Permafrost-Related Mass Movements: Implications from a Rock Slide at the Kitzsteinhorn, Austria

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Abstract

Rock instability in high mountain areas poses an important risk for man and infrastructure. At 3 p.m. on 18 August 2012 a rock slide event was documented at the Kitzsteinhorn, Austria. The release zone was detected on a north-exposed rock face below the cable car summit station (3.029 m). Analysis of terrestrial laser scanning (TLS) data delivered an accurate identification of the release zone yielding a rock fall volume of approximately 500 m^3. Cubic Blocks with lengths of up to 4 m and block masses of up to 125 t were released during the event. The failure plane is located in a depth of approximately 3–4 m and runs parallel to the former rock surface (mean inclination 47°). Comparison with borehole data located less than 50 m from the release zone shows that failure plane depth is consistent with active layer depth. The event documentation is supplemented with observations of rock and air temperature, data on precipitation and snow depth, electrical resistivity tomography data, observed active layer depth and geological/geotechnical background data. The comprehensive ambient data suggests the influence of high temperatures and water availability for the triggering of the rock slide.

Keywords

Rock permafrost • Rock slide • Rock fall • Monitoring

48.1 Introduction

Numerous rock fall events in the European Alps suggest an increasing occurrence of mass movements due to rising temperatures. In recent years particularly during extensive hot periods large numbers of rock fall events have been reported (e.g., hot summers of 2003 and 2005). However, in most cases reconstruction of triggering mechanisms is problematic due to a lack of information at and before the event. Preparatory factors of subsurface (e.g., geological setting, permafrost conditions), surface (e.g., topography, snow cover) and atmospheric conditions (e.g., climatic and meteorological conditions) and their complex relationships must be taken into account.

The presented activities have been carried out within the research project MOREXPERT (‘Developing a Monitoring Expert System for Hazardous Rock Walls’) funded by Competence Centers for Excellent Technologies (COMET). MOREXPERT, which was started in September 2010, has

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initiated a new long-term monitoring site focusing on permafrost and rock fall interaction in steep bedrock in the Austrian Alps (Keuschnig et al. 2011; Hartmeyer et al. 2012).

48.2 Study Site

The study site is located at the Kitzsteinhorn (3.203 m, Hohe Tauern Range, Austria), a particularly interesting site for the investigation of glacier retreat and potential permafrost degradation and their respective consequences for the stability of alpine rock faces. The Kitzsteinhorn is constituted of rock of the Bündner schist formation and belongs to the Glockner Nappe, specifically the Glockner Facies, which consists of calcareous mica schist, prasinite, amphibolite, phyllite and serpentinite (Schober et al. 2012). The affected slope is a north-facing back wall of a glacial cirque with a mean inclination of 47°. It extends from the cable car summit station (3.029 m) down to the upper margin of the Schmiedingerkees glacier (2.950 m). The rock face is underlain by permafrost, over the last decades it has been affected by intense glacier retreat at the base and the complete loss of its ice cover.

48.3 Localization and Quantification of the Rock Slide Event

The blockslide occurred on 18 August 2012 at 3 p.m. Touristic visitors and employees, who were present at the cable car summit station at the time of the event, registered the blockslide acoustically and/or visually. Therefore, the exact time and location of the event is known.

The release zone is situated approximately 50 m below the summit station (3.029 m, see Fig. 48.1) at the base of the rock slope, directly above the glacier. At the failure plane ice was visible immediately after the event. The release zone and blockslide volume of 500 m^3 was quantified with TLS. Cubic blocks with lengths of up to 4 m and block volumes of up to 125 t were released during the event. The failure plane is located in a depth of approximately 3–4 m and runs parallel to the terrain surface. During the event several of these joint-bordered rock bodies were detached resulting in a blockslide. After detachment the blocks slid over the glacier surface for more than 200 m. The entire material was deposited on the glacier surface allowing easy identification of movement path and location of deposition.

