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Spatial and climatic characterization of three glacial stages in the Upper Krnica Valley, SE European Alps

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ABSTRACT

The southeastern European Alps represent the spot where mean annual precipitation is at its highest in the entire Alpine chain. Accordingly, the glacial evolution here might have a different spatial and chronological pattern if compared with other alpine areas. This paper discusses geomorphological evidence of three glacial stages from the Krnica Valley in the Julian Alps of Slovenia, and is the first step towards a comprehensive palaeoglaciological studies in this alpine sector. Very well-preserved glacial landforms in the Upper Krnica Valley allowed the reconstruction of glacier surface topographies and corresponding equilibrium line altitudes (ELAs) by means of field-based geomorphological and sedimentological data and by using geospatial analysis. The uppermost frontal moraines belong to the Little Ice Age (LIA) and the corresponding ELA is estimated at 1973 m a.s.l. Other two stages with the ELA depressed by 50 m and 161 m compared to the LIA ELA, suggest early Holocene and Younger Dryas ages of the palaeoglaciers, respectively. This assumption ensues from absolute age datings and related ELA depressions observed elsewhere in the European Alps. The presence of buried ice under the debris in the Krnica cirque, imaged through geophysical investigations, point to peculiar microclimatic conditions able to preserve relict glacier ice. This is favoured by the recursive presence of snow on the ground caused by the extreme summer shading and the significant winter snow-recharge triggered by snowblow and avalanche feeding. The possible evolution of such relict ice under the ongoing climate warming is also discussed.

1. Introduction

Southeastern Alps were at the edge of a large Alpine ice cap during the Last Glacial Maximum (LGM) (Ehlers and Gibbard, 2004); however, the maximum extent of glaciers in this part of the Alps is in general not systematically documented, neither the deglaciation nor later Holocene glacial advances. The Julian Alps is the southeasternmost part of the Alps, stretching between Italy and Slovenia. This alpine sector is especially known for its high amount of precipitation, one of the highest in the entire Alpine chain (Norbiato et al., 2007). Four major glaciers in the Julian Alps (Tagliamento, Soča, Sava Dolinka and Bohinj) (Bavec and Verbič, 2011; Monegato et al., 2007) were draining the Alpine ice cap during the LGM, but only the terminal part of the Tagliamento glacier is both well-defined and precisely dated using absolute age-dating methods (Monegato et al., 2007; Fontana et al., 2008). Two glacial advances took place in this piedmont area (Monegato et al., 2007), earlier between 26 and 24.6 ka cal BP and later between 23.5 and 22 ka cal. BP (recalibrated by Monegato et al., 2017). The deglaciation period is only documented by some geological and geomorphological evidence in the hinterland of the main valleys (e.g. Bavec et al., 2004; Colucci et al., 2014; Monegato, 2012; Tintor and Andrič, 2014), however no datings or glaciological modelling

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exist for this period. A correlation of glacier advances after the LGM decay with those elsewhere in the Alps is also problematic (Reitner, 2007, 2012) and LGM and Lateglacial fluctuations are generally documented only for the northernmost side of the eastern Alps (e.g., Van Husen, 1997; Reitner, 2007). Nevertheless, few works conducted on peat bogs in the Dolomites point to a rapid and complete deglaciation of alpine valleys at the end of the Lateglacial (Poto et al., 2013). On the contrary with well-studied Younger Dryas moraines in the central and eastern Alps (Ivy-Ochs, 2015), the evidence for the Younger Dryas as well as the early Holocene glacial advances in the Julian Alps is in general missing. Rock glacier's distribution in the southeastern Alps suggests the Younger Dryas age for the documented relict landforms, with the majority of them situated between 1708 and 1846 m a.s.l.; this represents the lowest rock glacier's altitude for the Alps (Colucci et al., 2016a). The glacial evolution during the late Holocene has been recently also reconstructed by reproducing the glacial topographic changes from the Little Ice Age (LIA) to the year 2012 (Colucci, 2016; Colucci and Žebre, 2016). The glacierized area had shrunk by about 84% since then and today only isolated very small glaciers and ice patches, covering an area of less than 0.5 km^2 still survive.

The Krnica Valley in the Slovenian Julian Alps (Fig. 1) preserves several glacial deposits likely belonging to different stadials, which makes it a key area for Lateglacial-to-Holocene studies. The Quaternary filling of the valley floor is very complex, containing glacial and fluvial deposits, remobilized or superimposed by mass movement processes. First surveys on glacial deposits reported the presence of till and documented a series of lateral moraines at the valley outlet (Melik, 1955). Those findings were later confirmed by a series of geological drillings in the area (Pavlovec, 1961). In the spirit of the Alpine Lateglacial morphostratigraphic division set by Penck and Brückner (1901/1909) and solely on the basis of geomorphological evidence Melik (1955) suggested Bühl stadial age for these moraines. Further reports additionally deal with glacial deposits in the upper valley sections, where four series of glacial deposits were identified. These were ascribed to Lateglacial advances (Gams, 1992; Kunaver, 1999). Lower sections of the valley contain largely modified glacial deposits while within the upper section some well-preserved lateral and terminal moraines develop (Kunaver, 1999). The uppermost two parallel ridges enclosing the glacial cirque and behind which a series of perennial snow patches are today present, were associated with the LIA maximum (Colucci, 2016). Although some researches on Quaternary deposits and landforms in Krnica have been completed by now, more in-depth geomorphological and sedimentological data, allowing assumptions on glacial evolution and further chronological analyses, are still missing.

