrent	3.4 km
Year of first data	ca 1890

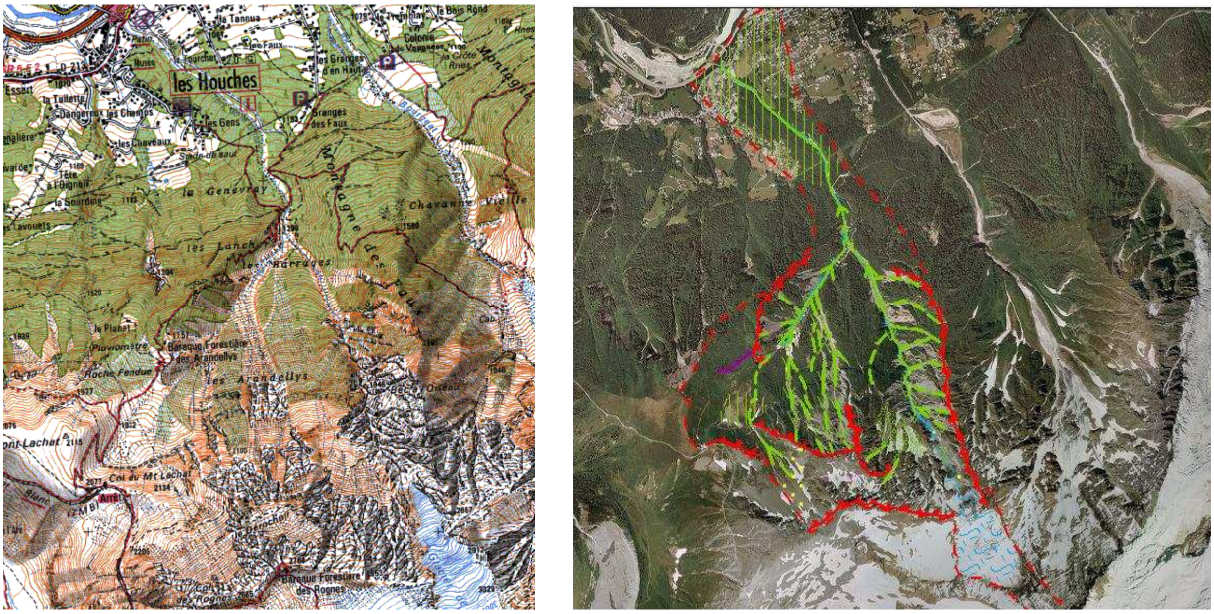

Fig. 2.1 – The Torrent des Arandellys. Left : topographical map (IGN top 25). The hanging rockglacier is located at the place named « Le Dérochoir ». Right : orthophoto of the catchment (IGN BD Ortho 2003). The green hatched area is the potential impact zone of large debris flows.

The Torrent des Arandellys is situated in the southwestern part of the Mont-Blanc massif, on the north flank of the crest separating the Bionnassay glacier valley from the Chamonix valley. The torrent is fed by two branches : the eastern branch originates from the debris-covered front of the Griaz glacier, the western branch from a steep rock slope. A rockglacier is hanging over a subvertical rockwall in the upper catchment, whereas several gullies in marly rocks bring material to the middle part of the channel. The village of Les Houches is partly built on the cone, and the torrent is known for frequent and large debris flows. In the late 19th century, several very large debris flows occured, and the catchment was delimited as a RTM perimeter (perimeters for torrent control and restoration of the National Forest Office).

The relevant part in regard to permafrost influence is the hanging rockglacier front. It develops over several hundreds of meters above an almost vertical, intensely fractured, rockwall. The debris accumulate at the head of the channel some 300 m below, where they will be eventually mobilised by debris flows. The rockglacier front is up to ten meters high and is obviously instable on certain parts, with open cracks on the upper edge. At the end of the 19th century, this area was already recognized as a main debris source area for the debris flows. Important rockfalls occurred since 1888, and were recognized as the main source for a series of large debris flows. The rockglacier was then identified as a «debris covered glacier» and water flows were observed at the front. Ice was found at 1.5 to 2 m depth in drainage trenches made in 1893 in order to drain the water (Garcia 2008, 2009).

The front does not seem to be very active today, and an estimation of instable volumes at the front lead to a potential volume of a few hundreds of m3. Deformations of a path built around 1895 across the rockglacier allow a reconstruction of total displacements by comparison of the original map of the path in 1895 an orthorectified aerial photograph of 1974 and the orthophoto of 2004. They indicate total displacements in the central part of the rockglacier in the order of 10-20 m in the first 80 years, and of 4-8 m in the following 30 years. This gives mean velocities in the order of 15-20 cm.yr-1 in the fastest central part. The calculation of the distance between the path and the rockglacier front in 1974 and 2004 indicates a retreat of the front of 6 to 8 m, or 23 cm-yr-1. The calculation of the eroded volume gives a total of some 4000 m3 in 30 years for the most active zone, which would represent a mean annual supply of 100-200 m3. This is consistent with the observation of the potential instable volume (Garcia 2009). This seems to be unsufficient to explain repeated large debris flows, and the hanging rockglacier probably supplies only a small part of the total debris volume.

The question remains however on the trigger of the crisis in the late 19th century : was there an acceleration of the rockglacier, temporally enhancing the debris supply ? If it is the case, this would indicate that this rockglacier experienced an acceleration in the 1880' to 1890's. A possible indication is given by the map of 1895, where the rockglacier front is drawn at a much higher distance from the path, but this seems hardly compatible with the position of the rockwall.

Another hypothesis is that the rockfalls of the 1880's occured from the underlying rockwall, which is deeply and intensely fracturated. The retreat of the rockwall could lead to an increased overhanging of the rockglacier front and to its fast retreat to a new equilibrium slope.

In any case, an acceleration of the rockglacier could have a direct and strong impact on the debris supply, the total volume of the rockglacier being evaluated to ca 500'000 m3. Therefore this catchment has been ascribed the highest vigilance level. DGPS monitoring points have been placed in summer 2009 in order to compare to the mean velocities calculated from orthophotos, and to monitor surface displacements.

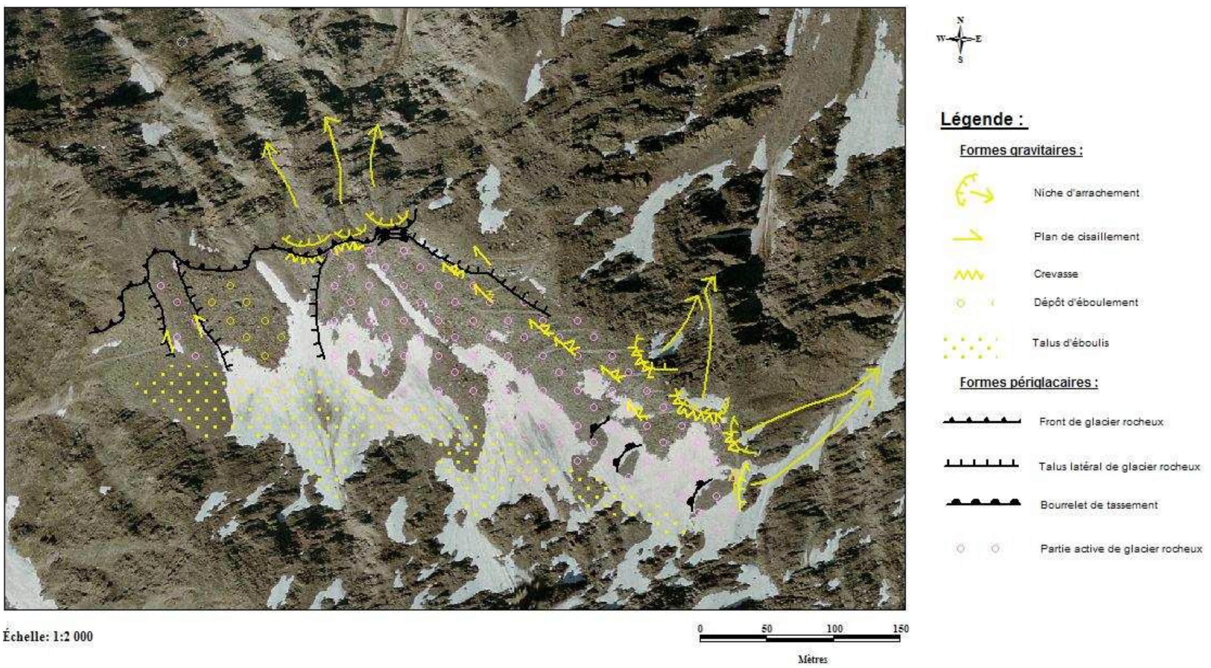

Fig. 2.2 – The rockglacier Dérochoir, in the upper catchment of the Torrent des Arandellys (IGN BD Ortho 2003). The orthophoto shows the rockglacier front hanging over the rockwall, and the main debris supply paths.

Sixt Fer à Cheval

Latitude	46.0558
Longitude	06.8510
Elevation [m a.s.l.]	950-2800
Slope	40 %
Aspect	N to NW
Type of feature	Rockglacier, scree, debris
Evidence of permafrost	Observation of ground ice
Occurence of debris flows	Yes
Type of torrent	transport limited
Influence on debris supply	
Influence on water supply	
Area of catchment	6 km2
Length of torrent	
Year of first data	

The Fer à Cheval is a very large and famous rock cirque, forming the head of the Giffre valley. The 500 m high, semi-circular rockwall is dominated by steep slopes, partly covered by small glacier remnants and debris slopes resting on steep dippinf rocks. Several torrents start from this upper zone, cross the wall through narrow gorges, before building cones in the cirque bottom.

