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Relict rock glaciers as important aquifers in sensitive ecosystems: The example of the Natura 2000 protection area Niedere Tauern Range, Styria

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Abstract

The hydrological significance of active rock glaciers for water storage is studied since the mid 1970ies. In contrast, the hydrology of relict rock glaciers lacking permafrost today is still poorly understood. Despite this shortage of knowledge, relict rock glaciers and their hydrogeology are important in the alpine landscape of Austria. In this study we focussed on the European protection area (Natura 2000) Niedere Tauern (surface area 1261 km²) located in Styria, Austria. At the regional scale the spatial distribution of relict rock glaciers and their catchment areas were investigated. Results show that the drainage of approximately 9% of the area above 1500 m a.s.l. and 23 % above 2000 m a.sl. are influenced by relict rock glaciers as aquifers. Results of the subunit Seckauer Tauern Range even show 16% above 1500 m a.s.l. and 42% above 2000 m a.s.l. At a local scale the hydraulic properties of a relict rock glacier are investigated at the Schöneben Rock Glacier with a distinct spring at the front. Hydrograph analyses indicate for instance both a fast component on groundwater recharge events with a low storage capacity and a base flow component with a high storage capacity. The spring hydrograph can be decomposed in three exponential recession functions with different recession coefficients depending on the range of discharge. This indicates a multi-storage system. Our results clearly indicate that on a regional scale relict rock glaciers are highly relevant for the drainage system and ecology in the studied alpine region. On a local scale it is shown that rock glaciers are not only essential water buffers in alpine catchments relevant for ecosystems (continuous water supply during dry periods) but also natural hazards (flood-risk reduction after storm events) and are essential groundwater resources.

Keywords

rock glacier catchment, relict rock glacier, alpine water cycle, Natura 2000 protection area, Niedere Tauern Range, Styria

Introduction

Since the mid 1970ies various authors have been working on the hydrological significance of active rock glaciers for water storage (e.g. CORTE 1976, GARDNER & BAJEWSKY 1987, SCHROTT 1998, GIARDINO et al. 1992, BRENNING 2005, AZÓCAR & BRENNING 2010). Research on the hydrology of active rock glaciers in the Austrian Alps was initiated in the late 1990s (e.g. KRAINER & MOSTLER 2002, KRAINER et al. 2007). In contrast, the hydrology of relict rock glaciers received far less scientific attention compared to active ones. Relict rock glaciers contain no permafrost today but indicate past permafrost conditions during cooler periods as for instance the Lateglacial period. Pioneering research work on the discharge behaviour of relict rock glaciers in the Niedere Tauern Range (Austrian Alps) was carried out in the 1990s by GÖDEL (1993), UNTERSWEG & SCHWENDT (1996) and UNTERSWEG & PROSKE (1996) and re-initiated very recently by WINKLER et al. (2010, 2012).

The drainage dynamics and the storage capacity of these large sediment bodies are still poorly understood. LIEB et al. (2010) and KELLERER-PIRKLBAUER et al. (2012) presented data on 1300 "relict rock glacier units" covering 98 km² in the Austrian Federal Provinces of Styria (406), Carinthia (357), Salzburg (237), Upper Austria (1) and the county of Eastern Tyrol (299). These authors used the term "rock glacier unit" in order to describe obviously different rock glacier generations or units composing one rock glacier. For instance a rock glacier might consist of two different units: a younger active rock glacier unit might overrun an older relict rock glacier unit. Therefore, the number of rock glacier units in their inventory (1647) is more than the number of rock glaciers itself (1528). A similar inventory study by KRAINER & RIBIS (2012) revealed 1342 relict rock glaciers for Northern Tyrol alone with a total surface area of 61 km². Therefore, some 2600 relict rock glaciers were mapped in the Austrian Alps so far covering an area of at least 150 km².

