Geomorphology 273 (2016) 178–188

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Rock glacier development in the Northern Calcareous Alps at the Pleistocene-Holocene boundary

Andrew P. Moran [a,*], Susan Ivy Ochs [b], Christof Vockenhuber [b], Hanns Kerschner [a]

[a] Institute of Geography, University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria
[b] Laboratory of Ion Beam Physics, ETH Zurich, Otto-Stern-Weg 5, 8093 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 2 May 2016
Received in revised form 18 July 2016
Accepted 9 August 2016
Available online 10 August 2016

Keywords:
Rock glaciers
Palaeoclimate
^{36}Cl
Alps

ABSTRACT

Relict rock glaciers provide information on past discontinuous permafrost and former mean annual air temperatures. A lack of records showing former permafrost distribution along the northern Alpine fringe prompted the investigation and numerical dating of a belt of relict rock glaciers in the Karwendel Mountains of the Northern Calcareous Austrian Alps. In two neighbouring cirques that were still glaciated during the early Younger Dryas, eleven ^{36}Cl exposure ages from boulder surfaces were obtained. The ages imply the onset of rock glacier activity around ~12.3 ka with subsequent stabilization and permafrost melt out no later than ~10.1 ka. Hence, rock glacier formation coincided with glacier retreat in the cirques around the mid-Younger Dryas and continued into the early Holocene. As permafrost induced features, the rock glacier termini indicate the local past lower limit of discontinuous permafrost in open cirque floors at ~2000 m asl, which is around 400 m lower than during the mid-twentieth century at comparable locations in the Karwendel Mountains. Thus, a mean annual air temperature reduction of ~−2.6 to −3.8 °C relative to the mid-twentieth century is inferred. Based on a minimum glacier equilibrium line altitude in the cirques, a summer temperature reduction of less than −2.6 to −1.8 °C is shown, suggesting an increased seasonality at the time of rock glacier activity.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In high mountain environments, cryogenic processes account for the development of a variety of geomorphological landforms. Among those features, rock glaciers, as defined by Wahrhaftig and Cox (1959); Haeberli (1985), and Barsch (1996), constitute one of the most obvious and widespread indicators of periglacial activity in the Alps (Haeberli, 2000). Rock glaciers usually exhibit a tongue or lobe-shaped geometry with surfaces marked by transverse and longitudinal ridges, furrows, and undulations and consist of clasts, unconsolidated regolith, and ice of varying contents and multiple origins (Haeberli, 1996). Their development is dependent on a sufficient provision of debris (Barsch, 1988), often provided by talus at the foot of steep rock faces (Humlum, 1988), moraines (Haeberli, 1979), and protalus lobes (Johnson et al., 2007), combined with the occurrence of discontinuous permafrost conditions (Haeberli, 1985). Rock glaciers have been mapped by many authors throughout the Alpine region (e.g., Lieb, 1991, 1998; Schoeneich, 1992; Baroni et al., 2004; Kellerer-Pirklbauer, 2005, Kellerer-Pirklbauer et al., 2012; Krainer and Ribis, 2012; Scotti et al., 2013) and have been monitored over continuous periods of time at several locations worldwide (e.g., Hoelzle et al., 1998; Ikeda and Matsuoka, 2003; Roer et al., 2005, 2008; Hausmann et al., 2007; Bodin et al., 2009; PERMOS, 2013).

Rock glaciers, as permafrost-induced geomorphic features, are climate indicators because the occurrence of permafrost is a function of climatic parameters. On a large scale their occurrence depends in particular on mean annual air temperature (MAAT; Kerschner, 1985; Humlum, 1988; Haeberli et al., 1993; Steig et al., 1998; Haeberli, 2000; Refsnider and Brugger, 2007), while on a more local scale short-wave radiation is of importance. The latter can be parameterized by aspect and topographic shielding (Geiger, 2013). The rock glaciers occur primarily in dry mountain regions where the equilibrium line altitude of glaciers (ELA) is at high elevations relative to the lower limit of permafrost (Haeberli, 1985). Consequently, a shift in climate toward warmer conditions can induce the depletion of permafrost leading progressively to the melt out of ice and a ceasing of rock glacier motion. According to Haeberli (1985) and Barsch (1996), warming brings about a transition from an active rock glacier (occurrence of permafrost with movement), via an inactive state (some permafrost, no movement), to a relict rock glacier (neither permafrost, nor movement). Therefore the investigation of relict rock glaciers in various mountain areas contributes to the interpretation and reconstruction of past climate (Kerschner, 1978; Konrad et al., 1999; Sailer and Kerschner, 1999; Frauenfelder et al., 2001; Hughes et al., 2003; Aoyama, 2005). In recent years first surface exposure dating of rock glaciers with the cosmogenic nuclide ^{10}Be was