All these torrents produce periodic debris flows, but the most active is the Nant des Pères. In December 2002, a huge event occured, with a total volume estimated to 300'000 m3. Tens of smaller debris flows occured in the following years (Garcia 2008).

The 2002 event started in the upper slopes, between 2400 and 2800 m asl, where a thin debris cover slides on a steep rocks slope dipping at 30°. The observation of aerial photographs and field campaigns allowed the identification of a small rockglacier and of creep features on some debris covers. Thus, the presence of permafrost is likely, but it is at its lower limit of occurrence. The degradation of the permafrost could be involved in the debris supply to the torrent.

The debris supply to the torrent occurs however in two steps : the debris mobilised in the upper slope accumulates in a funnel shaped slope on top of the cirque wall, from where it is remobilised through the gorge.

The difficult access to the upper catchment didn’t allow more detailed investigations.

Fig. 2.3 – Topographical map of the Fer à Cheval cirque (IGN top 25). The Nant des Pères is in the middle of the image.

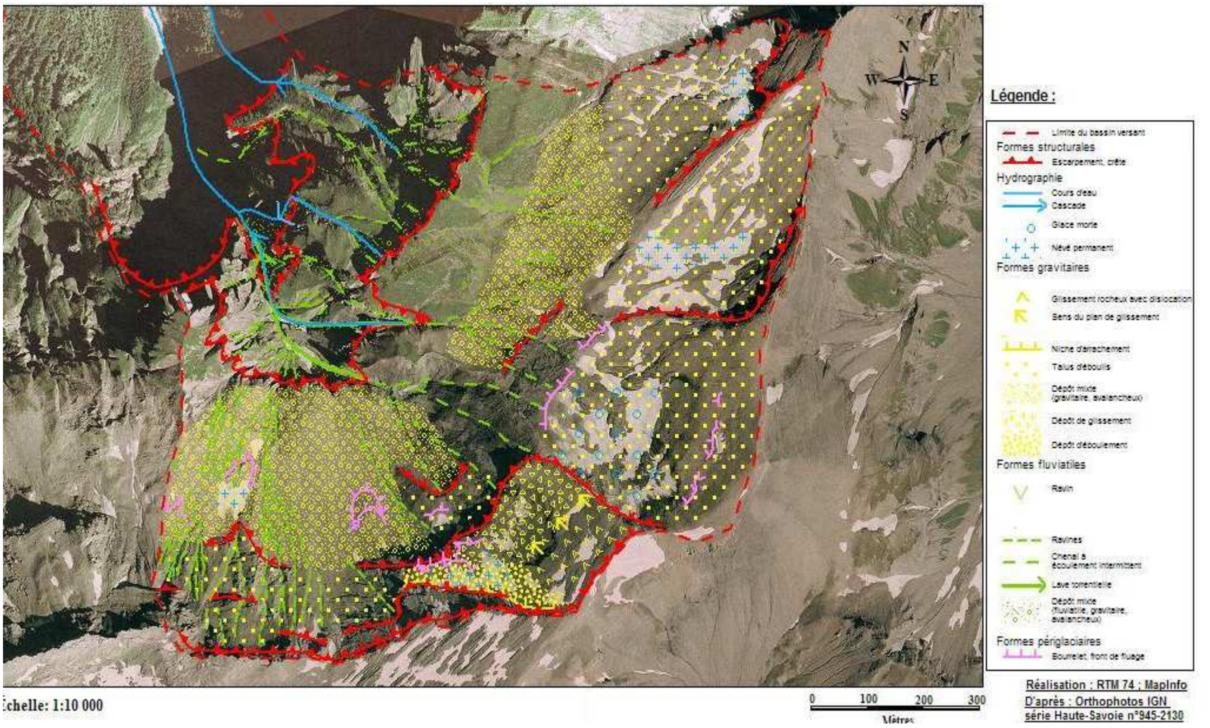

Fig. 2.4 – Simplified geomoprhological map of the upper catchment of the Nant des Pères. A small rockglacier and creeping debris can be identified, indicating a possible influence of permafrost degradation in the debris supply.

Nant d'Armancette – Contamine-Montjoie

Latitude	45.8039
Longitude	06.7602
Elevation [m a.s.l.]	1100 – 3670
Slope	45°
Aspect	E to NE
Type of feature	scree / moraine ...
Evidence of permafrost	Observation of ground ice
Occurence of debris flows	Yes
Type of torrent	unknown
Influence on debris supply	
Influence on water supply	Ice melt
Area of catchment	7 km2
Length of torrent	5 km
Year of first data	

The Nant d'Armancette is a torrential basin in the south-western part of the Mont Blanc massif. It ranges from 3670 to 1100 m asl, for a total area of 7 km2, a length of 5 km and an average slope of around 45°. In the upper part of the catchment, two small glaciers cover 10 to 15 % of the area, surrounded by steep rockwalls. The torrential system develops below 1700 m asl, with several channels carved in scree slopes at the foot of the rockwalls, and converging to a gorge between 1500 and 1250 m. The upper catchment develops in gneiss and micaschists, whereas surficial deposits are covering the lower part.

Fig. 2.5 – Topographical map of the Nant d'Armencette (IGN top 25). Buried ice was observed after the 2005 event in some channels just on the foot of the rockwalls.

On August 22 2005, a large debris flow occured. Field observations made the day after the event showed buried ice under scree slopes in the upper catchment, with observed thicknesses of a few decimeters to several meters. The ice was eroded by the channels. Although the presence of permafrost can not be excluded in the upper catchment, the observed ice more probably originates from snow avalanche deposits buried by debris.

Fig. 2.6 – Buried ice observed in one of the channels, the day after the event of August 2005. Fig. 2.7 – Avalanches cones at the foot of the rockwalls, illustrating how snow can be buried by debris and eventually develop as ice lenses.

Clarée valley

A study on the torrential systems of the lower Clarée valley, in the southern French Alps, has shown a decrease of torrential activity since the 19th century, indicated as well by a lower frequency of damaging events in the historical record, as by a narrowing of the active bed on debris cones and their revegetation (Garitte 2006). The investigated torrential catchments do not exceed altitudes of around 2500 m, and don't therefore reach into the permafrost belt. The debris supply is mainly provided by talus and erosion of surficial deposits. The decrease of downward transport of debris is explained by a decrease of the upstream debris supply by frost weathering.

A dendrogeomorphological study on a mixed debris/talus cone in the upper Romanche valley, at the same latitudinal range, showed a significant inverse correlation between recorded tree damage frequency and temperature, confirming that temperature directly influences the frequency of rockfall (Corona 2007).

These examples show that climate warming not necessary leads to an increase in torrential activity. In cases where the catchment develops below present permafrost zones, in what is commonly designated in France as the infra-periglacial belt, the decrease of frost-thaw cycle intensity and fequency could lead to a decrease of debris supply by frost-shattering and hence to a decrease of debris flow intensity/frequency and of related hazards.

Chauvet lake – Upper Ubaye valley

In the upper Ubaye valley, in the southern French Alps, a lake outburst flood occured in summer 2008. It was due to the draining of the Lac Chauvet. Field observations made after the event showed that the lake drained through buried ice under a talus cone. The presence of ice at this location was known since the 1990's (Assier 1993).

Latitude	44.5514
Longitude	06.8385
Elevation [m a.s.l.]	2750
Slope	
Aspect	W
Type of feature	Rockglacier / scree / moraine ...
Evidence of permafrost	Observation of ground ice, ground surface temperature, geolectric
Occurence of debris flows	Yes
Type of torrent	Transport limited
Influence on debris supply	Erosion on debris flow path
Influence on water supply	Thermokarst lake / ...
Area of catchment	
Length of torrent	
Year of first data	

The lake formed since the 1930's within the forefield of the Chauvet glacier. It is thus probable that the dam is formed by buried glacier ice of the Little Ice Age. Electrical resistivity soundings indicate a surficial debris cover, 35 m of massive ice ovelying 40 m of frozen debris (Assier 1993). The presence of permafrost is uncertain.

Previous outburst floods are known from 1935-1936, 1956, 1969, 1991, and 1997. The last, well documented outburst, started on July 17 2008 and lasted 4 days. On orthophotos and maps between these dates, no lake is visible. This indicates that the lake forms periodically and has only a short lifetime before draining.

This example illustrates a potential hazard related to thermokarst, that was largely unknown until recently. Thermokarst features appeared at several locations in the last years, and have been observed especially after hot summers (2003 and 2009) in form of pot holes or small lakes in debris accumulations. They revealed the presence of buried ice at locations where its occurrence was unknown. In some cases, new lakes may form and eventually drain, or existing lakes may drain due to the weakening of the ice/debris dam, as it was the case for Chauvet lake.

Fig. 2.8 – The Chauvet lake in summer 2008 (photo M. Peyron)

Fig. 2.9 – The outlet of the Chauvet lakeduring the outburst of July 17 2008 (photo M. Peyron).
Fig. 2.10 – The debris flow from Chauvet lake on July 18 2008 (photo M. Peyron).

