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Structure and kinematics of a long run-out rockslide: the Holocene Fernpass Sturzstrom (Northern Calcareous Alps, Tyrol, Austria)

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One of the largest mass movement deposits in the Alps, the fossil Fernpass rockslide, is made up of two diametrically opposed "Sturzstrom" branches up to ca. 12 and 16 km long respectively with a total volume of about 1 km^3. Radiometric dating indicates that the calcareous slide was released at about 4200–4100 cal. yrs BP in the middle Holocene and was clearly not directly triggered by late-Pleistocene glacier withdrawal. Detailed field investigations show that lithological parameters, bedding conditions, uncemented fracture zones and slope-morphology are responsible for the occurrence of several deep-seated mass movements in this region. The Fernpass rockslide originated from a well exposed and exceptional deeply incised niche, which is made up of an incompetent succession of platy dolomites, limestones and marls of the several hundred metres thick Seefeld Formation (Norian, Upper Triassic). Polyphase and heteroaxial folding and faulting generated N-S-orientated folds and E-W-orientated major fold systems, E-W-orientated normal and reverse faults, NE-orientated sinistral and NW-orientated dextral fracture zones. The northern scarp flank is situated at the southern limb of an E-W-trending anticline and exhibits several large-scale sliding planes, i.e. the bedding planes and NE-orientated fault planes. In contrast, the southern scarp flank is characterised by complex deformed successions of the Seefeld Formation, where the size of the sliding planes is limited to some tens of metres.

However, the failure zones of the Fernpass rockslide and its juxtaposed slopes evolved by multiple step-path failure mechanisms, i.e. the complex coalescence of differentially orientated brittle discontinuities. This controlled the slope deformation, the geometry of the wedge-shaped scarp and the sliding planes and the block size distribution. Deep-seated cataclasis along the prominent NE-orientated Loisach-Fernpass fault system, here indicated by the occurrence of evaporitic and dolomitic shear bodies of the Raibl Group (Carnian) near the Fern-Pass, enabled fluvio-glacial erosion and substantial valley-deepening. This in turn caused stress redistribution of the valley-slopes and uncovered preferably orientated sliding planes, both permitting subsequent slope instabilities. In general, the slope kinematics was controlled by translational sliding along several subparallel sliding planes. The

geometry of this large wedge-failure is characterised a moderately inclined line of intersection, which dips between max. 40° upslope and clearly flattens to less than 10° down slope.
Due to an oblique impact of the failing rock masses against their opposite mountain slope, they were proximally piled up as a remarkably thick debris ridge and split into two Sturzstrom branches. Whereas the run of the northern rockslide branch is kinematically coherent, the strongly and curiously deflected flow of the southern branch asks some fundamental questions about the processes involved. Based on radiometric dating, a temporal differentiation between two failure events, one accumulating in the northern rockslide branch, and another, accumulating in the southern rockslide branch, is not indicated yet. Most probably, the southern branch originated from a gravitational collapse of the thick debris ridge, which makes up the proximal accumulation area.
The internal structure of the rockslide deposits is characterised by chaotic breccias with varying fragmentation and heterogeneous block-size distributions and considerable amounts of sand- to clay-sized matrix. Exposed successions of the proximal depositional facies show a bulky framework of coarse debris and, occasionally, slabs up to 100 m in side length therein. Hybrid seismic measurements, near the apex of the present Fern-Pass, revealed an intensive glacially steepened prefailure topography of the valley-flanks with an undercut slope toe. Remarkably, the well-defined top of the bedrock units is here buried by 500–600 m thick soft rock deposits. Most of this Quaternary filling is assumed to originate from the rockslide event. However, therein several zones in the upper sections are characterised by significantly higher seismic velocities compared to adjacent areas. Coinciding with equivalent field outcrops, this seismic pattern indicates spatially varying internal structures, i.e. the occurrence of mega-clasts and solid rock-slabs within a more disintegrated matrix.
The basal sliding zones of the Fernpass rockslide, probably made up by fine attrition-breccias, are not exposed. But according to field data, drillings and GPR-measurements at medial and distal accumulation areas, the some tens of metres thick rockslide deposits surged upon fine-grained and water-saturated valley fill sediments. Therefore we assume that the excess run-out of the Fernpass rockslide was favoured by the large rockslide volume, channelling effects in the narrow valley, dynamic disintegration and crucially by undrained dynamic loading. Laminar flow, at least of the superficial parts, is indicated by relict Pleistocene fluvio-glacial deposits, which were transported piggy-back on top of the failing rock masses and now cover the medial and distal accumulation areas. Continuous gravitational spreading, probably subsequent to the rapid Sturzstrom flow, caused a further decomposition of the rockslide deposits and the generation of the present morphology, which is characterised by the well-known cone-shaped Toma-hills and several kettle-like lakes in the depressions between.