Potential rock weathering by freeze-thaw processes in alpine cirques of Austria in 2006-2015 exemplified by the Hinteres Langtal Cirque, Austria

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Rock temperature data give a good indication of the effects of air temperature anomalies on ground thermal conditions particularly if a long-lasting seasonal snow covers is absent. Such rock temperature data are furthermore useful to quantify the intensity and potential of near-surface physical weathering in bedrock and hence of potential rock shattering. In this contribution we present selected results from an ongoing bedrock-temperature monitoring program which is accomplished at fives study areas – 3 × cirques with rock glaciers (DOV, HLC, REI), 1 × valley walls overlooking a glacier (PAG), and 1 × a mountain pass location (HEV) – in the Austrian Alps (Fig. 1a).

The bedrock-temperature monitoring program itself is part of a comprehensive ground temperature monitoring network in alpine Central Austria initiated in 2006 aiming to understand the effects of present climate conditions and variability on the ground thermal regime of mountain environments in Austria. Regarding the bedrock-temperature monitoring, nine surface boreholes in vertical and near-vertical rockwalls with different slope orientations and two additional boreholes at flat rock sites were drilled and instrumented in summer/early autumn 2006. The eleven rock temperature sites (RTS) are located between latitude 46°55'N to 47°22'N and longitude 12°44' to 14°41'E at five different study areas (Fig. 1a). The RTS have been all installed in metamorphic rock (6 x gneiss, 5 × mica schist) and in the elevation range 1960-2725 m asl (mean 2491 m asl).

Three temperature sensors have been inserted at each RTS at vertical depths of 3, 10 and 30–40 cm. The three sensors are connected at each site to a 3-channel miniature temperature datalogger manufactured by GeoPrecision, Germany (accuracy of ±0.05 °C). Several temperature-derived parameters are calculated from the temperature data. These parameters form the basis of the assessment of the potential bedrock weathering and consist of: (a) the mean annual rock temperature at the rock surface and at different depths, (b) the number of freeze-thaw-cycles (FTC) and (c) effective freeze-thaw cycles for frost shattering (eFTC; Matsuoka [1990]), (d) the duration and intensity of freeze-thaw-cycles, and the number of days (e) and hours (f) within the so-called "frost-cracking-window" (hFCW; dFCW) using the two different temperature "windows"-3 °C to -6 °C and, respectively, 3 °C to -8 °C (cf. Fig. 5 in Hallet et al. [1991]). Therefore, both the volumetric-expansion model and the segregation-ice model for frost weathering were considered [Hallet et al., 1991, Matsuoka, 2008]. The effects of (g) aspect and (h) snow cover on the thermal regimes at the monitoring sites are additionally addressed. The temporal time frame was one hydrological year (HY 01.10.-30.09).

Results from all RTS sites show that the number of diurnal FTC and eFTC varied substantially during the observation period at all sensor depths. However, this variation differs from site to site related to snow cover condition, elevation and aspect. For instance, at one lower-elevated (2255 m asl) north-exposed RTS site (PAG-B) the number of FTC and eFTC was lowest during the hydrological year 06/07 (snow poor and warm winter) whereas highest in 11/12 (snow poor but rather cool winter). In contrast, results are completely different at two substantially higher-elevated but also north-exposed RTS (DOV-B; 2638 m; HLC-B; 2693 m asl) with highest FTC values in 06/07 and lowest in 11/12. Furthermore, at one flat bedrock site (HLC-C at 2650 m asl) the number of FTC and eFTC was highest in 06/07 related to the thin and short winter snow cover.

Exemplarily results regarding the duration of the frost cracking window in hourly resolution (hFCW) at the three different sites in the Hinteres Langtal Cirque (HLC) are depicted in Figure 1c-d. The cirque floor is almost completely covered by a highly-active rock glacier (Fig. 1b). The three RTS are located at different aspects (SW-, NE-, and W-facing slopes) and at different topographic positions (2 × near vertical rock face, 1 × flat surface of a boulder; Fig. 1b). All three sites are covered by seasonal snow for about half a year (estimated based on the temperature data).

