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Incised relict landscapes in the eastern Alps

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ABSTRACT

We investigate landscape evolution in a region of the Alps that has escaped glacial erosion during periodic glaciations of the last million years. The research is thus suited to investigate landscaping processes on a longer time scale at the eastern end of the Alps. Morphometric analysis reveals the presence of incised relict landscapes in several regions. In the Koralpe range topographic analysis is interpreted in terms of the relict landscape being present on both sides of the eastward tilted Koralpe block. This suggests that the relict landscape is younger than the tilting of the range, which is inferred to have taken place between 18 and 16 Ma. In the Pohorje region, a relict landscape is developed across the contacts of a 19 Ma pluton. We use apatite (U–Th)/He thermochronology to constrain the possible age of the Koralpe and Pohorje relict landscapes. The results indicate that the Pohorje massif had cooled below 70 °C by about 15 Ma suggesting that the relict landscape must be younger — consistent with the interpretation of the Koralpe range. These results suggest that many relict landscapes of the eastern Alps may have formed after 15 Ma in a period of tectonic quiescence and erosion. However, in both ranges channel profile projections show that about 387 ± 105 m uplift and incision occurred subsequently. This incision is likely to have occurred during the last 6–5 Ma in response to the uplift of the whole region. It testifies to a renewed and ongoing uplift event that is earlier than the glaciation periods but might easily be confused with impact of glacial erosion elsewhere in the eastern Alps.

1. Introduction

Topography is the result of a competition between erosion that removes material from the Earth's surface, and tectonic forces that can create relief through uplift mechanisms. The interaction and competition between these different forces that shape the morphology of mountain belts is a topical subject in modern geoscience. In particular in the European Alps, the debate on landscape evolution and its relationship with tectonics and climate remains ongoing (Cederbom et al., 2004; Persaud and Pfiffner, 2004; Champagnac et al., 2007; Hergarten et al., 2010; Norton et al., 2010; Willett, 2010; Valla et al., 2011; Sternai et al., 2012). Here aspects of the long-term landscape evolution of the Alps are inferred by focusing on a part of the eastern Alps that was free of ice during the last periodic glaciations (van Husen, 1997), but features a mountainous landscape with summits up to 2200 m surface elevation: the easternmost part of the eastern Alps (Fig. 1). As this region was not affected by glacial scour, it represents an excellent opportunity to document the landscape evolution of the area on a time scale that reaches substantially further back than the periods of glaciation.

Paleosurfaces or relict landscapes have long been documented in the studied area, in particular for the Koralpe Mountain (Fig. 1). Winkler-Hermaden (1957) already suggested that the Koralpe Mountain features preserved ‘paleosurfaces’, or relict landscapes as we term these landforms here. More recently, the Koralpe landscape has been considered as an Oligocene paleosurface by Frisch et al. (2000). Robl et al. (2008) have also suspected that knickpoints may be recorded in the river profiles of some of the tributaries of the Drava and the Mur draining the Koralpe and Pohorje mountains, possibly indicating transient erosion. However, the Koralpe and Pohorje landforms were never mapped using quantitative methods and digital elevation models (DEM) and the age of their formation and incision remains largely unconstrained (although see: Rantitsch et al., 2009). To investigate the landscape evolution, the uplift history and the links with tectonic events in this part of the Alps, channel profiles and slope maps were analyzed to derive maps of incised relict landscapes for the Koralpe and Pohorje mountains. Channel profile projections of eight selected rivers were then used to estimate the amount of incision into these relict landscapes. We combine our results with 20 new apatite (U–Th)/He ages from the Koralpe and Pohorje mountains that are used to constrain the interpretations in absolute time. Finally, an integrated landscape evolution scenario is inferred for the studied area linking tectonic and landscape evolution of the region since the early Miocene.