Large areas of the Austrian Alps are predominately built up by crystalline rocks as for instance the Niedere Tauern Range. Alpine catchments in crystalline rocks are often characterised by a high number of springs having typically yearly mean discharge rates below one litre per second. However, water economic studies in the 1990ies (UNTERSWEG & SCHWENDT 1996) in the Niederen Tauern Range in Styria showed that springs with higher discharge rates (up to tens of litres) are related to relict rock glaciers. WINKLER et al. (2012) provide preliminary results with regard to the storage capacity and drainage dynamics of relict rock glacier aquifers. The storage capacity has for instance positive implications for flood-risk reduction and the riparian ecology below rock glacier springs. The aquifer base flow provides steadily water during dry periods. The predicted increase of extreme weather conditions such as an increasing number of hot days and heavy precipitation events in Central Europe (e.g. BENISTON et al. 2007) suggest a rising importance of these aquifers with regard to the sensitive ecosystem in alpine catchments. Therefore, increasing the knowledge about these alpine aquifers is important for man and nature due to various reasons.

In this study we focus at a regional scale on the hydrological role of predominantly relict rock glaciers in the European protection area (Natura 2000) Niedere Tauern Range located in Styria, Austria. At a local scale we present hydrogeological data and interpretations of the Schöneben Rock Glacier located in the east of the study area. Preliminary results are presented. With this study we contribute to the understanding of the impact of relict rock glaciers on the hydrology of alpine catchments and therefore the relevance for man and particularly nature.

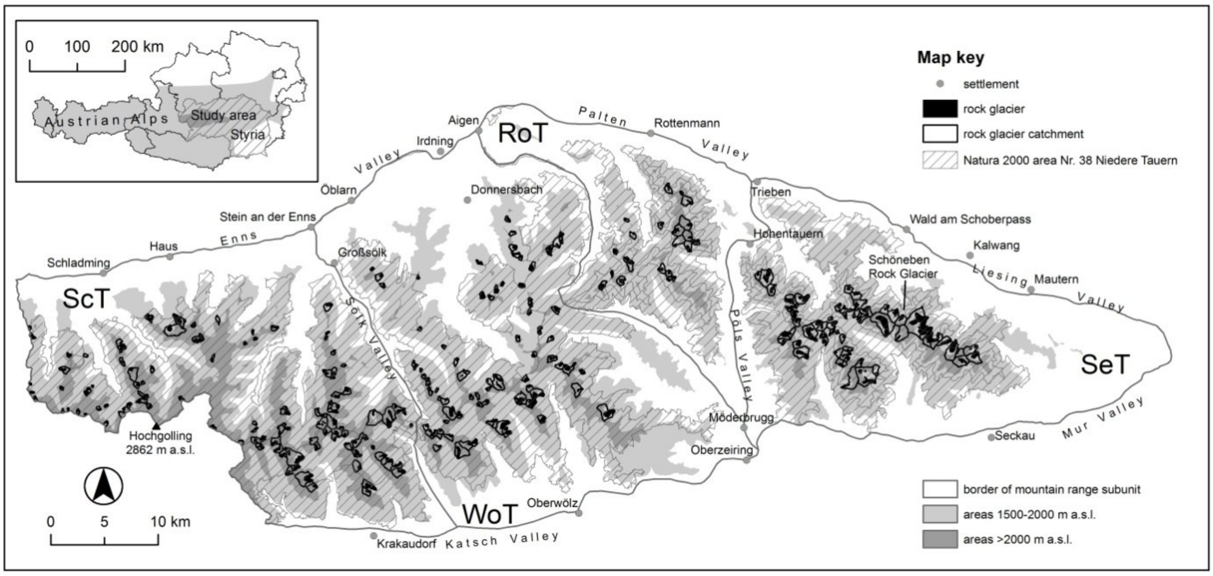

Figure 1: Spatial distribution of rock glaciers (according to Lieb et al. 2010) and their catchments in the Natura 2000 area Nr. 38 Niedere Tauern. Areas above 1500 and 2000 m a.s.l and the delineation of the four different subunits of the Niedere Tauern Range in Styria (ScT-Schladminger Tauern Range, WoT-Wölzer Tauern Range, RoT-Rottenmanner Tauern Range, SeT-Seckauer Tauern Range) are indicated. Furthermore, the locations of the Schöneben Rock Glacier and the highest summit in the entire study area are shown.

