The age of the Fernpass rockslide (Tyrol, Austria) and its relation to dated mass movements in the surrounding

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Some of the largest fossil mass movement deposits in the Alps cluster spatially in the Fernpass region (Tyrol, Austria). One of them, the prominent Fernpass rockslide in the Northern Calcareous Alps, is characterised by two channelled Sturzstrom branches, which contain a rock mass volume of about 1 km^3 and cover excess run-out distances of about 12 and 16 km lengths respectively. This catastrophic event was succeeded by a smaller rockslide and the development of an unstable slope that has not yet failed. In previous studies, the failure-age of the Fernpass rockslide has been debated controversially. Morphological and lithostratigraphical field criteria, e.g. moraine-line debris-ridges, funnel-shaped "dead-ice" sink-holes and the spatial distribution of Pleistocene cover rocks, were used to differentiate between a late-glacial main event and a succeeding post-glacial collapse. But detailed field investigations suggest that the fluvioglacial cover deposits originated from the scarp area and were transported piggy-back on top of the failing rock masses. Moreover, at Fernpass neither the rough scarp nor the intensively structured accumulation area feature any signs of a smooth morphology and argue against glacial overprints.
Recently this was confirmed by the first absolute dating of the rockslide event. Here the geological situation enabled the application of three different dating methods on individual sampling sites. Close to the scarp-area, rockslide-dammed torrent deposits yielded a ^{14}C minimum-age of 3380–3080 cal. yrs BP. For the base of this approx. 15 m thick backwater sequence an age of about 3950 ± 600 cal. yrs BP is assumed. This coincides well with two cosmogenic radionuclide ^{36}Cl exposure ages of large-scale sliding planes at the northern scarp flank. There the exposure ages of the sampled platy dolomites are 3600 ± 900 yrs and 4800 ± 1100 yrs and suggest a mean age of 4200 ± 1200 yrs for the failure event. Further data were gained from the curiously and strongly deflected southern rockslide branch, where, remarkably, the loose debris is occasionally lithified by previously not mentioned post-depositional Aragonite and Calcite cements. Characterised by high

Uranium-contents up to 180 ppm, early-diagenetic cements were dated by the $^{230}Th/^{234}U$-disequilibrium method, applied for the first time on a Holocene mass movement in the Alps. This yielded a minimum isochron age of 4150 ± 100 yrs for the accumulation of the rockslide debris. Based on this, a temporal differentiation between two failure events, one making up the northern rockslide branch, and another, making up the southern branch, is not indicated yet. All dating coincide remarkably well and indicate the Fernpass rockslide most likely occurred about 4200-4100 yrs ago. Thus, this event was clearly not in contact with late-glacial ice and not triggered by deglaciation processes.

The failures of the Fernpass rockslide and its adjacent mass movements were clearly structurally controlled by fault-related valley-deepening and coalescence of brittle discontinuities. Active faulting and related rock strength degrading processes are here confirmed by some of the strongest earthquakes ever measured in Austria and by others, which are characterised by low magnitudes but shallow seated focal depths in about 3–5 km depth. Repeated seismic loading, even if only at subcritical intensities, initiates brittle fracture propagation due to inelastic material fatigue. Thus, earthquakes can produce intensively fractured and uncemented rock masses to substantial depth and act as effective preparers of mass movements.

To evaluate the temporal and spatial distribution of failure events, a GIS-linked geodatabase has been set up, focusing on Holocene mass movements in Tyrol and surrounding. This compilation of dated landslides and debris flows shows (i) a continuous temporal distribution of landslide activity with some accentuations during the early Holocene. An age-cluster at about 10.000–9000 cal. BP comprises some of the largest Alpine rockslides, e.g. the catastrophic events at Köfels, Kandertal and Flims. (ii) In contrast, a significant emphasis of deep-seated rockslides in the Subboreal at about 4200–3000 cal. BP occurred in the Fernpass region. Here similar ages of failure were established for some adjacent rockslides, e.g. at Eibsee, Fernpass and several at the Tschirgant-massif. (iii) Moreover, several radiometric dating indicate reactivations of site-specific slope vulnerabilities, locally causing repeated failure events. However, even early Holocene landslides did not fail immediately after late-Pleistocene glacier retreat, but took a preparing lag-time of at least a few thousand years.

Temporally, the middle Holocene rockslide-activity in the Fernpass region coincides with the progradation of some larger debris flows in the nearby main valleys and, partially, with glacier advances in the Austrian Central Alps. Indicating climatic phased of raised water supply, this gives evidences of elevated groundwater flows and water pressure changes within the intensely fractured rock masses. As a result, deep-seated slope deformations are induced by the complex and polyphas interaction between lithological, structural and morphological basic dispositions, subcritical fracture propagation, variable seismic activity and climatic changes.