2. Geological setting

The Pohorje Massif and the Koralpe region are both part of what has been termed the Styrian Block, which encompasses the entire region

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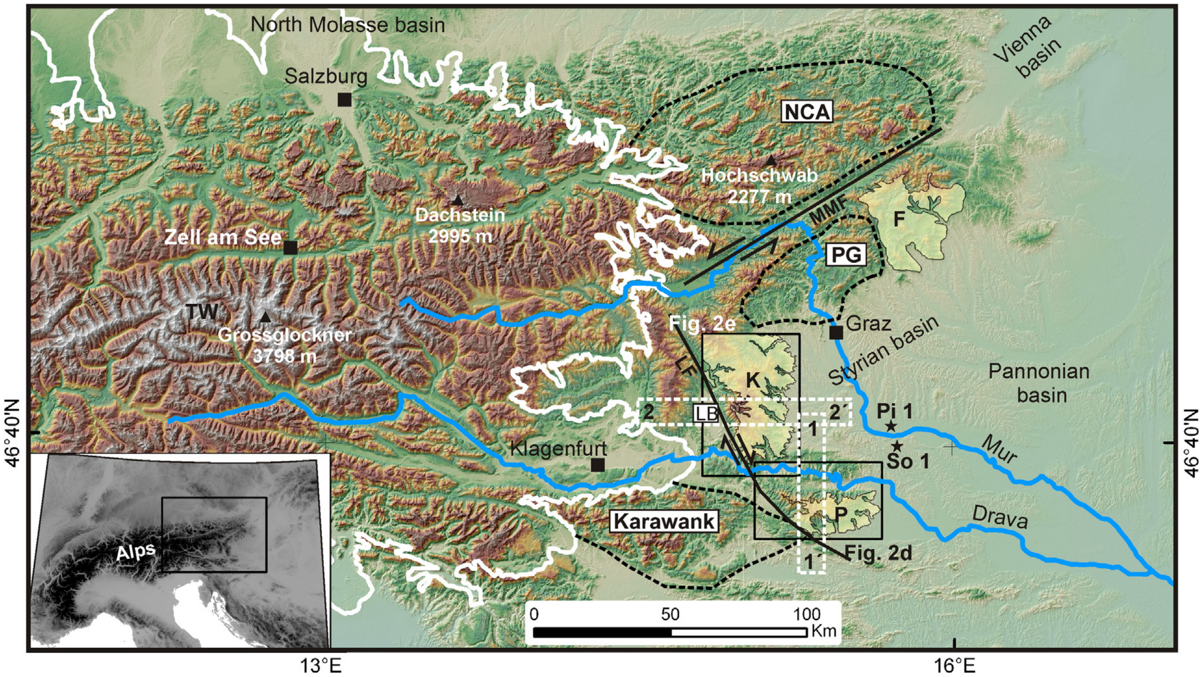

Fig. 1. Topography of the easternmost part of the European Alps and location of the studied areas. Thick white line represents limit of glaciation during the glaciation periods. Relict landscapes outside this region are shown as shaded regions. NCA = Northern Calcareous Alps; TW = Tauern window; PG = Paleozoic of Graz; K = Koralpe relict landscape; P = Pohorje relict landscape; LB = Lavanttal basin; LF = Lavanttal fault; MMF = Mur-Mürz fault. F refers to the Fischbacher Mountain that also represents an incised relict landscape. Location of wells for subsidence analysis: So 1: Somat 1; Pi 1: Pichla 1 (Ebner and Sachsenhofer, 1995; Sachsenhofer et al., 1998, 2001). White dashed rectangles are extent of swath profiles of Fig. 4 (profiles 1–1′ and 2–2′).

east of the Lavanttal fault system and south of the Mur-Mürz system including the Styrian basin (Fig. 1) (Wagner et al., 2011). The Lavanttal fault system and the Mur-Mürz systems are both some of the major structures controlling the Miocene lateral extrusion of the eastern Alps (Ratschbacher et al., 1991; Frisch et al., 1998; Robl and Stüwe, 2005; Wölfler et al., 2010, 2011) and are therefore closely linked to the tectonic evolution of the region (Fig. 1). The regional base level for the entire eastern end of the Alps is set by the Danube which ultimately drains into the Black Sea. More locally, the current base levels for the region under investigation are the Drava and the Mur rivers (Fig. 1). These two major rivers seem to be morphologically well-equilibrated and do not record significant knickpoints other than the ones located at the LGM terminal moraines (Robl et al., 2008). The Styrian basin consists of sediments that were deposited between approximately 18 and 7 Ma (Ebner and Sachsenhofer, 1995). This region is characterized by a smooth hilly landscape and extensive alluvial plains and fluvial terraces (e.g. Wagner et al., 2011).