Study area

Regional scale: Niedere Tauern Range, Styria

The study area comprises the Styrian part of the Niedere Tauern Range in Austria between 47°11'-47°33'N and 13°35'-15°00'E (Fig. 1). The study area covers an area of 2440 km². Distinct mountain passes along the primarily east-west trending main divide separate the mountain range into four major subunits named from west to east Schladminger, Wölzer, Rottenmanner, and Seckauer Tauern Range hereafter abbreviated as ScT, WoT, RoT and, respectively, SeT. The highest summit is Hochgolling reaching 2862 m located in ScT. About 50% of the total area is located above 1500 m a.s.l. and some 10% exceed an elevation of 2000 a.s.l. Geologically, the study area is built up by two crystalline basement units of the Upper Austroalpine (Silvretta-Seckau nappe system and the Koralp-Wölz nappe system) consisting predominately of different types of gneisses and mica schists (GASSER et al. 2009).

Most of the subalpine and alpine zone of our study area is protect as the "Natura 2000 area Nr. 38 Niedere Tauern". This protection area covers 1260.9 km² and is the largest of all Natura 2000 areas in Styria (Fig. 1) As the Natura 2000 is an important initiative of the European Commission to conserve Europe`s rich natural heritage with its threatened habitats and species, knowledge about groundwater availability at present but also in the future considering the climate change scenarios indicated above is of crucial importance.

Local Scale: Schöneben Rock Glacier

The Schöneben Rock Glacier (hereafter abbreviated as SRG) is located in the eastern most subunit SeT at E14°40'26" and N47°22'31" (Figs. 1, 2). The SRG with a length of about 750 m and a width up to 200 m covers an area of about 0.11km². The SRG ranges 1905 m a.s.l. at the rooting zone of the rock glacier to 1715 m a.s.l. at the front where a distinct spring is located (Fig. 2). The rock glacier is orientated towards NE and consists predominantly of coarse-grained to blocky gneissic sediments at the surface. However, at several locations particularly near the talus slopes finer-grained debris-flow sediments occur. The SRG exhibits a rugged microtopography with bended transverse ridges and furrows several meter deep at its lower part and longitudinal ridges and furrows at its central and upper part. The SRG can be regarded as a relict rock glacier indicated by regional permafrost modelling results (KELLERER-PIRKLBAUER 2005). However, patches of permafrost in the upper part of the rock glacier are feasible considering research results from a neighbouring cirque (KELLERER-PIRKLBAUER 2011).

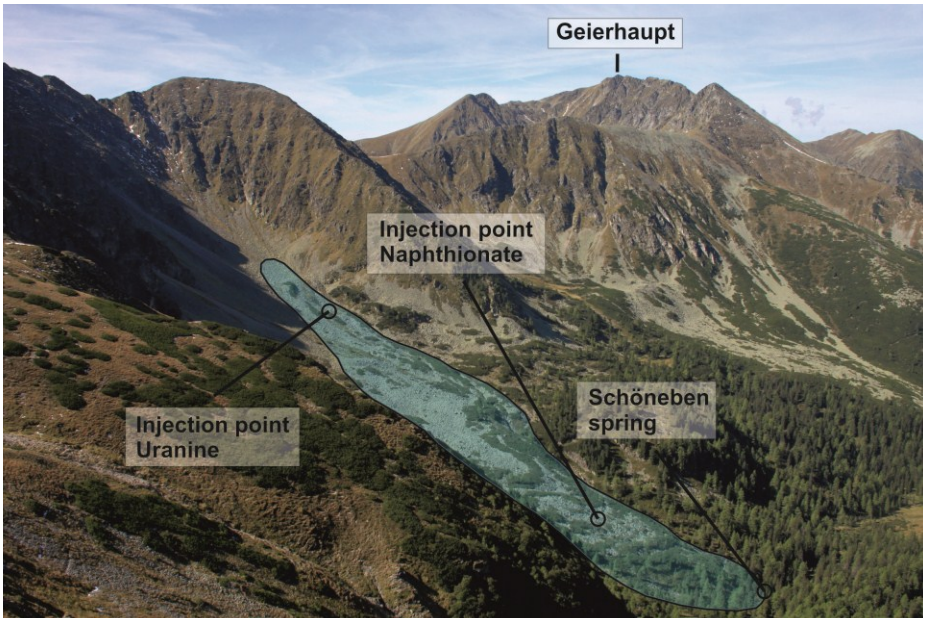

Figure 2: Schöneben Rock Glacier (SRG) is located in the subunit Seckauer Tauern Range (SeT). The rock glacier faces towards NE. View direction of photograph towards W to Mt. Geierhaupt (2417 m a.s.l.), the highest mountain of the entire SeT. The rock glacier spring is located at 1715 m a.s.l. (Photograph by A. Kellerer-Pirklbauer).