3.2 Italy

Autonomous Province of Bolzano South Typol

Andreas Zischg, Kathrin Lang, Volkmar Mair

The database of documented debris flow events in the Autonomous Province of Bolzano South Tyrol enlists 14 debris flow events with spatial relation to permafrost areas. In this chapter are described a selection of this dataset with more detailed information available.

Tschenglser Bach catchment, community of Laas

Latitude	46.57
Longitude	10.63
Elevation [m a.s.l.]	900 to 3100
Slope	36
Aspect	N
Type of feature	Scree slope and rockglacier
Evidence of permafrost	GST
Occurence of debris flows	Yes
Type of torrent	Transport capacity limited
Influence on debris supply	Melting of ground ice in scree slopes
Influence on water supply	
Area of catchment	9 km^2
Length of torrent	5000
Year of first data	1998

In August 16th, 1999 a debris flow event occurred in the Tschenglser Bach catchment, community of Laas, Italy. The starting zone of this debris flow layed on a scree slope below a rockwall. The starting zone is located on a scree slope on an altitude of 2700 m with an inclination of more than 35°, the slope is exposed to north. This torrent catchment is very active, small events are observed every year.

In the upper parts of the starting zones of this debris flow have been made BTS analyses by Zischg (2008) within the Interreg Alpine Space project “ClimChAlp – Climate Change, Impacts and Adaptation Strategies in the Alps”. In winter 2006-2007 have been installed 5 temperature dataloggers. Additionally, in the lower parts of the starting zones have been made BTS temperatures. The analyses showed that only the dataloggers on the highest part of the starting zone measured temperatures typical for permafrost in wintertime. The other dataloggers showed warmer temperatures. The punctual BTS measures showed that in most parts of the scree slope permafrost is not plausible. Only a few measurements showed temperatures lower than -2° C. Single ice lenses in the scree slope cannot be excluded. Fields studies in summertime showed that the debris flow uncovered old avalanche deposits under a debris cover with a diameter of about two meters while eroding the channel. During the de-installation of the dataloggers in the upper parts of the starting zones after quite a long dry period and more than two months after the snowmelting period, extended areas of super-saturated debris have been observed. The over-steepened scree slopes become instable. In the other part of the catchment, a small glacier disappeared in the summer 2003. Therefore, the hydrological characteristics of this catchment have been changed remarkably.

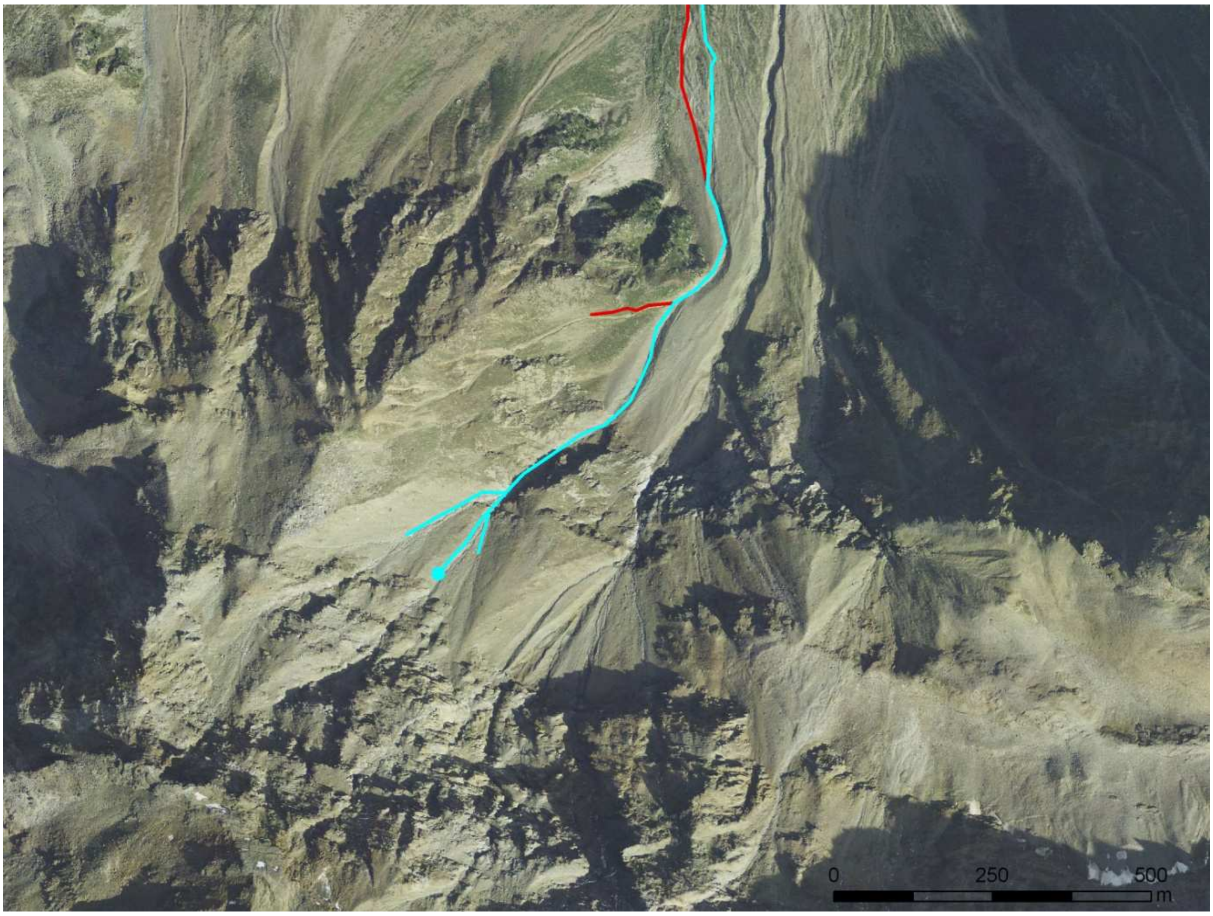

Fig. 2.11 – Upper catchment area of the Tschenglser Bach torrent, community of Laas, Italy.

Fig. 2.12 – Upper part of the starting zones of the debris flow in the Tschenglser Bach catchment

Fig. 2.13 – Saturated soils in the upper part of the starting zones of the debris flow in the Tschenglser Bach catchment

