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PROMINENT MASS MOVEMENTS IN THE TYROL (AUSTRIA): THE DEEP-SEATED TSCHIRGANT, TUMPEN AND KÖFELS ROCKSLIDES

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Situation

Some of the largest fossil mass movements in the Alps are concentrated in the Upper Inn Valley – Ötz Valley area (Northern Tyrol, Fig. 1). They feature various types of rockslides and rockfalls, with deposition volumes ranging between some ten to some hundred million m^3 and with run-out distances extending up to several kilometres (Prager et al., 2007). Essential for a better understanding of the processes leading to these slope instabilities is a lithological, structural and morphological mapping of the scarp areas, a radiometric age dating of events as well as a survey of the geometries and sedimentary fabrics of the deposition material.

Tschirgant rockslide

The prominent Tschirgant rockslide broke off the structurally extremely complex southern margin of the Inntal thrust nappe (Northern Calcareous Alps). The scarp is mainly composed of dolomites and limestones of the Wetterstein Formation (here predominantly featuring reef- and peri-reef facies) and of intensely fractured carbonates, evaporites and siliciclastics of the Raibl Group (at the toe and the top of the slope). These Middle and Upper Triassic successions are characterised by polyphase and heteroaxial folding and faulting (see Prager et al., this volume). As a result of this deformation, the obscurely bedded, yet tectonically intensely overprinted carbonates of the Wetterstein Formation exhibit several extensive fracture planes, which dip out of the slope and form preferably oriented sliding planes (Fig. 2a).

At the scarp and summit area of the Tschirgant, Pleistocene soft rock deposits are predominantly encountered at elevations of up to 2220 m, and occasionally even at higher altitudes (Fig. 2a). These fluvio-glacial cover rocks and the comparable situation at the nearby Fernpass rockslide (Prager et al., 2006) indicate that similar clasts of metamorphic composition at the top of the calcareous rockslide deposits are not to be attributed to a late-glacial overprint of the slide masses (Heuberger, 1975), but were instead carried along piggy-back style from the scarp area. The spatial distribution of these Pleistocene sediments atop the rockslide deposits also indicates that kinematically the rockslide process was at least partially characterised by laminar, i.e. non-turbulent block sliding.

Outcrops show that rock fragments of different sizes (from gravels to blocks in the ten-metre range) are embedded in a silty-sandy to gravelly-stony matrix. The clast-supported fabric and the fractal grain-size distribution of these unsorted debris masses provide evidence that the Tschirgant rockslide deposits were kinematically dominated by flow movements and are the result of a highly mobile Sturzstrom. Locally, especially underneath larger and southerly exposed blocks (which frequently contain "Großoolithe" in the decimetre range as well as collapse breccias in karst cavities, which have passively been transported from the scarp area), the rockslide debris is often lithified by post-kinematic cements, forming breccias several decimetres thick (Fig. 3a). Comparable meteoric cements also occur at the nearby Fernpass rockslide, where they were dated radiometrically using the U/Th disequilibrium method (Ostermann et al., 2007).

Drillings revealed that here finely-ground, low-permeable base deposits, are overlain by coarse blocky debris (Patzelt & Poscher, 1993). It is to be pointed out that the calcareous Tschirgant rockslide is one of a few rockslides in the Alps, where the contact of the basal slide deposits with the substrate is naturally exposed. These contact zones display a complex geometry, where in the course of the rockslide event, presumably water-saturated valley-floor sediments were injected into the