Material and Methods

At the regional scale the spatial distribution of relict rock glaciers and their catchment areas were investigated. Based on the polygon-based rock glacier inventory of Central and Eastern Austria (Lieb et al., 2010, Kellerer-Pirklbauer et al., 2012) the catchment area of each rock glacier was delineated manually in ArcGIS10. Frequently, more than one rock glacier is located in one rock glacier catchment (i.e. older rock glacier further below; younger rock glacier at higher elevation). In such instances only the larger, higher-ranked hydrological catchment was delineated. Consequently two or more rock glaciers were attributed to one rock glacier catchment. In a second step an attribute table was generated for each delineated catchment. Various parameters (mainly related to topography) were recorded and listed. In this paper we focus particularly on the hydrological catchment area of the rock glacier and their areal proportion to the rock glaciers in these catchments. A comprehensive rock glacier catchment analysis including climatic and hydrological considerations at a regional scale will be presented elsewhere.

At the local scale the storage capacity and the drainage dynamics of the SRG were investigated. The existing data base comprises the SRG spring discharge continuously monitored since 2002 and, water temperature and electric conductivity continuously measured since 2008. In addition meteorological data – precipitation and air temperature – were provided for the nearby automatic weather station "Hochreichhart" (HZB-number 123274). This station is operated by the Hydrographic Service of Styria and located at 1500 m a.s.l. in the neighbouring valley 2.5km to the east of the rock glacier.

Based on indications that relict rock glacier springs show a similar discharge behaviour as Karst springs (Gödel 1993, Untersweg & Schwendt 1996) hydrograph analyses and natural and artificial tracer tests were performed to investigate the rock glacier aquifer properties. Recession curves of the spring hydrographs are analysed for periods of no or negligible recharge in order to identify the base flow component applying e.g. the analytic solution of Maillet (1905). The time series of the electrical conductivity and water temperature were used as natural tracers to differentiate the two discharge components recently recharged water (event water) and the base flow. Furthermore an artificial tracer test with two injection points at the rock glacier surface using fluorescent dyes (Naphthionate and Uranine; see Fig. 2 for locations) was conducted to characterize the storage capacity of the rock glacier.

Table 1: Summary statistics for the rock glacier catchment inventory according to number, area and percentage of areas above 1500 m a.s.l. and, respectively, 2000 m a.s.l.

Mountain range subunit	Rock glacier catchments [n]	Area median [m²]	Area mean [m²]	Area total [km²]	Percentage of areas >1500 m a.s.l. [%]	Percentage of areas >2000 m a.s.l. [%]
ScT	119	170,693	290,756	34.6	8.1	18.1
WoT	86	171,241	279,070	24.0	5.7	20.4
RoT	22	319,483	390,909	8.6	6.3	27.3
SeT	68	382,606	600,000	40.8	15.6	42.0
Total	*295*	*239,078*	*366,102*	*108.0*	*8.6*	*22.7*

Results and Discussion

Results from the regional study revealed that 295 rock glacier catchments with 376 rock glacier units are located in the study area (Table 1, Fig. 1). Almost all of these rock glacier catchments are also located in the Natura 2000 area Niedere Tauern. Most of these catchments are located in the westernmost subunit ScT. However, the generally largest rock glacier catchments are in the easternmost subunit SeT (Fig. 3a). The rock glacier catchments in the subunit RoT are of similar size to the ones in the SeT. In contrast, the rock glacier catchments in the two subunits to the west (WoT and ScT) are substantially smaller with median and mean values for rock glacier catchments of, respectively, about 0.17 km² and 0.28-0.29 km². Therefore, the pattern with small rock glacier catchments in the west and the increasing size of these catchments towards the east is similar to the pattern for rock glaciers. 108 km² or 4.4% of the Styrian part of the Niedere Tauern Range belong to rock glacier catchments. Considering only areas above 1500 m a.s.l. and 2000 m a.s.l., the percentage values increase to 8.6% and 23% respectively. Results of the subunit SeT even allocate 16% of the total area above 1500 m a.s.l. and 42% above 2000 m a.s.l. to rock glacier catchments. The largest rock glacier catchment is also found in the subunit SeT with an area of about 3.5 km² (Fig. 3a). The high values in subunit SeT can be explained by the existence of very large rock glaciers (also on global scale) which started to form already early in the Lateglacial period and continued to grow for thousands of years until the early Holocene where they turned to relict rock glaciers.