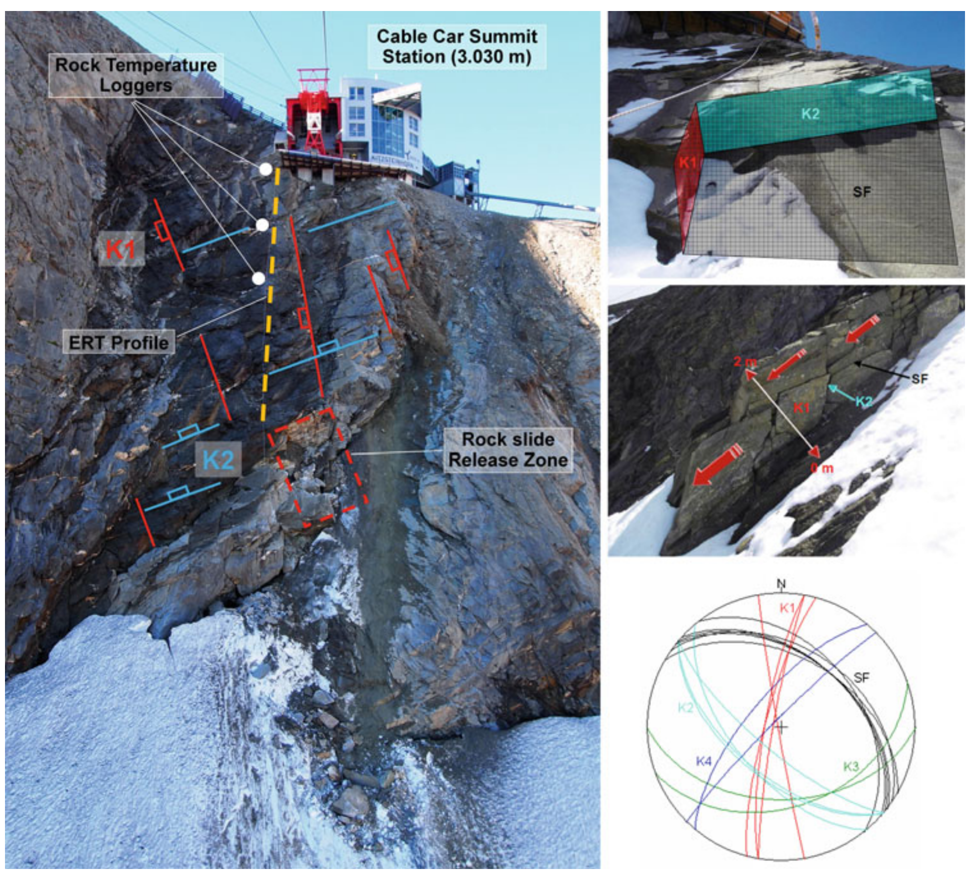

Fig. 48.1 On the *left* side: frontal view of the affected rock face with position of permanently installed monitoring instruments (ERT, rock temperature loggers). On the *left* and *right* side: geotechnical setting and orientation of discontinuities

48.4 Disposition and Type of Movement

The north face has an inclination of 23–67° and a mean value of 47°. The rock mass (calcareous mica schist) at the affected slope shows distinct schistosity (SF). The schistosity dips parallel to the slope, flat to medium steeply in direction NNE-NE and acts as an open interface structure. In addition to the schistosity, the joint sets K1 and K2 represent the main interface sets. K1 dips steeply to W and K2 dips medium-steeply to steeply to SW. The joint sets K3 and K4 are less frequent. The former dips medium-steeply to flat to S–SSE, the latter steeply to NW. K1 and K2 are oriented approximately orthogonal to the schistosity and constitute cubic to rhomboidal rock bodies (see Fig. 48.1). During the event several of these joint-bordered rock bodies were detached resulting in a blockslide.

48.5 Destabilizing Factors

48.5.1 Preparatory Factors

Rising temperatures have led to a substantial glacier retreat that has been particularly pronounced since the 1980s. Due to intense ablation the surface of the Schmiedingerkees glacier has been lowered by approximately 30 m over the last 40 years (see Fig. 48.2). Glacial debuttressing represents a major long-term destabilizing factor for the discussed rock face. In combination with the loss of the ice cover these processes have led to the exposure of oversteepened rock to atmospheric influences and intensified mechanical weathering. Geological discontinuities have become subject to a different thermal regime which includes the development of an active layer and convective heat transport in unfrozen clefts.

Despite the close proximity of the release zone to the upper glacier margin and the seasonal minimum of the snow height at the glacier at the time of the event, the triggering of the event cannot be explained by glacial debuttressing alone: The initial fracture seems to have occurred clearly above the current glacier surface (see Fig. 48.3).

48.5.2 Preparatory Factors

According to Krautblatter et al. (2013) the destabilization mechanism can be discussed using driving and resisting forces. Rock temperature (Davies et al. 2001) and the availability of water are important for slope stability in permafrost-affected rock. For example subsurface temperature variations affect ice pressures (driving force) and the strength of ice and rock (resisting force).

Meteorological data from a weather station (see) located less than 500 m from the release zone shows that air temperatures had not fallen below 0 °C for more than 2 weeks (1 August 2012–18 August 2012) prior to the event (mean 5.5 °C). Rock temperature measurements (sensor depth 0.8 m) which were performed less than 50 m from the release zone also delivered values well above 0 °C for the same time period (mean 4.5 °C, see Fig. 48.4).