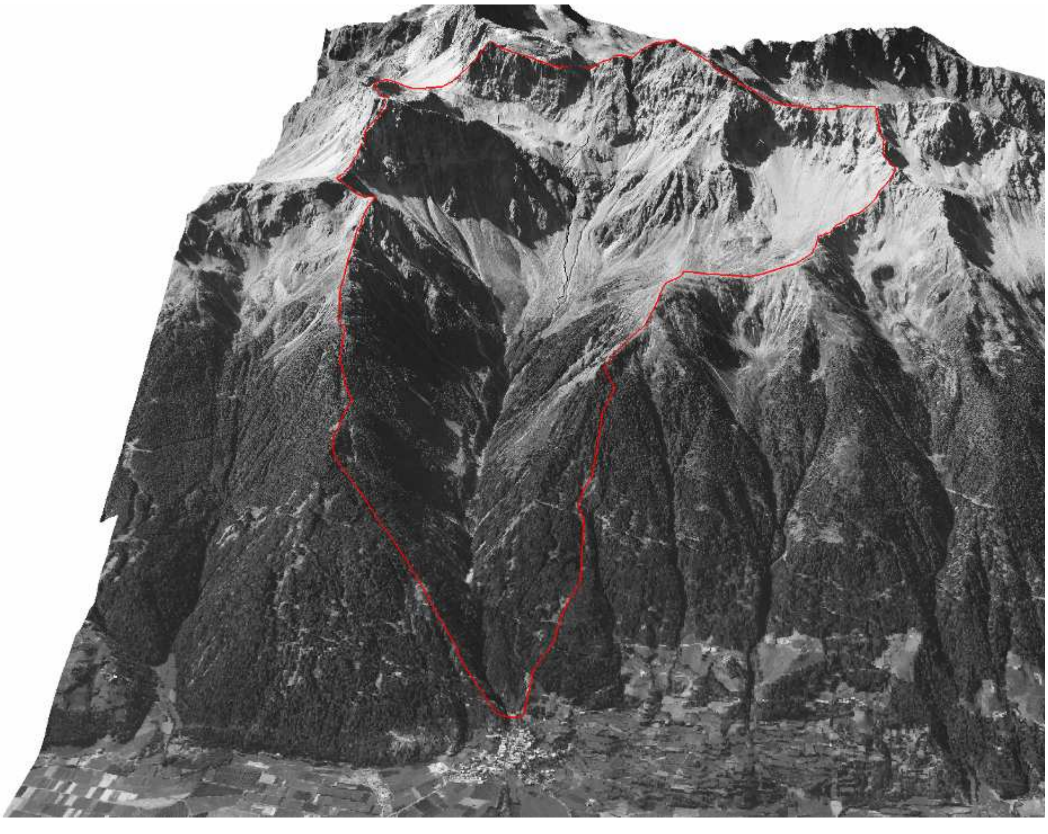

Fig. 2.14 – 3D view of the Tschenglser Bach catchment

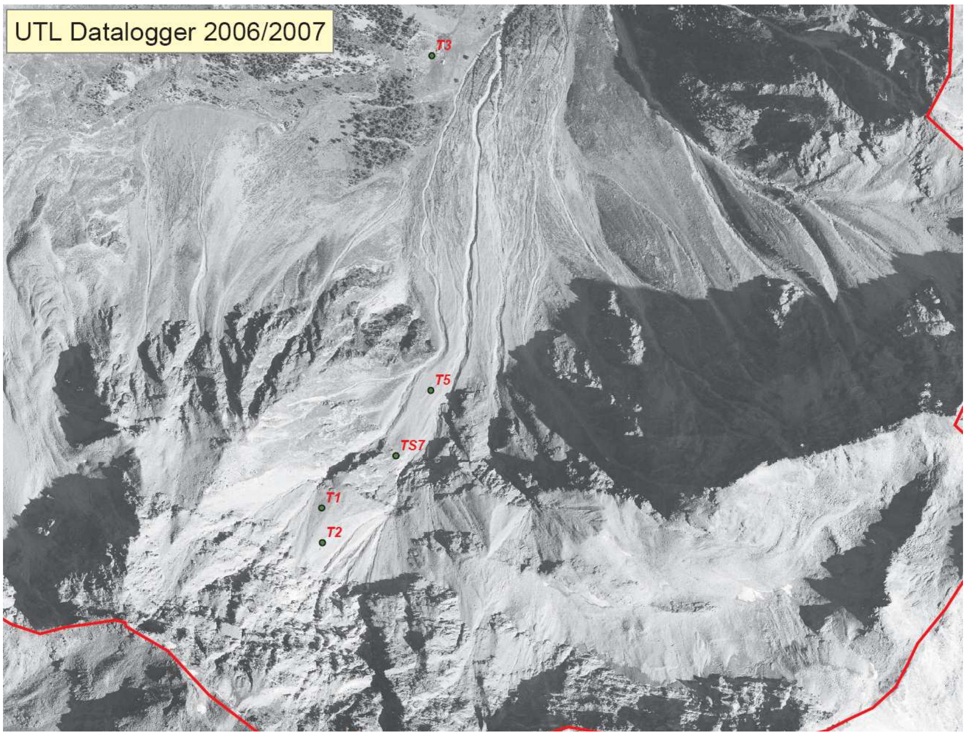

Fig. 2.15 – Location oft he temperature dataloggers in winter 2006-2007, upper part of the Tschenglser Bach catchment

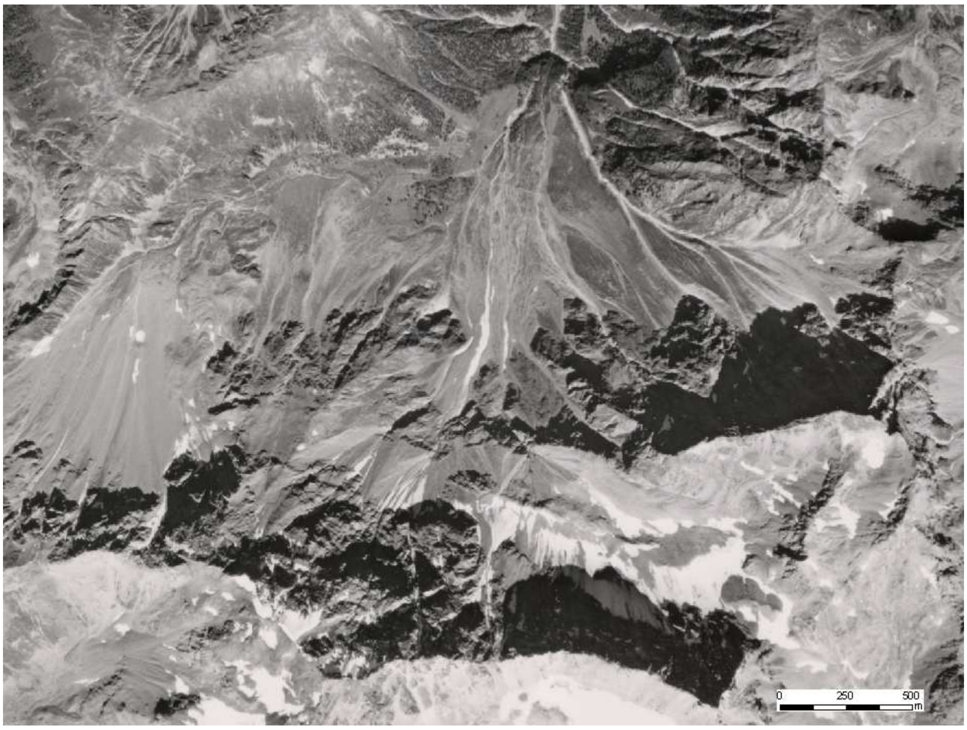

Fig. 2.16 – Aereal image of 1986

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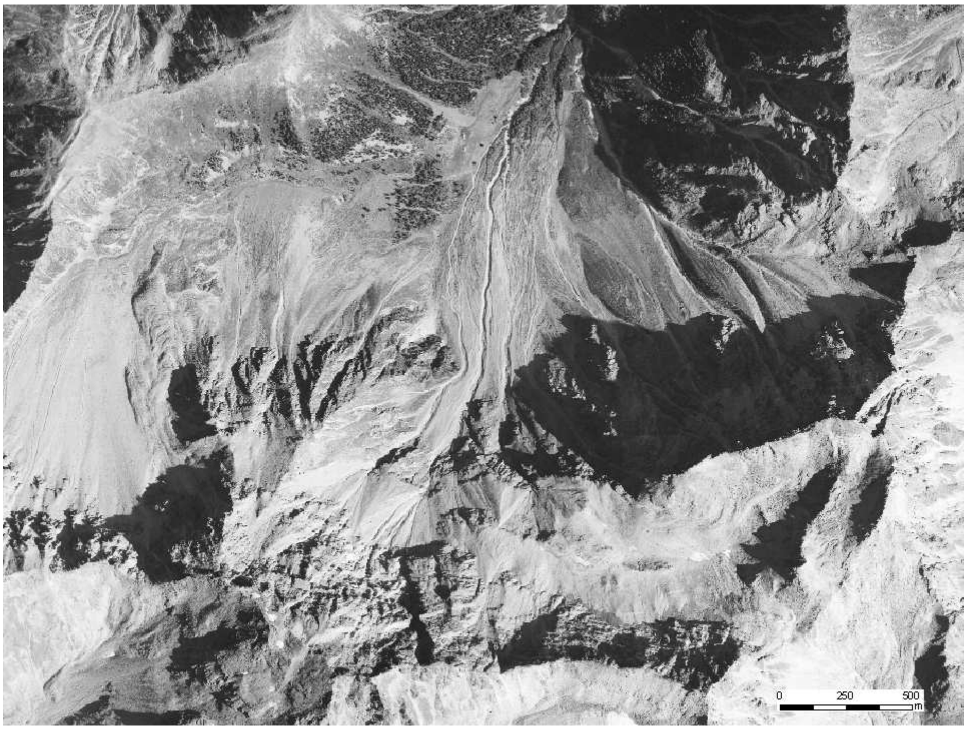

Fig. 2.17 – Aereal images of 2003.

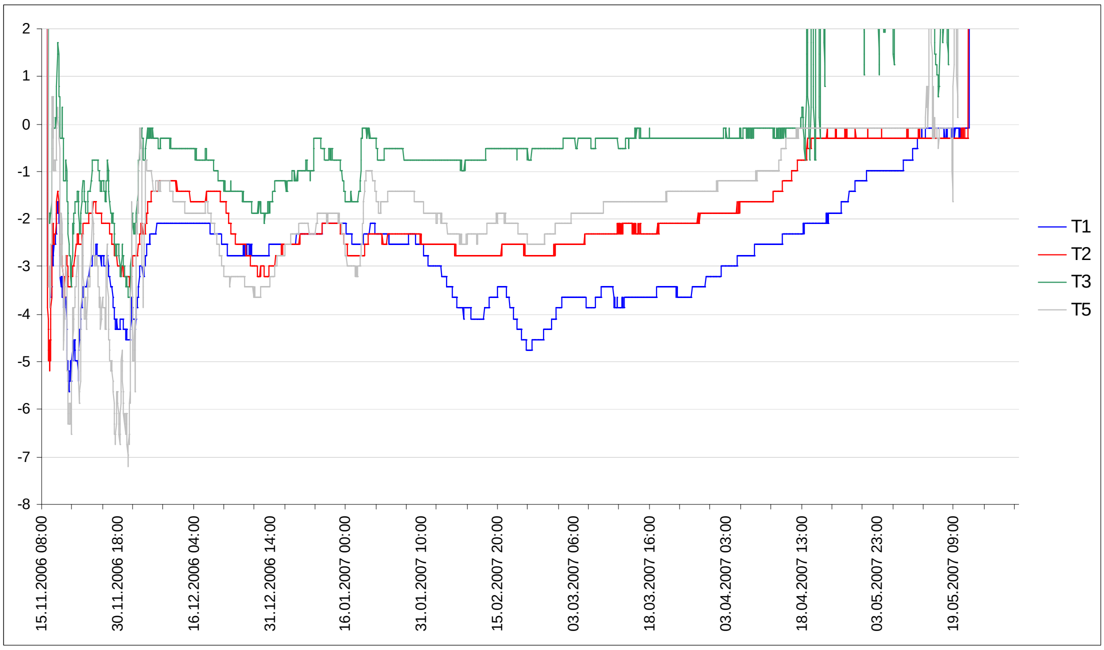

Fig. 2.18 – Temperatures at the bottom of the snow cover during winter 2006-2007.