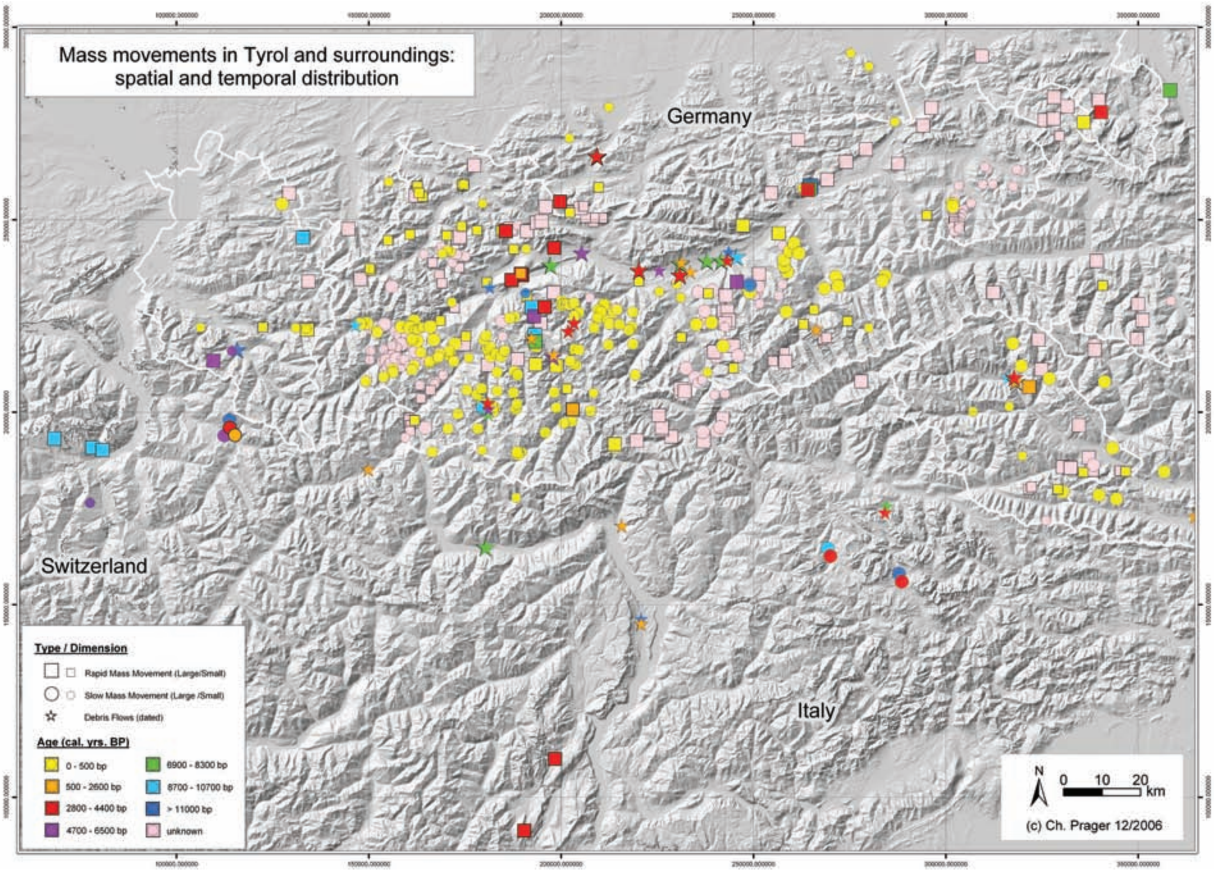

Fig. 1: Distribution of landslides in space and time in the Tyrol and its surroundings (Prager et al. 2007, modified).