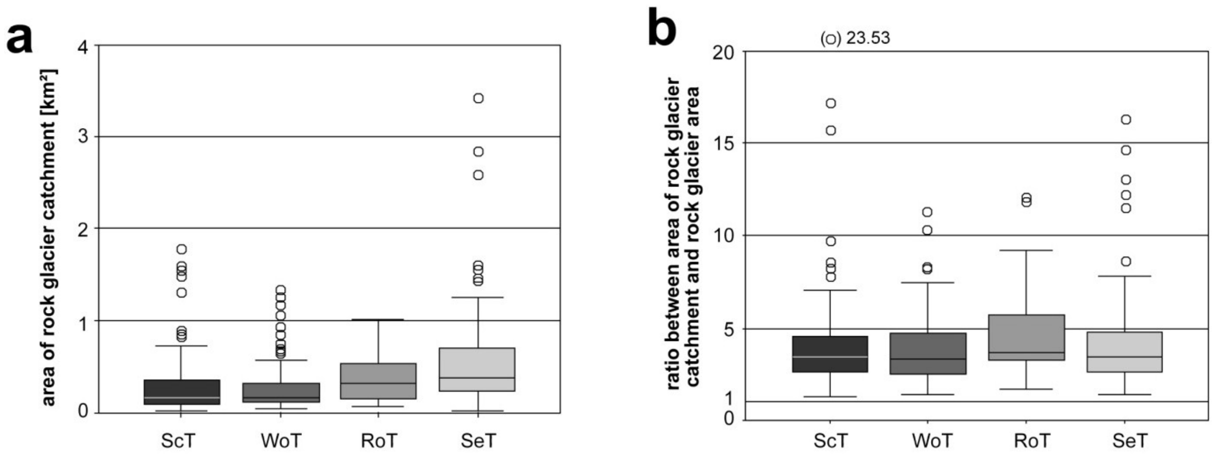

Figure 3: Box plot diagrams of (a) the surface area of rock glacier catchments and (b) the ratio between the surface area of the rock glacier catchment and the surface area of one to more rock glaciers within this catchment differentiated for the four different subunits of the study area; o=outliers. One outlier outside scaling range is indicated with the value.

Results regarding the ratio between the surface area of the rock glacier catchment and the surface area of rock glaciers within the catchment are depicted in Fig. 3b. Generally, the median of the ratio value is very similar in each of the four ranging from 3.3 (in WoT) to 3.7 (in RoT). This indicates that rock glacier catchments are generally about 3.5 times larger compared to the surface area covered by rock glaciers alone. However, the boxplot diagram in Fig. 3b also clearly depicts the large scatter in the data for all four subunits. This is in contrast to the debris-supply area of rock glaciers which are (according to inventory data from other mountain regions; e.g. WAHRHAFTIG & COX 1959, JANKE & FRAUENFELDER 2007) only some 1.4 to 2.0 times larger compared to the rock glacier below the rock faces.

Because of the lack of comparable studies on rock glacier catchments in other regions in Europe and elsewhere it is difficult to bring our results in a broader context. One approach to overcome this lack of similar studies is to compare "our" rock glaciers with rock glacier sizes from other regions. The largest rock glaciers in our study area are located in the subunit SeT with an average value of 84,000 m². This value is similar compared to rock glaciers in the Front Range of Colorado, USA, with 83,000 m² (JANKE & FRAUENFELDER 2007), but more compared to talus-derived (57,000 m²) or glacier-derived rock glaciers (79,000 m²) in the Eastern Swiss Alps (Frauenfelder et al. 2003). Furthermore, this value is also substantially more than for rock glaciers in the Sierra Nevada, USA with 20,000 m² on average (MILLAR & WESTFALL 2008). These comparative figures illustrate that our study region is an area with large rock glaciers even on a global scale and – based on the strong correlation between rock glacier area and rock glacier catchment area (KELLERER-PIRKLBAUER et al. unpublished) – with some of the largest rock glacier catchments worldwide.