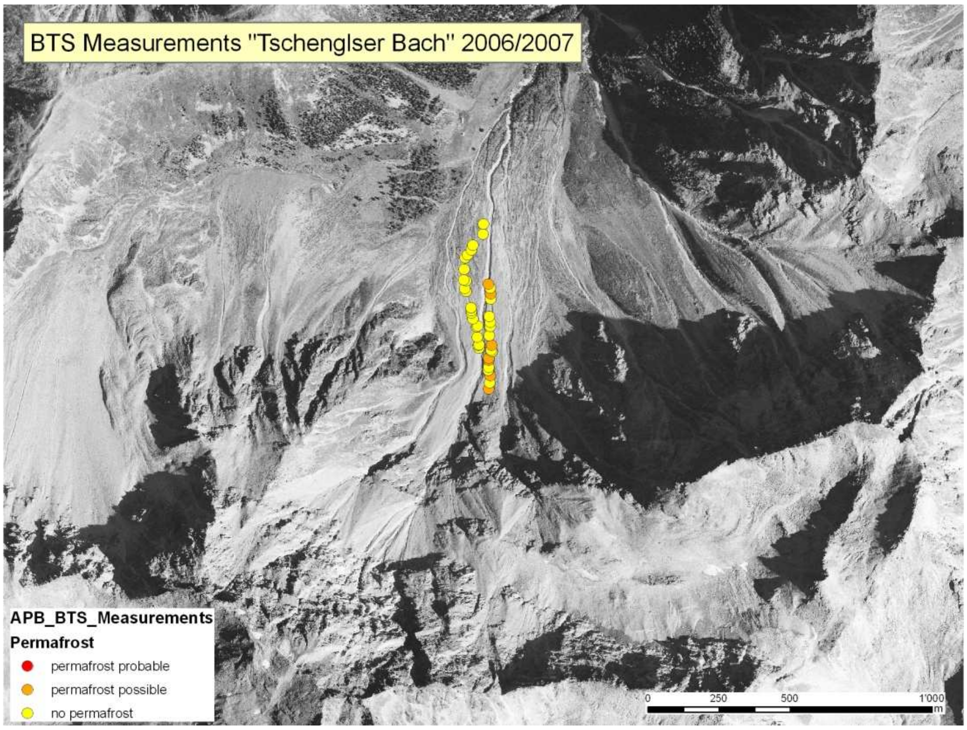

Fig. 2.19 – Results oft he punctual BTS measurements on February 23th and March 29th, 2007.

Fig. 2.20 – Upper part oft he debris flow starting zones in the Tschenglser Bach catchment.

Laasertal, community of Laas

Latitude	46.55
Longitude	10.7
Elevation [m a.s.l.]	1900 to 3500
Slope	36
Aspect	N
Type of feature	Scree slope
Evidence of permafrost	Observation of ice
Occurence of debris flows	Yes
Type of torrent	Transport capacity limited
Influence on debris supply	Melting of ground ice in scree slopes
Influence on water supply	
Area of catchment	15 km^2
Length of torrent	3.5 km
Year of first data	1999

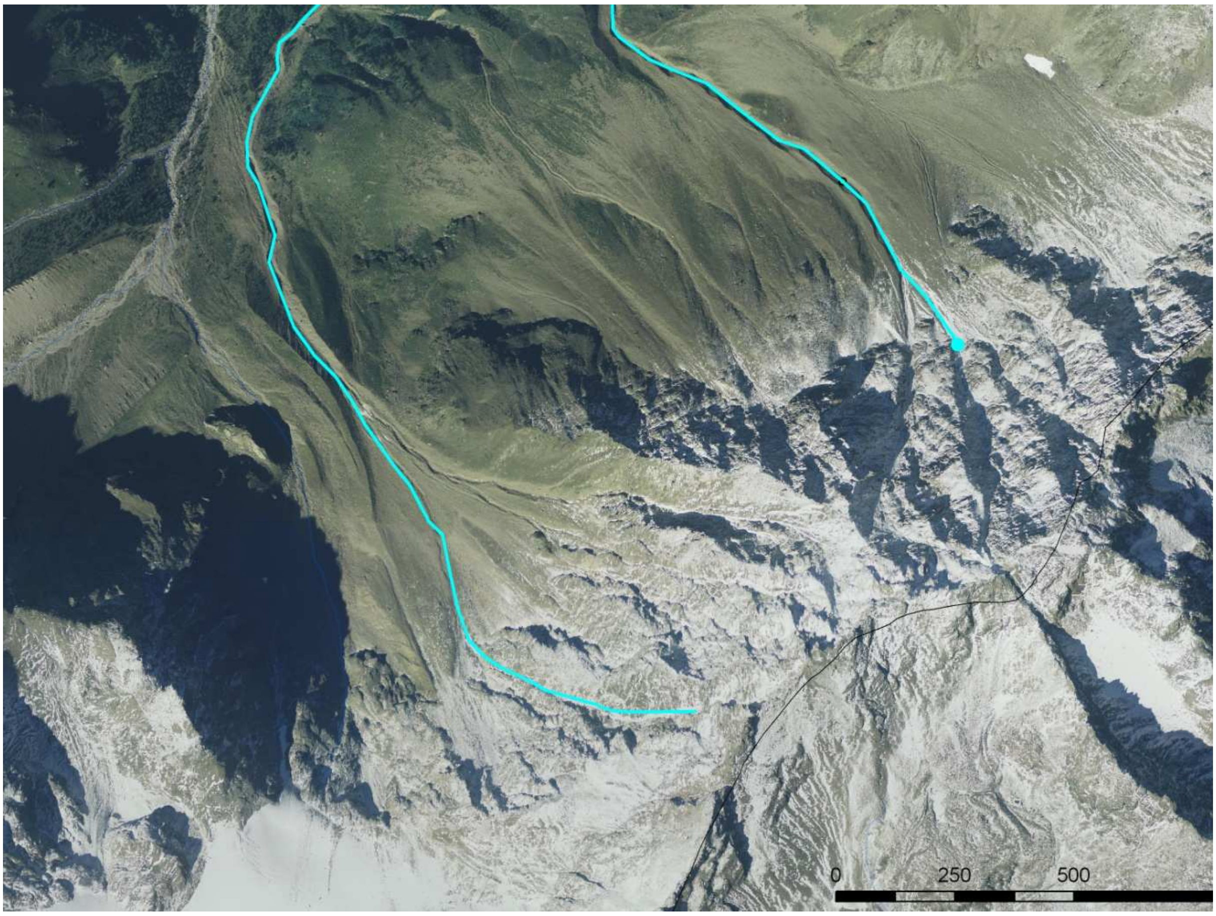

Fig. 2.21 – Upper part of the debris flow starting zones in the Laasertalbach catchment.

In August 20th, 1999 a debris flow event occurred in the Laasertal Valley, community of Laas, Italy (IDW 1999013). The starting zones of two debris flow events are located on an altitude of 2700 m on scree slopes exposed to north. The first debris flow started in the deglaciated forefield between the moraines of the little ice age. The other starting zone is located beneath a rock wall at the contact zone between rock face and scree slope. The scree slopes in this area are totally free of vegetation. Perennial snow patches are observed in all of the available orthoimages (years 1986, 1999, 2003, 2006, 2008). The existence of ground ice in these scree slopes is probable. In 1997, the author passed this area and observed ice lenses resp. fossil avalanche deposits in the debris flow channels in this area beneath the surface (covered earlier by rock fall deposits) but uncovered by the erosion of the debris flow. The event damaged 120 m of a forestry road and a pipe for water catchment.
In August 29th, 2003, another event occurred in this debris flow channel (IDW 2003059).