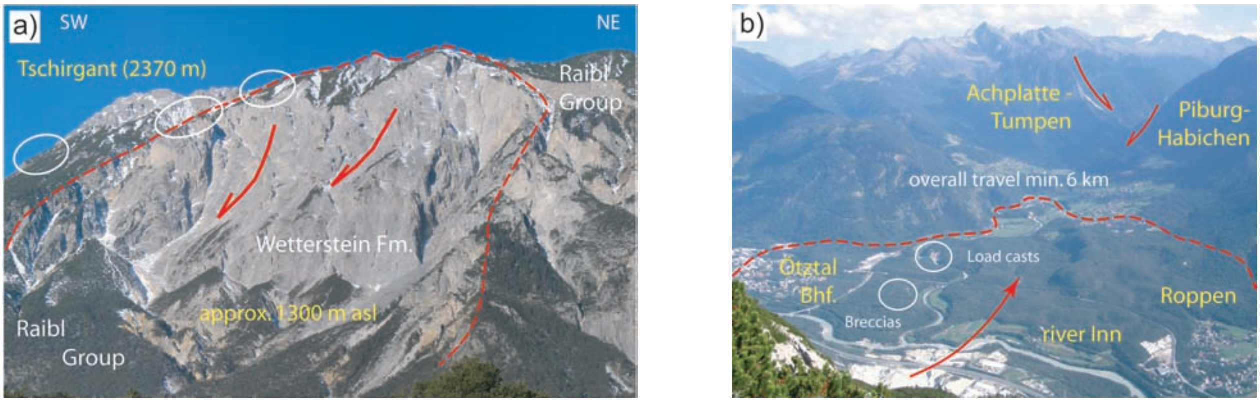

Fig. 2: Tschirgant rockslide a) scarp with desktop-like sliding planes dipping out of the slope and significant outcrops of Pleistocene soft rock deposits at the top of the slope (indicated by white circles); b) view down to slide deposits in the Inn Valley and the Northern Ötz Valley (selected excursion destinations indicated by white circles) as well as to failure zones of other rockslides in this area.

rockslide masses filling up steep extension structures (Patzelt & Poscher, 1993; Abele, 1997) and where diamicts were created by a mingling with the rockslide. The undrained loading of the substrate caused a considerable run-out in excess of 6 km into the Northern Ötz Valley (Fig. 2b). As a result, the Inn Valley was buried and approx. 15–20 m thick gravely sandy backwater sediments were accumulated in the Roppen area (Ampferer, 1904). Based upon field surveys and several radiocarbon dating, a Holocene failure event around 2900 ^{14}C yrs was determined for the Tschirgant rockslide (Patzelt & Poscher, 1993).

Fig. 3: Clast-supported fabric of a) Tschirgant sturzstrom deposits (unsorted debris of reef limestones), here lithified with post-kinematical cements; b) Tumpen-Maurach rockslide, featuring shattered granodioritic gneiss blocks.

Tumpen landslides

In the northern Ötz Valley, significant valley steps and flat upstream valley floors are encountered, which genetically may be attributed to multi-phase landslide events and thus to associated backwater sediments (Heuberger, 1975 including references). Natural and artificial exposures in the Tumpen area demonstrate that here competent orthogneissic rockfall deposits feature clast-supported fabrics of metre-sized blocks and sandy-stony matrix in the pore spaces (Fig. 3b). In comparison to the calcareous Tschirgant sturzstrom, these deposits are marked by less silty-sandy rock fragments, a reduced compactness and thus a higher porosity and permeability respectively.

In the Tumpen area, sink-hole collapses in soft-rock sediments have repeatedly been documented over the last 300 years and have led to extensive ground reconnaissance surveys. According to these surveys, a differentiation is to be made in this area between at least five different slide masses, which were transgressed by fluvio-lacustrine deposition sequences with a minimum total thickness of 60 m. By a relocation of the Ötz, the distance between the river and the underlying rockslide deposits has been reduced in the past. This river diversion, especially in combination with groundwater level fluctuations, may lead to soft-rock deposits being swept into the permeable subsoil by subrosional processes and thus to increased sink-hole collapses (Poscher & Patzelt, 2000).

Köfels rockslide

With a volume of more than 2 km^3, the Köfels rockslide represents the largest crystalline rockslide in the Alps (Fig. 4a, Fig. 4b). The rockslide slab, which is predominantly composed of granitic gneisses from the poly-metamorphic Ötztal-Stubai complex, blocked the Ötz river and caused the accumulation of ca. 100 m thick fluvio-lacustrine backwater-deposits (Heuberger, 1975). Radiocarbon dating of buried wood and surface exposure dating of quartz veins from rockslide boulders (Ivy-Ochs et al., 1998) indicate that the main slide event occurred around 9800 cal. yrs BP and was succeeded by a smaller rockslide event.

One outstanding characteristic of the famous Köfels site consists in the existence of frictionites ("pumice"), which so far have only been discovered at two locations worldwide, namely at the Köfels and the Langtang Himal (Nepal) rockslides. These fused rocks (Fig. 4c) have their origin in the friction heat, which developed on several shear planes during the rapid sliding movement. Another remarkable feature of the Köfels area are very high radon concentrations, which are emitted from the highly fractured and crushed rockslide deposits (Purtscheller et al., 1995).