The hydrograph analyses of the Schoeneben rock glacier spring indicate both a very fast discharge component after precipitation events and a slow base flow component (WINKLER et al. 2012). The spring hydrograph can be decomposed in three exponential recession functions with different recession coefficients (Fig. 4). This drainage dynamics are comparable to complex heterogeneous aquifer-types such as Karst aquifers indicating two or more aquifer components with diverging storage capacities.

The water temperature and the electric conductivity of the rock glacier spring show seasonal variations between 1.7 and 2.36°C and 35 µS/cm and 61 µS/cm, respectively. Both parameters respond almost simultaneously after a time lag of about three hours on recharge events with decreasing values representing the fast discharge component with a very low storage capactity.

Tracer experiments with the fluorescent dyes support the results especially the recession coefficients of the base flow (α ranges of 0.003 to 0.006 [d^{-1}]) with an averaged retention time of 79 to 108 days after the tracer injection.

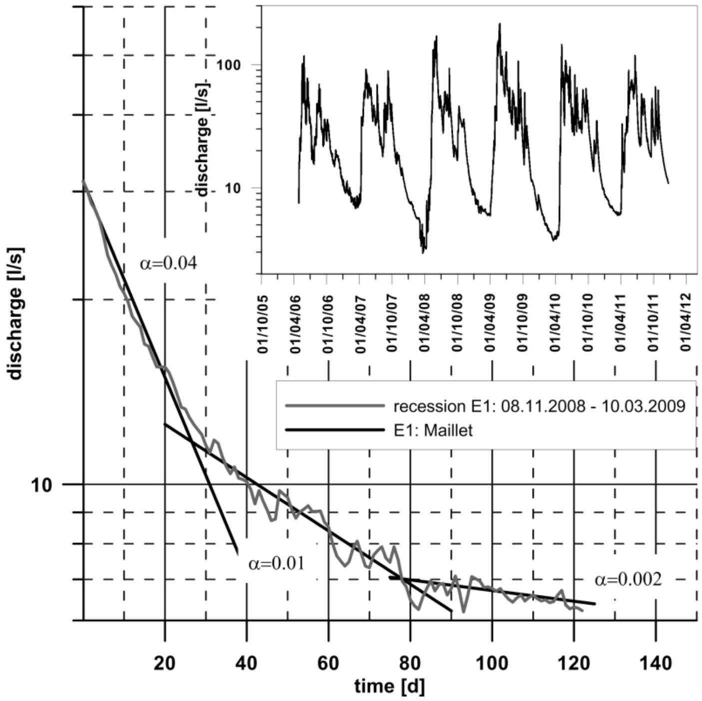

Figure 4: Selected long time recession over the winter period with the fitted recession coefficients based on the exponential model (Maillet 1905) in black including the recession coefficients for the three differentiable recession parts.

Conclusions

Most of the 295 identified rock glacier catchments in the Styrian part of the Niedere Tauern Range are located in the Natura 2000 area.

Some 8.6% of the entire area above 1500 m a.s.l. in the Styrian part of the Niedere Tauern Range is drained through rock glaciers. This values increases to 42 % if we focus on the areas above 2000 m a.s.l. in the eastern-most subunit SeT.

Rock glacier catchments are on average about 3.5 times larger than the respective areas covered by rock glacier sediments in the catchment. However, in extreme cases the catchment is 11.3 and 23.5 times larger than the rock glacier hence very large catchments drain over relatively small rock glaciers. This emphasises the importance of these sediment accumulations and there hydrogeological properties.

On the one hand the storage capacity of these aquifers enhances a buffering of the water amount coming from heavy precipitation events thereby reducing the intensity of natural hazards as flood events. On the other hand the aquifers represent an essential groundwater resource especially during dry periods to provide the existence of the sensitive ecosystems in alpine catchments.

Thus we conclude that relict rock glaciers are highly relevant for the drainage system and in further consequence for the water ecology in the Natura 2000 area Niedere Tauern.

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