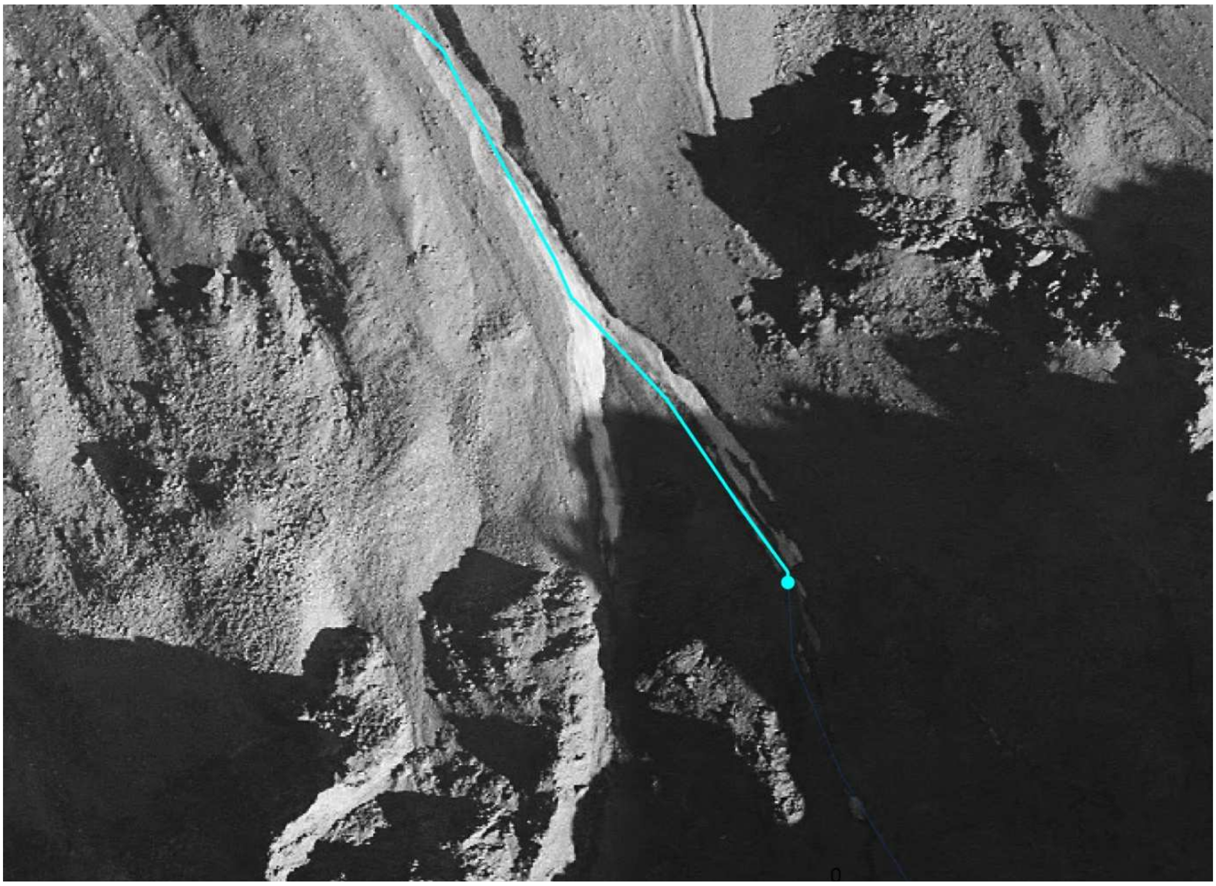

Fig. 2.22 – Upper part of the debris flow starting zones in the Laasertalbach catchment.

Grödner Joch, community of Wolkenstein

Latitude	46.54
Longitude	11.81
Elevation [m a.s.l.]	1900 to 2800
Slope	36
Aspect	N
Type of feature	Rockglacier
Evidence of permafrost	Creeping of rockglacier, observation of ice
Occurence of debris flows	Yes
Type of torrent	Transport capacity limited
Influence on debris supply	Hanging rockglacier front
Influence on water supply	
Area of catchment	1 km^2
Length of torrent	1 km
Year of first data	2003

On July 21th, 2003 more debris flow events occurred near Grödner Joch, Italy. The most important debris flow event started on the front side of a rockglacier that is situated 500 m above the pass road at the upper edge of a rock face (Geological service 2003). The triggering event of the debris flow was a hailstorm with a precipitation of around 17 mm in 24 minutes. Due to the mobilisation of material of the rockglacier, a direct link to permafrost is proven. The existence of permafrost and the conditions of it in this rockglacier have been analysed by Mussner (2009). The rockglacier advanced until the upper edge of the rock face and therefore the material of the rockglacier has been moved to a location where it becomes relevant for the infrastructures beneath the rock face. The movement of this rockgalcier has been accelerated during the summer 2003. The material mobilized from the rockglacier front has been transported downwards and developed a debris flow event. The event damaged and blocked the important pass road to the Grödner Joch.

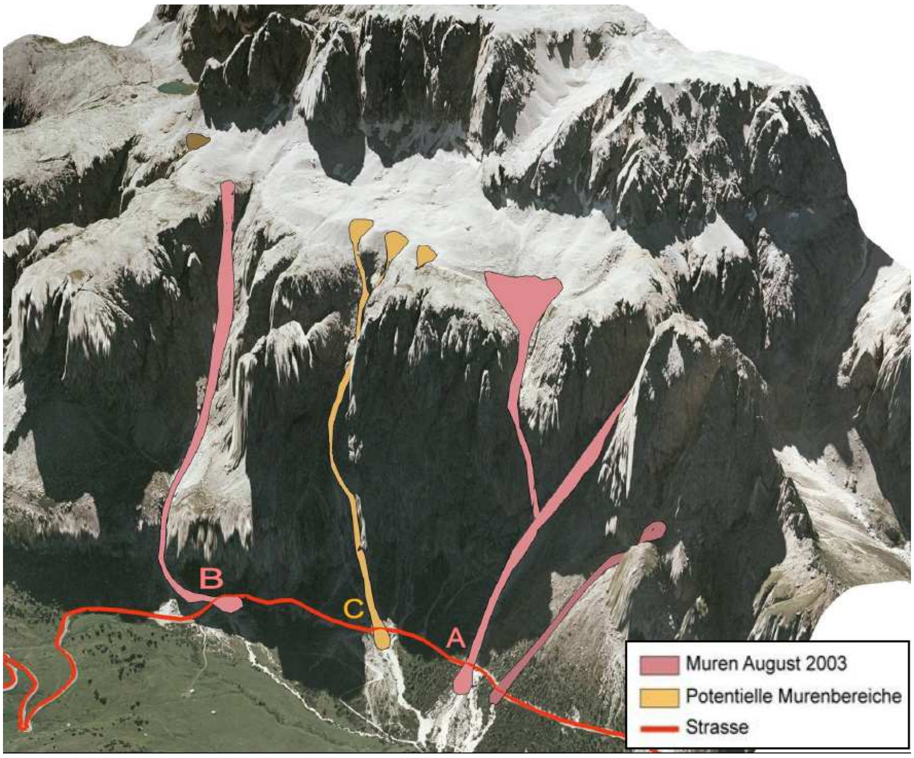

Fig. 2.23 – 3 D view of the Murfreit rockglacier and the debris flow events of summer 2003. Source: Mussner 2009.

Fig. 2.24 – Erosion and mobilization of parts of the rockglacier front. Picture: Geological service

Fig. 2.25 – Deposits on the pass route to the Grödner Joch.

Autonomous Region of Valle d'Aosta

Michèle Curtaz

Pellaud Basin, Rhêmes Valley

Latitude	45°33'23.28"N
Longitude	7° 5'14.59"E
Elevation [m a.s.l.]	1810 to 3600
Slope	45° upper part; 15° on the alluvial fan
Aspect	East
Type of feature	rock walls + debris
Evidence of permafrost	Observation of ice in the rock mass
Occurence of debris flows	yes
Type of torrent	Transport limited
Influence on debris supply	Rockfalls in the upper part of the basin
Influence on water supply	none
Area of catchment	1,5 km^2
Length of torrent	1.8 km
Year of first data	2005

The Pellaud catchment basin is on the orographical right side of the upper Rhêmes Valley, a secondary valley of Aosta Valley Region. The catchment is a circle surrounded by metamorphic rock walls (gneiss and mica schist) about 500 m high, from 3550 m asl to 3000 m asl; below there are steep slopes (always more than 30°) with some cliffs that end at 2200 m asl in the alluvial fan where the Pellaud torrent runs up to the confluence (1810 m asl) with the main torrent of Rhêmes Valley, the Dora di Rhêmes. In the upper part of the basin there is a glacier (Pellaud Glacier) which has almost totally disappeared leaving some loose material on the slopes.

In autumn 2005 some rockfalls happened on the eastern side of the Becca di Fos (3459 m asl), in Rhêmes Valley (Aosta Valley – Italy). After being deposited on the steep slopes below the rockwalls, the rock material was carried by strong rainfall runoff to the lower part of the basin causing debris flows. In Autumn 2005 during the surveys by helicopter ice was seen in the fractured rock mass and in the scar of the rockfall.

When the rockfall happened along the torrent Pellaud there were the yard for the construction of prevention measures necessary after the flood event of July 1996; the yard were evacuated and scaling works were done in Autumn 2005 to reduce the still instable rock mass (about 30000 m^3). In spite of these intervention measures the rockfall and the debris flows didn't stop. Other events produced during the next years (2006-2007) and the site is still active. The increase in the frequency and in the magnitude of the debris flows lead to stop the construction of the torrent protection measures (the yard was in danger and every time they had to clean the river bed from the material transported and deposited in). This is a complex case, where the degradation of permafrost in fractured rock walls can trigger rockfalls that feed scree slopes and lead to bigger events of solid transport by the water. The site is still active: strong precipitations carry the fallen rock material deposited on the steep faces and transport it in the Pellaud Torrent producing debris flows events. The magnitude of these debris flows has been assessed variable in each event in the range 5000-15000 m^3.