* Corresponding author.
E-mail address: andrew.moran@uibk.ac.at (A.P. Moran).

http://dx.doi.org/10.1016/j.geomorph.2016.08.017
0169-555X/© 2016 Elsevier B.V. All rights reserved.

carried out in the Alps (Ivy-Ochs et al., 2009; Böhlert et al., 2011b). However, hitherto the dating of rock glaciers (Ivy-Ochs et al., 2009) as a climate proxy has focused on locations in the central Alps. Conversely, no absolute ages have been determined for moraines and rock glaciers in the Northern Alps. This region is of particular interest as the northern Alpine fringe receives considerably more precipitation (Schwarb et al., 2001; Tirol Atlas, 2013) than the central Alps and can be expected to show deviations from the central Alps reflected by permafrost distribution and ELAs of palaeoglaciers (Kerschner et al., 2000). Here we present the first ^{36}Cl ages of rock glacier stabilization in the Northern Alps. The purpose of this paper is to derive novel chronological and climate information from past rock glaciers in this region. The obtained ages also pose age constraints for below- and above-lying moraine systems, where currently still no absolutely dated moraine stratigraphy exists.

2. Research area

In this study we investigate two high-elevation sites in the Northern Calcareous Alps of western Austria. They are located in the Karwendel Mountains (Fig. 1), which consist of four chiefly parallel mountain ridges each extending in an east-west direction. The highest peaks rise to elevations around 2300 to 2750 m asl. The orographic effect they have on moist, incoming air masses from the Atlantic northwest induces high precipitation sums ranging between 1800 and 2300 mm/a at our research sites, which is ~300% higher than in some dry inner Alpine locations (Tirol Atlas, 2013). Contemporary treelines are found at elevations of up to ~1800 m asl but based on Lotter et al. (2006) can be expected to have reached above 2250 m asl in the Northern Alps during warm periods of the Holocene. Lieb (1998) estimated the modern lower limit of discontinuous permafrost in the Northern Alps above ~2400 m asl. Currently, most of the Karwendel Mountains are free of permafrost with exceptions restricted to small, high elevational, and well-shaded north-facing cirques and exposed peaks. Recent assessments on the occurrence of permafrost in a comparable region have been performed in the neighbouring Wetterstein Mountains by Gude and Barsch (2005), who show that discontinuous permafrost reaches there generally 200 to 300 m lower than in the central Alps.

Our research sites show evidence of former glacial and periglacial activity in this mountain group (Fig. 2). The corresponding landforms are located in the southern part of the Karwendel Mountains in the neighbouring Mandl (11°24′00″ E; 47°19′20″ N) and Pfeis cirques (11°25′20″ E; 47°19′36″ N) ~6 km north of the center of Innsbruck. They were first mapped by Kerschner (1993). The cirque floors are found at elevations of between ~2000 and 2100 m asl. All surrounding peaks and ridges consist of bedded to massive Middle Triassic Wetterstein limestone (Mutschlechner, 1949; Heissel, 1994). The lithology supports the formation of steep rock walls rising above extensive fine scree slopes and talus cones. The peaks surrounding the Mandl cirque reach elevations around 2300 to 2400 m asl (e.g., Gleirschtaler Brandjoch, 2372 m asl), whereas the Pfeis cirque lies at the foot of the somewhat higher summit of Rumer Spitze Mountain (2454 m asl). The Nordkette is characterized by an east-west strike dipping 30° to 60° to the north, whereas the area north of the Mandlkar is marked by a much more gentle dip of 5° to 30° to the southwest forming a large syncline (Ampferer and Hammer, 1898).