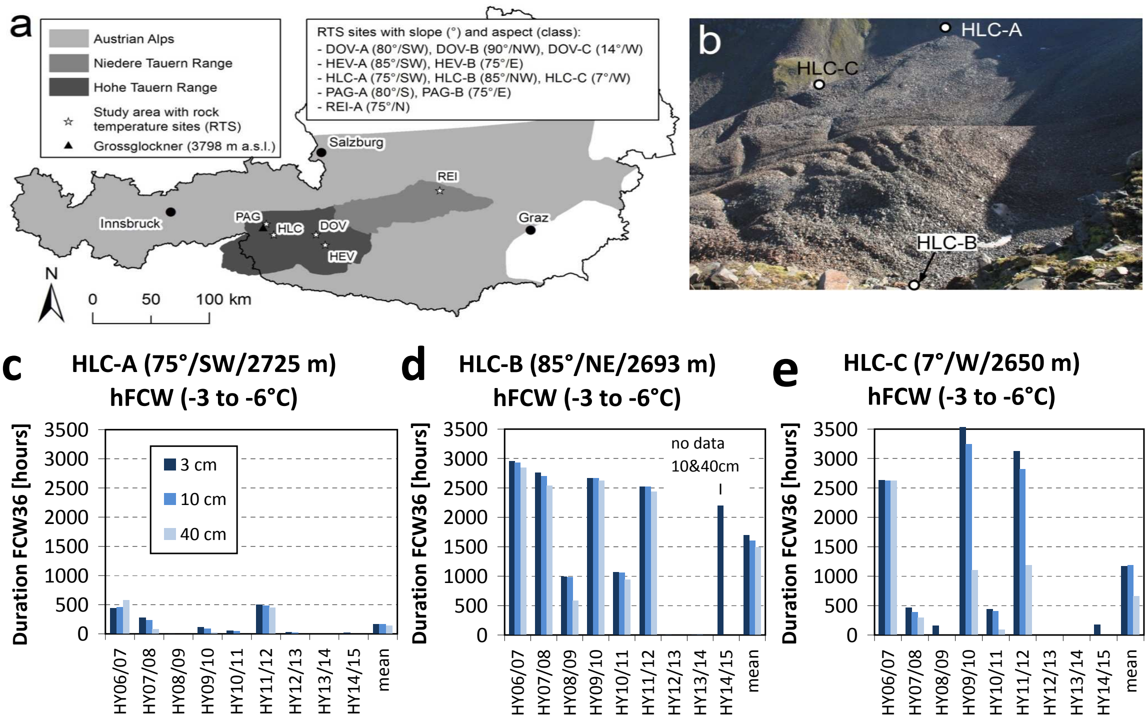

Figure 1: The five study areas with the eleven rock temperature sites (RTS) in Austria; (a) overview map; (b) field situation at the study area HLC with 3 RTS sites near a rock glacier;(c)-(d) duration of the frost cracking window (hours) at the HLC-sites.

The mean annual rock temperature of the sensor closest to the surface (3 cm) during the monitoring period was 2.8 °C at site HLC-A, 0.3 °C at site HLC-B, and 0.0 °C at site HLC-C. Results of hFCW indicate that aspect has a substantial effect. The duration of the FCW is 6 to 10 times longer (depending on sensor and year) at the north-exposed RTS compared to the south-exposed one. In some years the south-exposed RTS is not within the FCW at all. Furthermore, mild winter and/or snow-rich winter might cause almost a complete absence of hours within the frost-cracking window even at site HLC-B. The interannual change in this parameter-value varies substantially from year to year at all three sites. Particularly the boulder-rock site HLC-C has extreme variations from about 0 to >3500 hours/year.

Our observation suggests that predicted warmer and snow-poor winters in European Alps will enhance diurnal FTC and the intensity of near-surface physical weathering in the bedrock of the Austrian Alps. This seems to be feasible at least for north-facing slopes at elevations above c. 2600 m asl. The opposite is true for north-exposed slopes at elevations below 2200 m asl where the number of diurnal FTC might decrease. The duration of the FCW (in hours or days) is substantially longer at north-facing rockwalls compared to south-facing ones. However, plays a major role in the thermal regime of rockwalls even at near-vertical rock faces. Summarizing, our observations suggest that segregation ice formation is particularly important for rock weathering at north-facing rockwalls. In contrast, volumetric expansion during freezing might be the major control for rock weathering at the monitored south-facing rockwalls.

References

Hallet, B.; Walder, J. and Stubbs, C.W. [1991]: Weathering by segregation ice growth in micro-cracks at sustained sub-zero temperatures: Verification from an experimental study using acoustic emissions. *Permafrost and Periglacial Processes*, 2: 283–300.

Matsuoka, N. [1990]: The rate of bedrock weathering by frost action: Field measurements and a predictive model. *Earth Surface Processes and Landforms*, 15:73–90.

Matsuoka, N. [2008]: Frost weathering and rockwall erosion in the southeastern Swiss Alps: Long-term (1994–2006) observations. *Geomorphology*, 99:353–368.