In this paper, we focus on the upper 5 km of the Krnica Valley in the Julian Alps, following four main aims: (1) to present detailed geomorphological evidence for several glacial stages in the Krnica Valley (Julian Alps) by using fieldwork and LiDAR data; (2) to present evidence for a still existing layer of glacial ice embedded by a thick debris layer in the Krnica cirque by interpreting ground penetrating radar (GPR) data; (3) to reconstruct glacial dimensions and related equilibrium line altitudes on the basis of field evidence and GIS analysis, and (4) to provide the glacial evolution of the

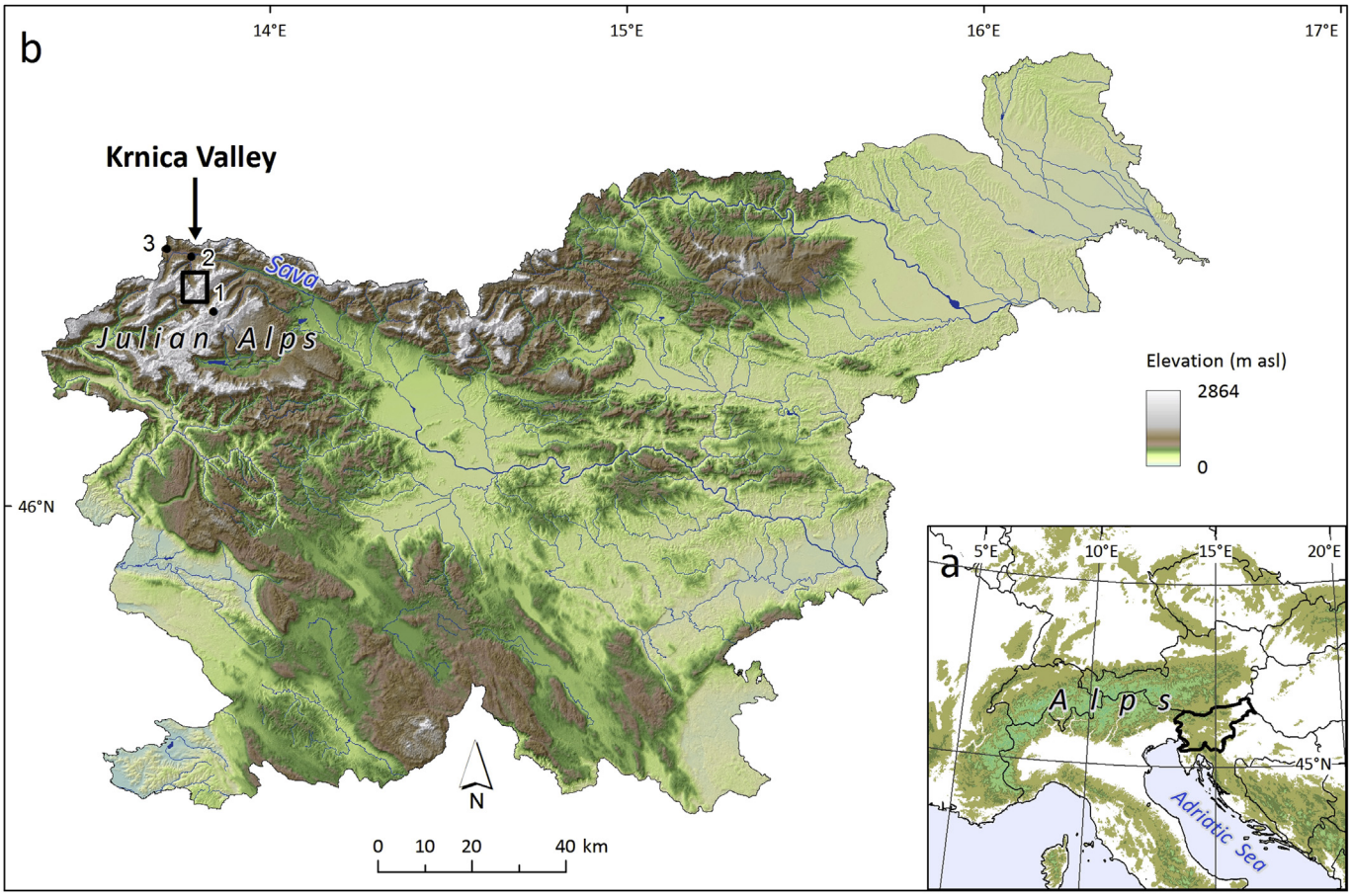

Fig. 1. (a) European Alps and location of Slovenia. (b) The Krnica Valley study area in the NW corner of Slovenia. 1 - Triglav-Kredarica observatory, 2 – Kranjska Gora, 3 – Rateče.

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