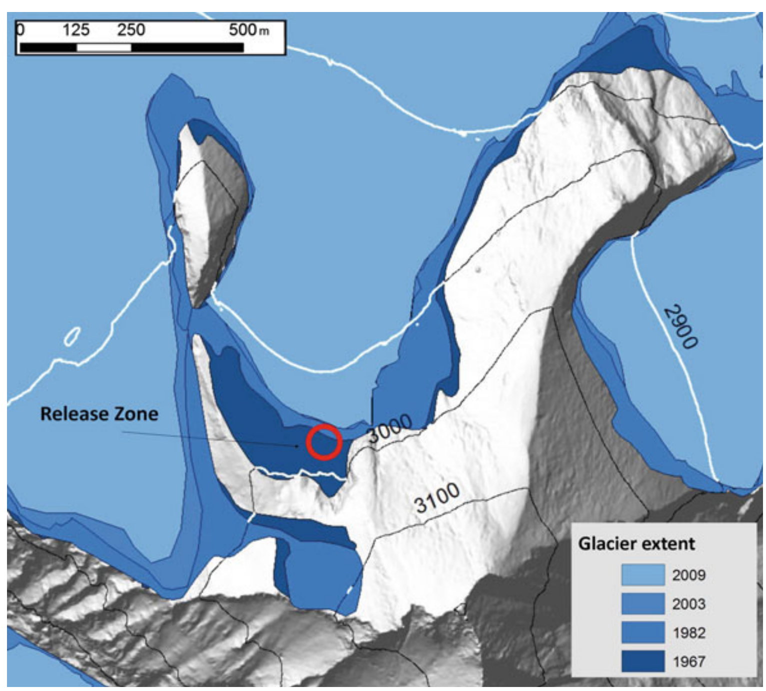

Fig. 48.2 Decreasing glacier extent and ice cover in the area of the release zone during the last decades

Fig. 48.3 Detachment of the blockslide: 18 August 2011 (*left*)—intact rock, 17 August 2012—crack visible in the tensile zone (*middle*), 19 August 2012—situation after the release (*right*)

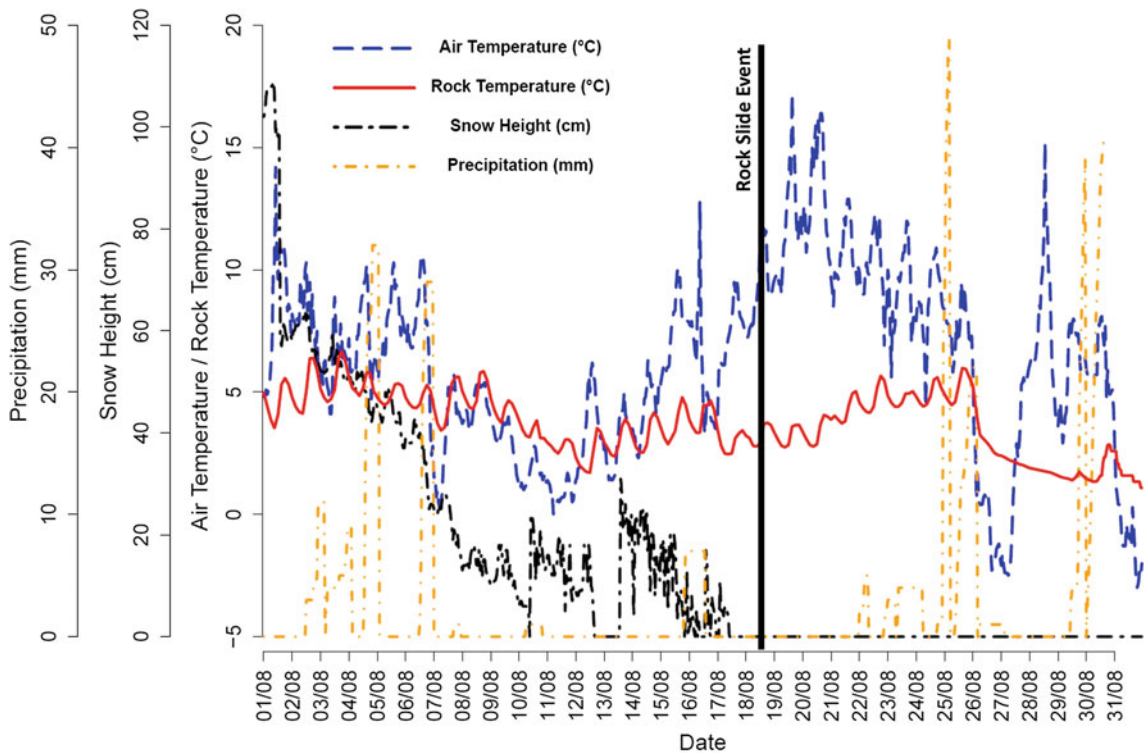

Fig. 48.4 Trends of air temperature, near-surface rock temperature, precipitation and snow height for August 2012. The rock slide event occurred on 18 August at 3 p.m

Comparison with visible ice in boreholes located less than 50 m from the release zone shows that failure plane depth is consistent with active layer depth (approx. 3 m).