The Pohorje Massif lies at the southeastern corner of the Alps (Fig. 1). The massif is about 35 km long and 15 km wide and it is surrounded by the westernmost parts of the Pannonian basin to the south and to the east. The elevation of the Miocene basin to the south is about 300 m and the highest summit of Pohorje is Črni Vrh with an elevation of 1543 m. The massif is made up of eclogite facies Cretaceous paragneisses of the Austroalpine nappe complex. The metamorphic rocks of the Pohorje Mountain were intruded by the Pohorje pluton, a 30 km-long and 4-8 km-wide magmatic body (Fig. 2d). U–Pb analysis on zircons implies an early Miocene crystallization age of the granite around 19 Ma and zircon fission track ages indicate rapid cooling of the pluton within about 3 Ma (Fodor et al., 2008). However, cooling and exhumation of Pohorje pluton below about 250 °C are currently unconstrained. However, detrital apatite fission track ages indicate that the pluton supplied already in the middle Miocene sediments into the Ribnica Trough in the center of the massif — (Sachsenhofer et al., 1997, 1998; Dunkl et al., 2005). This is supported by kinematic data from east–west striking, high-angle normal faults along the margin of the Ribnica Trough (Pischinger et al., 2008). Also, associated volcanic rocks at the western end of the massif indicate that the pluton cooled near the surface. Sölva et al. (2005) have noted that the course of the Drava river that dissects the massif indicates an antecedent river profile with young uplift of the massif.

The Koralpe region is a north–south striking range located between the Styrian basin to the east and the Miocene Lavanttal fault to the west (Figs. 1, 2e). The range measures ~40 km from north to south and ~25 km from east to west. It has an asymmetric topography from 2140 m on the Speikkogel summit to 300 m near the Styrian basin with a steep western slope and a gentle eastern slope, probably due to tilting of the range in response to the lateral extrusion of the eastern Alps and the early Miocene fault activity of the Lavanttal fault (Neubauer and Genser, 1990; Kurz et al., 2011). Lithologically, the range is famous for hosting the eclogite type locality and is one of the highest grade metamorphic regions of the Alps. It is made up of Cretaceous gneisses, amphibolites and eclogites. The Miocene Lavanttal fault system bounding the range to the west is part of the Pöls-Lavanttal fault system (Fig. 2e) that has a dextral offset (Exner, 1976; Wölfler et al., 2010, 2011). In the Lavanttal segment, a small pull-apart basin shows evidence for about 15 km of dextral offset (Reischenbacher et al., 2007). Vertical offset along the Lavanttal fault system is estimated to be >2 km, with relative upward movement of the Koralpe (Frisch et al., 2000). Onset of sedimentation in the Lavanttal basin is dated to ~18 Ma (Strauss et al., 2001; Reischenbacher et al., 2007). Based on the sedimentary evolution of the basin, the Lavanttal fault system is assumed to be active since the early Miocene, with peaks in activity at 18–16 and 14–12 Ma (Reischenbacher et al., 2007; Wölfler et al., 2010). Fault plane solutions for recent seismicity display dextral strike-slip movements (Reinecker and Lenhardt, 1999; Pischinger et al., 2008). The Koralpe Mountain was partly covered by small isolated glaciers during the recent glaciation periods. These glaciers have left small cirques around the highest peaks, but the glaciers only covered and modified a very small part of the Koralpe landscape (Fig. 2d) that we exclude from the geomorphic analysis.