2.1. Mandl cirque rock glaciers

The Mandl cirque contains four tongue- or lobe-shaped relict rock glaciers delimited by sharp ridges at their outer margins rising up to ~5 m on their proximal sides and to ~10 m on their distal sides. Their frontal slopes often have inclinations slightly lower than the angle of repose. The surfaces show rudimentary pedogenesis and a patchy high-montane vegetation cover typical for the elevation. As depicted in Fig. 2, the largest rock glacier (R1) lies beneath Gleirschtaler Brandjoch peak (2372 m asl) and covers the northern part of the cirque. It emerges from the foot of extensive scree slopes in the north and east and extends from its upper onset at ~2090 m asl to its terminus at ~1970 m asl. It is ~550 m long, exhibits a surface marked by frequent undulations and furrows in its lower parts, and consists of unsorted, unconsolidated material and only some scattered boulders. A second tongue-shaped rock glacier (R2) lies beneath Mandlspitze (2366 m asl) and is located ~200 m south of R1. It extends ~270 m northwestward and is ~170 m wide. The margin of a third rock glacier (R3) trends generally parallel to the southern scree slopes forming a small tongue at its mid-section. Altogether it is ~600 m wide and extends a distance of up to 160 m from the foot of the slope to its furthest terminal position. The fourth rock glacier (R4) forms an arc of ~600 m in length, fully surrounding R3, and lying tangent to R2. From their position in the field, the rock glaciers described above correspond to typical talus-derived rock glaciers (Barsch, 1996).

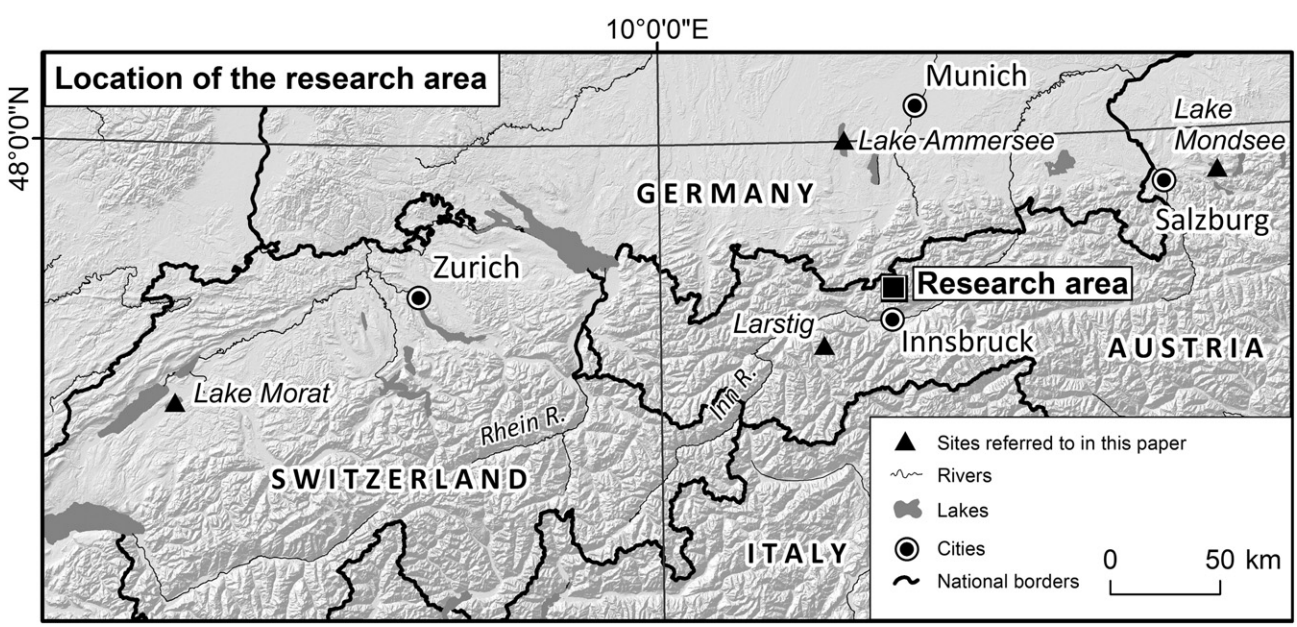

Fig. 1. Location of the research area in the Karwendel Mountains of the Northern Calcareous Austrian Alps.

Download English Version:

https://daneshyari.com/en/article/6431572

Download Persian Version:

https://daneshyari.com/article/6431572

Daneshyari.com