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Precise radiocarbon dating of the giant Köfels landslide (Eastern Alps, Austria)

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ABSTRACT

The landslide of Köfels located in the Ötz Valley (Eastern Alps, Austria) is the largest mass movement in crystalline rock in the Alps with a total volume of 3.3 km^3. Previous radiocarbon dates have suggested an age of the event of 9800 ± 100 years ago. The landslide and its radiocarbon dating were used to estimate a Holocene production rate for ^{10}Be for surface exposure dating. Tree-ring analysis and radiocarbon dating of new samples significantly refine the timing of the Köfels landslide and even enable to constrain the season during which this event occurred. Wiggle matching analysis of six radiocarbon samples constrains the event to 9527–9498 cal BP which is slightly younger and significantly more precise than the previously established age. The landslide occurred shortly after the onset of the vegetation period, i.e. in May or June. The new dating moves the Köfels landslide strikingly close to the less well constrained age of the Flims landslide, the largest of its kind in the Alps located 130 km west of Köfels (9475–9343 cal BP). This near-synchronicity of these giant mass movements raises the question of a possible common, albeit currently unknown, trigger.

1. Introduction

The landslide of Köfels is the largest mass movement in the crystalline zone of the Alps. It is located in the middle section of the Ötz Valley (Tyrol, Austria) and is named after the local village of Köfels (1401 m asl, Fig. 1). The landslide detached from the east-facing slope and buried parts of the Ötz Valley between Winklern and Umhausen as well as the opposing Horlach Valley where the village of Niederthai is located (Ostermann and Prager, 2014). The landslide debris is up to several hundred metres thick and the original landslide volume was estimated to 3.3 km^3 (Brückl et al., 2001).

The landslide occurred after deglaciation of the Ötz Valley and its age has been constrained by two independent methods, radiocarbon and surface exposure dating. The former was established on wood remnants recovered during the construction of a tunnel beneath and through the landslide debris in the eastern section of the landslide area. Heavily compressed wood remnants were found within the landslide deposits at a depth of 450 m below surface (Heuberger, 1966; Ivy-Ochs et al., 1998). Three radiocarbon analyses were performed and the combined mean was 8740 ± 25 BP. Ivy-Ochs et al. (1998) applied a calibration using tree-ring chronologies and reported a calendar age range of 7897–7696 BC, which corresponds to 9846–9645 cal BP. Using the current calibration curve (IntCal13, Reimer et al., 2013) the age range shifts to 9886–9564 cal BP (2 σ range) with a 94.5% relative probability for the time interval 9823–9585 cal BP. Exposure dating results of the Köfels landslide scatter, but the published overall age of 9820 ± 370 years (1σ; the datum was not explicitly stated, but most likely refers to A.D. 1995) agrees within uncertainties with the calibrated radiocarbon dates (Ivy-Ochs et al., 1998). In fact, the Köfels landslide represents one of the best calibration sites worldwide for the determination of the cosmogenic ^{10}Be production rate. Using the previously established timing of the event (Ivy-Ochs et al., 1998) a local production was obtained for the last 10,000 years (Kubik et al., 1998), which was subsequently revised (Kubik and Ivy-Ochs, 2004).

Here we present (a) new radiocarbon dating results which significantly refine the timing of the Köfels landslide, and (b) tree-ring analyses which enable us to constrain the season during which this event occurred.

2. Materials and methods

Two small wooden samples were recently rediscovered in the archive of the Institute of Geology, University of Innsbruck. Both are ca. 12 × 8.5 cm in size. The attached notes of the two samples (inventory numbers P7943 and P7933) indicate that both were collected during the construction of the tunnel from Umhausen to Niederthai about 400 m below surface (P7933) and at the contact zone between bedrock and debris in autumn 1951 (P7943). The discovery position can therefore be assumed to be similar to the situation where the previously radiocarbon-dated wood remnants were collected (Heuberger, 1966; Ivy-Ochs et al., 1998). The hand-written note attached to specimen