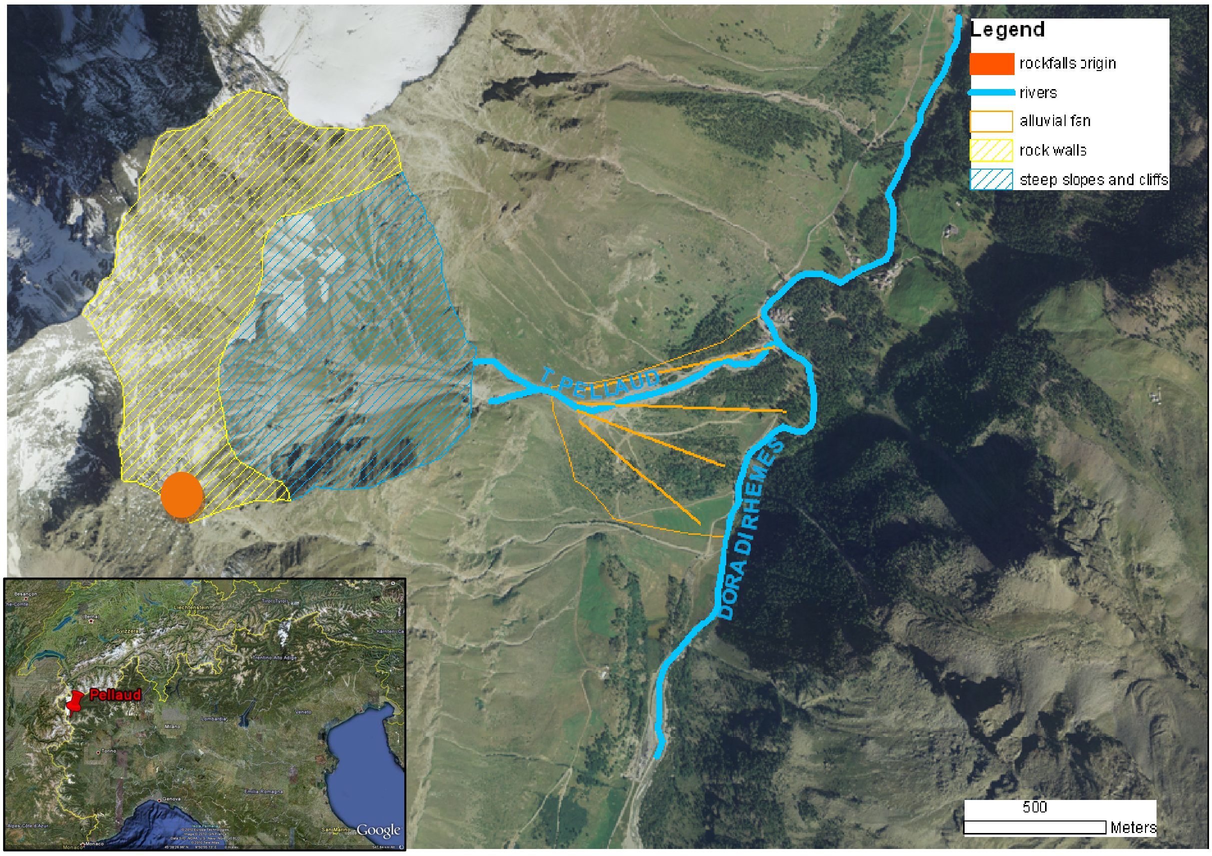

Fig. 2.26 – Location of Pellaud catchment basin.

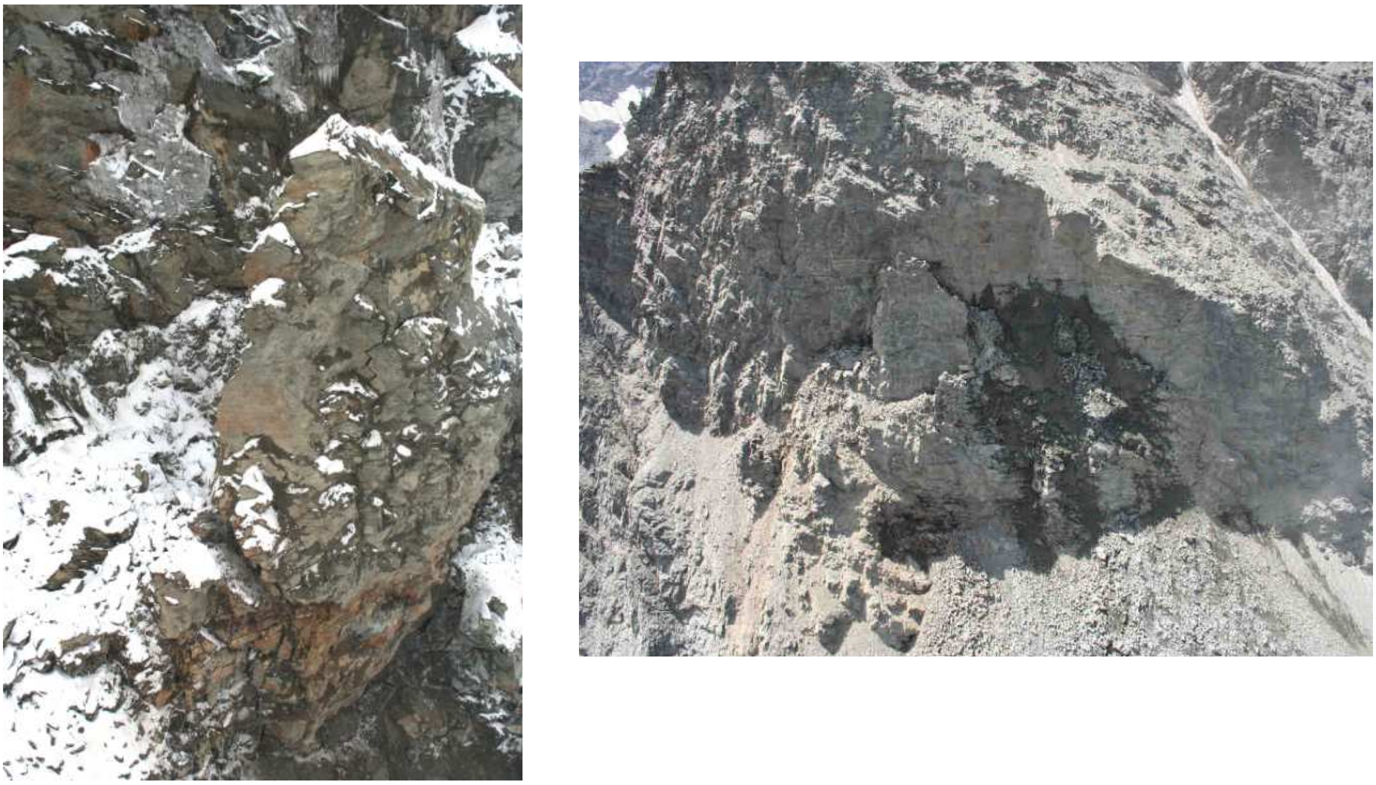

Fig. 2.27 – Ice in the rock mass (autumn 2005 – photo RAVA).

The new situation required to stop the construction of the protection measures on the alluvial fan and to change the original design in order to consider the increasing debris flows correlated to the rockfalls.

Sources:

Direzione assetto idrogeologico dei bacini montani – Regione Autonoma Valle d'Aosta (Direction for Hydrogeological management of mountain catchment basins)

Presentation of Direzione assetto idrogeologico dei bacini montani – Regione Autonoma Valle d'Aosta in Séminaire final PERMAdataROC, Courmayeur 16/05/2008

Servizio geologico regionale - Regione Autonoma Valle d'Aosta (Regional geological service)

Dolomites

A. Galuppo

Latitude	46.41°
Longitude	12.13°
Elevation [m a.s.l.]	2180 to 1600
Slope	35° to 5°
Aspect	NW
Type of feature	Scree slope
Evidence of permafrost	Observation of ice in the erosion zone (depth of erosion 25 m)
Occurence of debris flows	Yes
Type of torrent	
Influence on debris supply	
Influence on water supply	
Area of catchment	0.20 km^2
Length of torrent	
Year of first data	1994

In the Dolomites debris flows phenomena generally take place during summer season in coincidence with heavy and short duration rains. These rains are often due to very localized stormy cells that can cause different amount of precipitation in relation with orographic constraints. Every year a lot of such phenomena occur in the Dolomitic Region causing serious risk conditions for people and traffic along the roads. Nevertheless it is not so common to observe debris flows triggered by permafrost melting or related to. The only known event is that occurred on September 14, 1994 on the northern slope of Mt. Pelmo. This event, due to rapidly changing meteorological conditions caused the outcropping of a small plate of ice previously buried under a thick cover of debris, which extended to about hundred meters in length.

The event was triggered by intense rainfall (more that 115 mm in two days) and high temperature. As for short term rainfall 10 mm in 15 minutes were recorded just before the event. The mobilized volume was estimated in about 200000 m^3, the materials moved for about 1650 m and reached the SS 251 connecting Zoldo and Fiorentina Valleys.

The surface of buried ice in proximity to detachment zone, in metastable conditions for the partial melting due to the increased average temperature of the previous summer, may have acted as a sliding plane as well as an impermeable surface favouring a quicker saturation of debris.

As concerning the role of the temperature as triggering processes this is not easy to define. An analysis of the variations of the monthly average temperature in 1994, in comparison with the average monthly values of the previous decade, related to a nearby meteorological station, highlighted an increase in the summer temperatures in this area. So an influence of the permafrost melting in the triggering process can be supposed although not confirmed by direct measurements.

Even if the role of the permafrost melting is not yet well understood it has been possible to observe that the melting of the buried ice causes slow movements on the overlaying debris creating morphological evidences similar to rock glaciers. Further geophysical investigation lead some researchers to conclude that this is not a rock glacier. Therefore we can suppose that the presence of buried ice close to melting temperature keeps the debris in a quasi-saturated condition, in other words, make the debris cover prone to flow even if not heavy precipitations occur.