Data from a permanently installed Electrical Resistivity Tomography (ERT) profile installed in close proximity to the release zone indicate an increase of electrical conductivity less than 30 m from the release zone (see). The increased conductivity could be the result of higher temperatures and/or increased availability of rain and melt water. Near surface rock temperatures show no

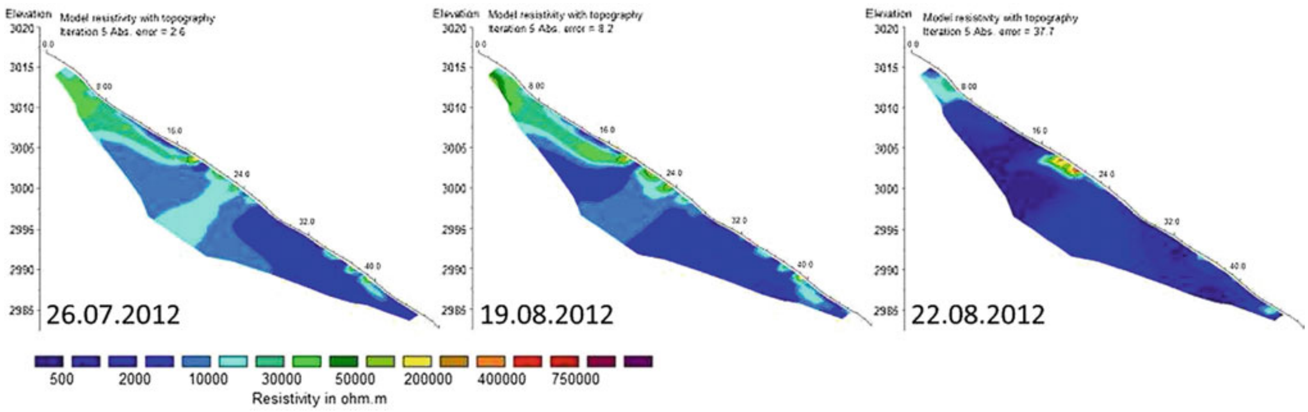

Fig. 48.5 ERT data; decreasing resistivity indicates higher temperatures and/or higher water content

positive or negative temperature trend prior to the event (see Fig. 48.4). Thus, decreasing resistivity has to correlate with an increased availability of (cleft) water (Fig. 48.5).

48.6 Conclusion

High air temperatures led to intensified snow and ice melt and to an increase of active layer thickness (see Fig. 48.4). After the event ice was visible in parts of the release zone. Combined analysis of rock temperature and ERT data is indicative of an increase of (cleft) water availability during the period leading up to the rock slide event. It can be concluded that increased water pressures in combination with decreased rock and ice strength caused by warming were the main trigger factors.

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References

Davies MCR, Hamza O, Harris C (2001) The Effect of rise in mean annual temperature on the stability of rock slopes containing ice-filled discontinuities. Permafrost Periglac Process 12:137–144

Hartmeyer I, Keuschnig M, Schrott L (2012) Long-term monitoring of permafrost-affected rock faces—a scale-oriented approach for the investigation of ground thermal conditions in alpine terrain, Kitzsteinhorn, Austria. Austrian J Earth Sci 105/2: 128–139

Keuschnig M, Hartmeyer I, Otto J-C, Schrott L (2011) A new permafrost and mass movement monitoring test site in the Eastern Alps—concept and first results of the MOREXPERT project. In: Borsdorf A, Stötter J, Veulliet E (eds) Managing Alpine future II—inspire and drive sustainable mountain regions. Proceedings of the Innsbruck Conference, 21–23 November 2011. (=IGF-Forschungsberichte 4). Verlag der Österreichischen Akademie der Wissenschaften: Wien

Krautblatter M, Funk D, Günzel FK (2013) Why permafrost rocks become unstable: a rock-ice-mechanical model in time and space. Earth Surf Proc Land 38:876–887. doi: 10.1002/esp.3374

Schober A, Bannwart C, Keuschnig M (2012) Rockfall modelling in high alpine terrain—validation and limitations. Geomech Tunn 5(4):368–378