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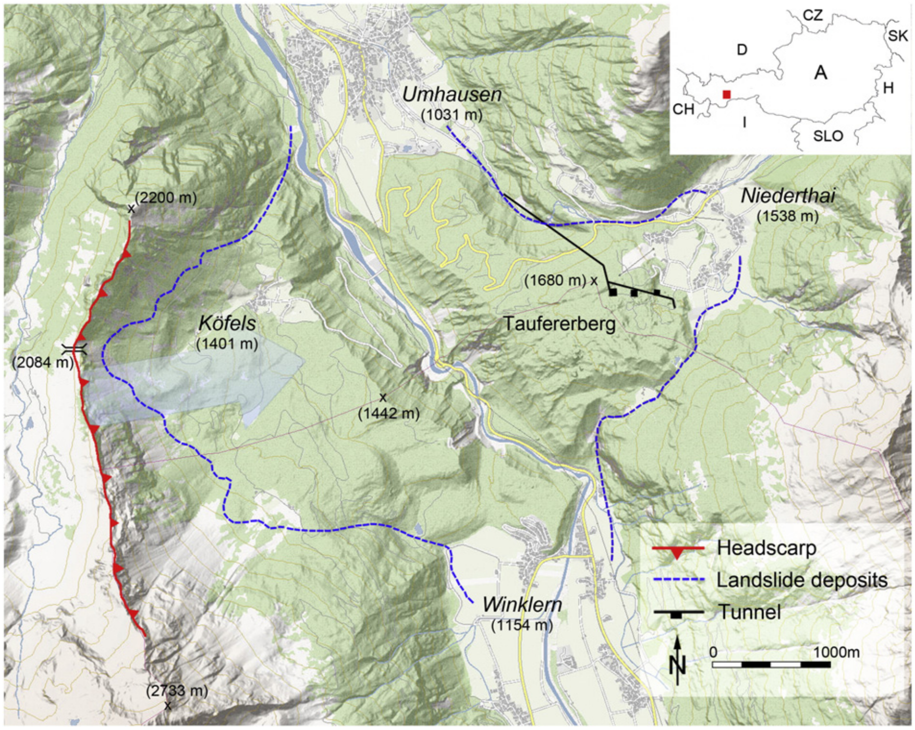

Fig. 1. Overview map of the Köfels landslide area. The landslide detached from the east-facing slope and its deposits cover parts of the Ötz valley. The tunnel where the analysed wood pieces were collected is indicated. For details see Brückl et al. (2001) and Prager et al. (2009). Map source: Land Tirol—tiris. In the inset map abbreviated country names are shown.

P7943 suggests that both samples are actually from the same tree and were examined by Helmut Gams (1893–1976), a former botany professor at Innsbruck University (see Supporting Online Material).

Wood identification and tree-ring width measurements were carried out on both samples at the Alpine Tree-Ring Group Laboratory, Institute of Geography, University of Innsbruck. A LINTAB measurement table and an optical microscope were used and the tree-ring width data were established at 0.001 mm resolution. Three radii were measured on each sample.

Radiocarbon analyses were carried out at the ^{14}CHRONO Centre for Climate, the Environment, and Chronology at the Queen's University Belfast using acceleration mass spectrometry (AMS). Ages were calculated according to Stuiver and Polach (1977) using the AMS measured $^{13}C/^{12}C$, which accounts for both natural and machine isotope fractionation. To improve accuracy and precision of the age estimation we established radiocarbon dates for six wood samples that were taken from slice P7933 at known temporal distances to allow a wiggle matching of the results, i.e. the combined calibration of the multiple radiocarbon dates under consideration of the known temporal distances (tree rings) between the individual dates. For the ^{14}C calibration we used OxCal 4.2.3 (Bronk Ramsey, 2001; Bronk Ramsey et al., 2001; Bronk Ramsey, 2009) and the IntCal13 calibration data set (Reimer et al., 2013).

3. Results

Both samples show very eccentric growth patterns (Fig. 2). Moreover, the wood of both is partly compressed with occasionally collapsed conifer tracheids. The micro-anatomical wood identification suggested *Pinus sylvestris* and agrees with the former identification mentioned on the attached notes. However, the shape of the tree-ring pattern is not concentric but very eccentric. This suggests that the samples identified as stemwood probably originated from a *Pinus mugo* tree, which is a shrubby, usually multi-stemmed tree that cannot be anatomically distinguished from an upright growing *Pinus sylvestris* tree.

The tree-ring analysis of both samples yielded irregular growth series with remarkably varying tree-ring widths and wedging out of some tree rings (Fig. 3). Several tree rings also show density fluctuations, i.e. pointing towards drought stress during the growing season (e.g. Rigling et al., 2001). Three radii were measured on sample P7933 (dendro-sample code bkoe-2) as well as on sample P7943 (code bkoe-1). The measurements started at the first complete tree ring after the pith on both samples. The tree-ring series prove that both slices originated from the same tree as already suggested by H. Gams (see above and Fig. 3). After the identification and insertion of missing rings the combined tree-ring measures of both slices resulted in a 117 year-long series (see Supporting Online Material).

Importantly, the last growth ring of both slices is only composed of few earlywood cells. A small bark vestige at bkoe-2 demonstrates the presence of the waney edge and allows determining the season during which the tree was killed. The tree died shortly after the onset of the growing season, i.e. during May or June.

Unfortunately, the irregular and disturbed growth patterns and the partly missing rings prevent a dendrochronological dating of bkoe-1/2,

Fig. 2. Slice P7943 (dendro-code bkoe-1). Left: sample with the originally broken end, right: cross-section showing the irregular growth patterns and the partly deformed wood.