The rockslide deposits are laterally and vertically characterized by a high variability in the degree of fragmentation and show different types of fabrics. Domains showing a fault-breccia texture composed of angular fragments within a finer-grained matrix of crushed material are located next to domains showing a high fracture density but without any fine-grained material. A diabase dyke, which embedded in its surrounding granitic-gneiss wall rocks was transported in the course of this rockslide, shows only a crushed and heavily fractured texture but no features of remarkable shear deformation along the intrusion contacts (Fig. 4d). This suggests that the sliding process was dominated by shearing along distinct high strain zones where the blocks lying in between were deformed through a dynamic shattering process. Thus these blocks and especially the topmost deposits show the typical, highly permeable openwork fabric, containing crushed rockslide clasts with a jig-saw-fit of corresponding grain boundaries.

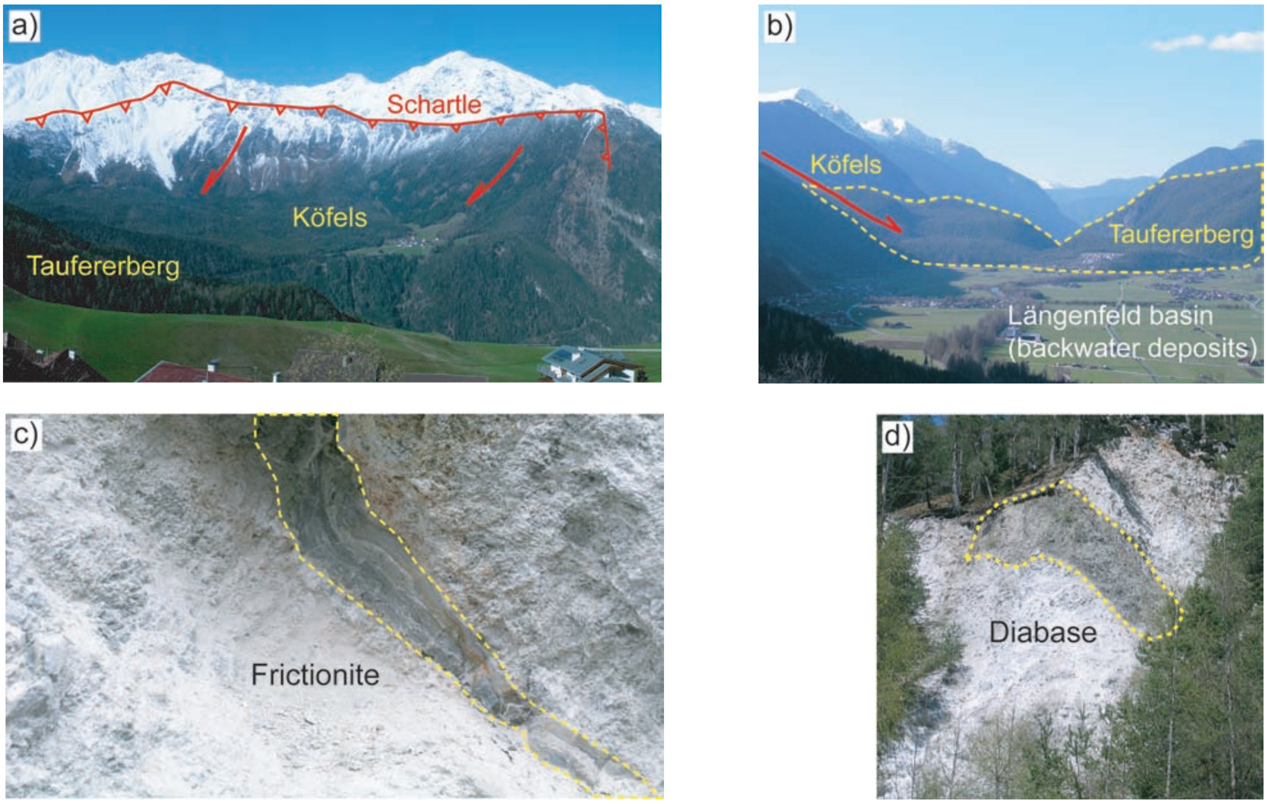

Fig. 4: Köfels rockslide a) Scarp area at the locations Köfels and Schartle; b) view towards North, showing several hundred metres thick rockslide deposits near Köfels and at Taufererberg and rockslide-dammed backwater deposits respectively; c) cm-thick frictionite lense in a fine-grained matrix of crushed granitic gneiss with fault-breccia texture; d) intensely crushed but slightly sheared diabase dyke within heavily fractured granitic gneisses.

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