FROZEN GROUND. The News Bulletin of the International Permafrost Association.
Number 28, December 2004, pages 9-10.

Permafrost Hazards in Mountains

Andreas Kääb, University of Zurich, Zurich, Switzerland (kaeaeb@geo.unizh.ch)

Climate change has significant impact on ground temperatures in cold mountains. Questions arise if and to what extent these changes influence the intensity and probability of potentially hazardous processes in regions with mountain permafrost. Buildings and utilities may be damaged by permafrost-induced debris flows or rockfalls. Construction activities are affected by thaw or instability in frozen material. These human activities influence the ground thermal regime at their base by altering the heat fluxes. Problems related to permafrost have become a significant cost factor for the maintenance or construction of high-mountain infrastructure.

Increasing rockfall activity and a number of large rock avalanche disasters are examples of mountain hazards. In the case of the September 20, 2002, rock-ice avalanche at Kolka-Karmadon in the Russian Caucasus, a combined rock-ice avalanche of approximately 10 million m^3 triggered the disastrous shear-off of an entire glacier tongue. The resulting avalanche and mudflow killed more than 120 people. The 10–15 million m^3 rock avalanche of September 18, 2004, in the Italian Alps may have been related to permafrost conditions or their changes.

Frozen Debris

Rock glaciers and other forms of creeping mountain permafrost may be the source of a number of hazards. Rock glaciers represent an efficient long-term debris transport system. They are able to displace debris volumes in the order of 10^3 to 10^4 m^3 per millennium into steep flanks or channels, where they contribute materials to the formation of potential debris flows. The advance of rock glaciers leads to frequent rock falls along the steep front of the rock glacier. If rock glaciers become unstable, slides enhance the rock fall activity or debris flow formation.

Ground warming as recently observed, for instance in the European Alps, is able to increase potential hazards. Increasing creep rates are currently observed for a number of rock glaciers in the European Alps. Presumably this acceleration is due to the rise of ground temperatures and subsequent decrease in ground-ice viscosity.

Ice-rich permafrost influences the hydrology and the mechanics of debris slopes. Ground water concentration above the permafrost table is able to trigger active layer detachments or debris flows. Thawing permafrost in debris slopes might lead to complex hydrological interactions including water storage in unfrozen caverns, and enhanced melt water release. Ground ice cements debris slopes. In the case of thaw, slope stability is decreased. On the other hand, ice-cemented debris prevents retrogressive erosion caused by debris flows.

In cold mountainous regions, ground thermal conditions in moraines are often a crucial factor in the damming of moraine lakes. Permafrost or near-permafrost conditions support the long-term preservation of dead ice bodies, that upon melting leave underground cavities. In these cold mountain regions, glaciers and permafrost often coexist in close spatio-temporal proximity. For instance, permafrost may be able to penetrate into recently deglaciated glacier forefields, to alter the thermal, hydrological and dynamic conditions of thick glacial deposits, and thus to influence related hazards. Such effects are of increasing interest in the light of the current worldwide glacier retreat.

Frozen Rock Walls

A second class of permafrost hazards concerns frozen rock walls. Permafrost in rock faces leads to ice-filled discontinuities, and influences the rock hydrology and the hydrostatic pressure. Steep temperature gradients in the surface zones cause the transport and refreezing of free water and subsequent growth of ice lenses. The resulting increase in pressure is able to destabilize the rock locally.

With a rise in temperature, frozen rock joints reach minimal stability at temperatures between –1.5°C and 0°C, i.e. even before thaw. In parallel, the hydrostatic pressure within the rock wall might change. As a consequence, enhanced rockfall activity and rock avalanches are expected, in particular, within the lower boundary of permafrost distribution.

Complex thermo-mechanically conditions are found in partially glacierized, alpine rock faces. Through advection of temperate firn the base of steep glaciers might be temperate or comparably warm. At the same time, enhanced heat flux at the front of such glaciers leads to cold frontal sections stabilizing the glacier front. Though

Starting zone of the rock face of the devastating September 2002 ice-rock avalanche at Kolka-Karmadon, Caucasus. Photograph by I. Galushkin.

little is understood, it is clear that changes in the surface temperatures can cause highly complicated feedback mechanisms and chain reactions both for rock and glacier stability. In that context, the retreat of steep glaciers and the connected uncovering of rock might have even more drastic and rapid consequences than a rise in the mean annual surface temperature itself. Beside the thermally-governed impacts, retreat of steep glaciers leads to mechanical changes in the underlying and surrounding rock wall. Indeed, increasing rockfall activity and a number of large rock avalanche disasters might have been influenced by thermo-mechanical changes; e.g. the rock-ice avalanche at Kolka-Karmadon and the Italian Alps avalanche close to the Ortler Mountain. The latter avalanche started from a south-facing rock wall at an elevation of around 3500 m asl, i.e. the roughly estimated zone of warm permafrost in this region.

Challenges

Present atmospheric warming affects terrestrial systems particularly where ground or glacier ice is present. Changes in the equilibrium of glaciers and permafrost thermal regimes are shifting hazard zones beyond historical knowledge. The lower boundary of permafrost distribution in the Swiss Alps, for instance, is estimated to rise presently at a vertical rate of 1–2 m per year.

Estimates of hazard potential based on empirical data from the past will not be directly applicable under these new extreme conditions. Empirical knowledge has to be complimented by improved process understanding. The impacts of environmental change on hazard potentials need to be continually monitored. A rapid transfer of this information is critical for the successful mitigation of hazards in highly sensitive high-mountain environments. New techniques for hazard assessments based on remote sensing and numerical modelling have to be fully exploited, and knowledge has to be transferred to affected regions in the underdeveloped countries where hazard potential are present.

High-magnitude, low-frequency events and their relation to changes in permafrost conditions represent a special challenge in risk assessment. Scientific efforts are necessary for understanding the complex spatio-temporal, thermo-mechanical processes in glacierized and frozen alpine rock walls, and large debris bodies under permafrost conditions. These are among the challenges the new ICSI/IPA Working Group on Glacier and Permafrost Hazards in High Mountains are addressing (see GAPHAZ WG report).

The International Union of Geological Sciences has together with the UNESCO Earth Science Division and the joint UNESCO-IUGS International Geoscience Programme initiated the programme Planet Earth–Earth Sciences for Society (www.esgs.org), a component of the International Year of Planet Earth. One of the nine scientific elements of the initative is the theme “Geohazards.” GAPHAZ plans to establish collaboraton with the Planet Earth programme.