Anyway this aspect can be a topic to investigate in detail in the future by means of instrumentation and field survey. The description of this phenomenon mostly derived from Del Longo et al. (2001).

3.3 Switzerland

Ritigraben torrent catchmen, Valais

Latitude	46.17
Longitude	7.85
Elevation [m a.s.l.]	2690
Slope	20
Aspect	W
Type of feature	Rockglacier
Evidence of permafrost	Observation of ice
Occurence of debris flows	
Type of torrent	Transport capacity limited
Influence on debris supply	Rockglacier
Influence on water supply	
Area of catchment	5
Length of torrent	3.5
Year of first data	1993

The most known torrent catchment where the debris flow activity is influenced by permafrost is the Ritigraben torrent in Valais. The debris flow activity on this torrent catchment is documented by Rebetez et al. (1997).

The starting zone of the debris flow of September 24, 1993 is situated at the front of the rockglacier in the upper part of the torrent catchment. After this event, massive ground ice exposed at the surface has been observed in the starting zone. The general rise in temperature in a region of permafrost may also play a role in the response of slope stability to extreme precipitation (Rebetez et al. 1997). At the foot of the Ritigraben, warming trends of both minimum and maximum temperatures have been particularly marked in the last two decades.

Fig. 2.28 – Torrent system of the Ritigraben with (1) rockglacier, (2) present flow path of debris flows and (3) alluvial fan. Source: Rebetez et al. (1997).

3.4 Austria

C. Riedl, ZAMG Salzburg

Debris Flow and Rockfall Sattelkar/Obersulzbachtal/Salzburg/Austria

Latitude	47,16°
Longitude	12,28°
Elevation [m a.s.l.]	2100 - 2700
Slope	30°
Aspect	W
Type of feature	Scree slope, rockglacier
Evidence of permafrost	Rockglacier, observation of ice
Occurence of debris flows	yes
Type of torrent	Transport capacitiy limited
Influence on debris supply	Availability of water
Influence on water supply	temperature
Area of catchment	1 km²
Length of torrent	~ 800 m
Year of first data	2005

Sattelkar is located in Obersulzbach valley in Salzburg, Austria, at an elevation between 2100 m and 2700 m a.s.l. The mean slope amounts to 30°.

Glacial erosion and postglacial sedimentation processes dominate the valley. The granitic gneiss is mainly smooth at its surface. On the rock morainic material and debris are deposited. The hydrogeological regime in Sattelkar is determined by the permeable debris and the impermeable rock below. The debris can temporarily store the precipitation in the 1 km² catchment area. The discharge takes place at 3 couloirs below Sattelkar. Due to the high altitude of Sattelkar some water is stored as ice and only the upper most soil layers are thawing during summer. Rock glaciers were detected in the middle of Sattelkar.

The morphology shows an older debris flow which occurred some hundred years ago.

Fig. 2.29 – Sattelkar with the area of the mass movement and the three couloirs.

Event description

Since August 2005 debris flows and rock falls are observed from Sattelkar. 150 000 m³ debris are in movement. In winter 2005/2006 the debris flow stopped due to the cold weather. With the snow melt and wet conditions in spring 2006 the mass movement was activated again and even intensified.

In 2005 the northern and the central couloir, in 2006 the central and the southern couloir were affected.

Availability of water, smooth rock surface and small grained morainic material control the active mass movement. The water flows on the rock and saturates the debris above, the friction is being reduced and water pressure rises.

With very high probability the reasons for debris flows and rock falls are the wet conditions during summer 2005 and spring 2006 and thawing of permafrost due to the strong wetting and the recent climate warming.

Risk management

The future of the debris flows from Sattelkar are very uncertain. A realistic scenario is that the movement stops after few years when a stabile angle of slope is achieved again.

As precaution for the path at the bottom of the valley a relocation to the opposite side of the river is the favoured one because different technical safety measures are too expensive. The path is important for the tourism in the region.

Fig. 2.30 – Front of the moving area with exposed rock surface

Fig. 2.31 – Adjusted rocks in the permafrost.

Fig. 2.32 – Debris flow over the path on the valley floor and retention of the Obersulzbach. Green line: new path.

Source

Land Salzburg, Landesbaudirektion, Geologischer Dienst, Zahl: 206-603/24/1764-2005 und 206-603/24/1923-2006, Betreff: Rutschung Sattelkar Obersulzbachtal, Gemeinde Neukirchen am Großvenediger.

Pictures: Ernst Pichler, Gerald Valentin

4. Conclusions

The case studies showed that there exists a few examples of debris flows where permafrost partially influences the hazard situation. Except in a few cases, the examples show also that the interrelation between permafrost and the occurrence of the debris flow event is difficult to quantify because in mostly of the cases, the event is documented only in the lower part. The situation in the starting zones is documented only in a few cases, where the team for event documentation had the possibility to make a helicopter flight to the upper parts of the catchment.

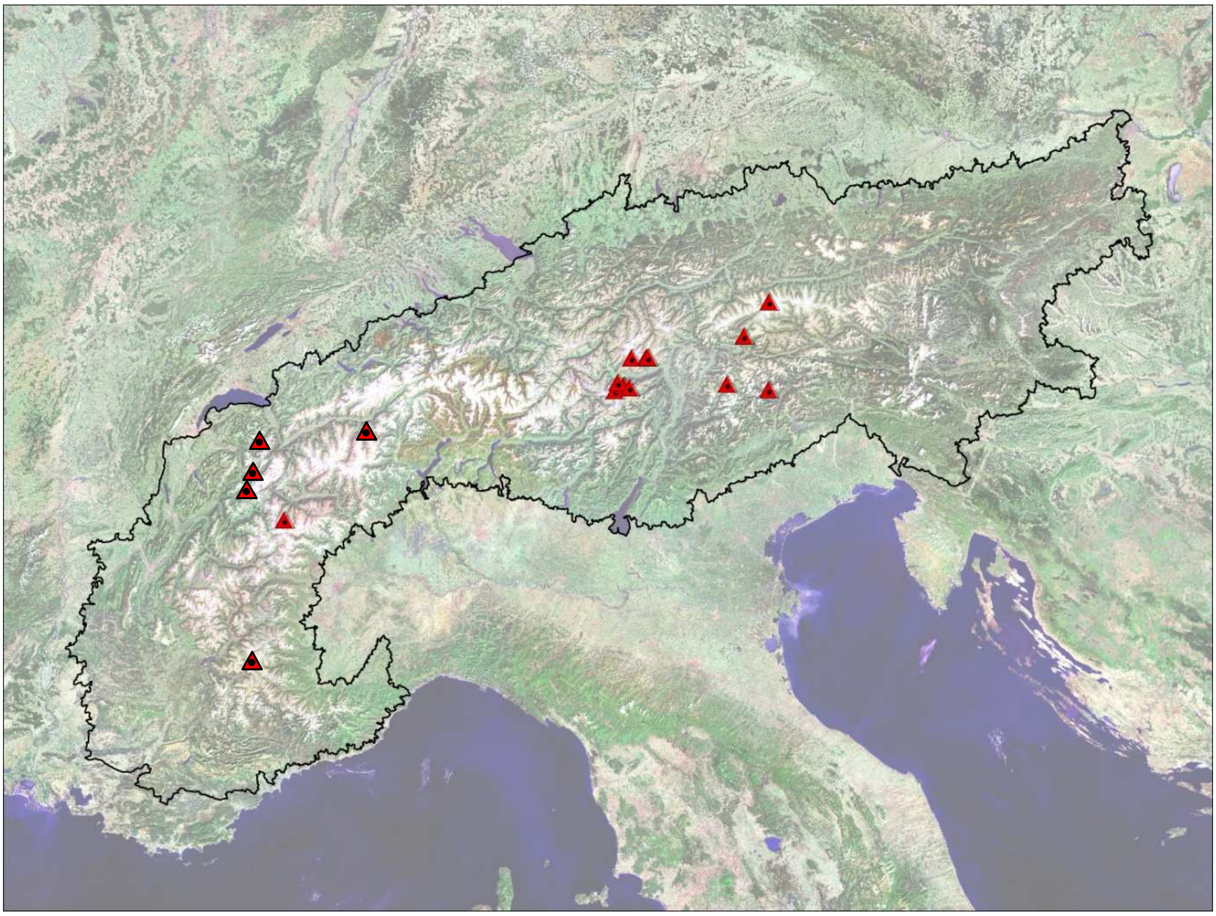

Fig. 2.33 – Localisation of the documented debris flow events.

The presented events show that debris flows with starting zones in permafrost areas are interesting only in special cases settlements and infrastructures in the Alpine valleys. Mostly, the affected damage potential is consisted of forestry roads, infrastructures of ski resorts or pass roads. An analysis of the permafrost distribution map and the hazard index maps of debris flow processes showed that:

- In ca. 20% of all torrent catchments with debris flow processes in South Tyrol the existence of permafrost is possible.
- ca. 1.4 % of the settlement areas in South Tyrol are affected by debris flow processes starting in permafrost areas, and 973 buildings and ca, 4000 inhabitants are potentially affected by these processes.

Therefore, the influence of permafrost to debris flow process is relevant only for a small part of the Alpine Space. Nevertheless, the safety of access roads and pass roads in high alpine areas is affected by these processes. The knowledge about the interrelation between permafrost and debris flow activity is poor in regards to the high relevance of roads in the Alpine Countries.

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