# Rockfall occurence in the southern border of the Tauern Window - structural, lithological and geomorphologic aspects

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## Introduction

Many regions in the Alps are recurrently affected by rockfall processes which pose a significant hazard to settlements and infrastructures (Fig. 1). Decision makers in the Federal State Governments/Local authorities are strongly dependent on adequate data in order to delineate potentially endangered areas to plan detailed investigations so as to implement preventive measures.



Fig. 1: High frequency of rockfall events in the area of Moertschachberg endangering the Asten Road (Melzner et al. 2012).

## Geomophologic overview

The area is characterized by two main strike-slip fault systems, assigned to the dextral *Iseltal Fault* and to the sinistral *Zwischenbergen-Wöllatratten Fault* (Fig. 2) (Linner et al. 2009). These tectonically predisposed zones of weakness have been subject to glacial or glacio-fluvial/fluvial erosion processes. The valleys presently follow these main faults in NW-SE or WSW-ENE striking directions and very probably in the associated synthetic and antithetic directions, respectively.

Due to glacial erosion by the former Moell Glacier during the Last Glacial Maximum, the Moell Valley takes the form of a typically wide U-shaped alpine trough. The altitudinal difference is over 1,000 meters from the bottom of the main valley to the mountain peaks. The side valley occur at notable higher elevations, which promoted post-glacial fluvial erosion processes and thus the formation of steeply incised gorges. The terminal moraines of the Gschnitz (Moell Glacier) and Egesen (glaciers of the side valley) are still visible (pers. comm. J. Reitner, GBA, work in progress).

After the breakdown of the net of glacial streams and exposure of the glacially over-steepened relief, the development of deep-seated deformations probably started during the late glacial time. These complex mass movements are the most characteristic morphologic feature of the study area. The trough valleys have been modified and appear today as asymmetric valley forms (Melzner et al. 2012).

## Geologic and tectonic overview

The southern part of the central *Tauern Window* with the main tectonic units *Sub-Penninic* and *Penninic nappes* is overthrusted by *Austroalpine nappes* (Schmid et al. 2004, Pestal et al. 2009).

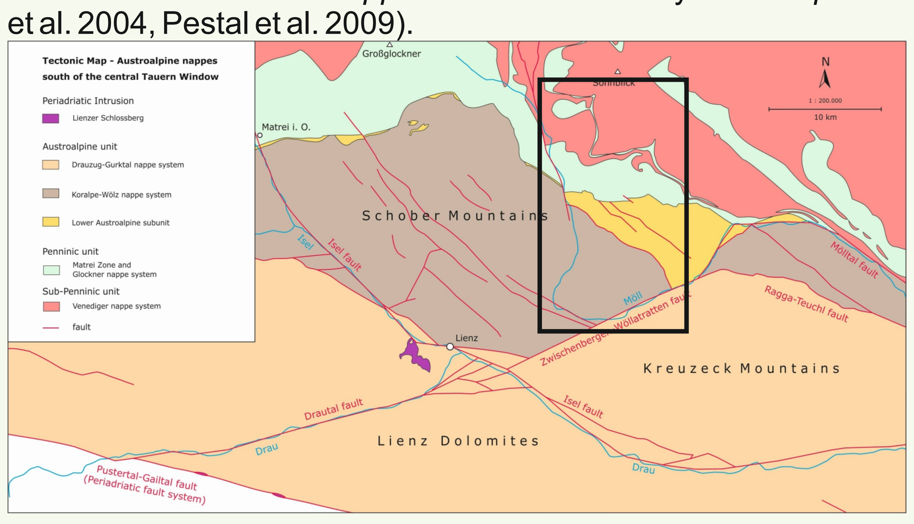


Fig.2: Tectonic Map-Austroalpine nappes south of the central Tauern Window (Linner et al. 2009). Black box indicates location of study area.

The Sub-Penninic and Penninic units dip steeply towards the southwest, whereas the Upper Austroalpine sub-unit dips gently to deeply towards southwest and, in part, to northeast (Fig. 3).

The lowest tectonic unit of the central Tauern Window incorporates the *Venediger nappe system* , which is found in the northern part of the study area (Fig. 2). Within the study area, the rocks of the *Zentralgneis Complex*, *Wustkogel Formation* and *Brennkogel Formation* are the most common lithologies of the **Sub- Penninic unit**.

The lower **Penninic unit** within the central Tauern Window is represented by the *Glockner nappe system* (Fig. 3 & 4) (Schmid et al. 2004). This nappe system comprises numerous lithologies of the Jurassic-Cretaceous *Bündnerschiefer Group*. However in the study area, the Glockner nappe system only comprises lithologies of Cretaceous age with ophiolite fragments.The upper Penninic unit incorporates the *Matrei Zone*. In contrast to the Glockner nappe system in the study area, the Matrei Zone contains Jurassic metasediments of the *Bündnerschiefer Group* with scarce metamagmatites. Rocks of Permian, Triassic, and early Cretaceous age are also quiet frequent.

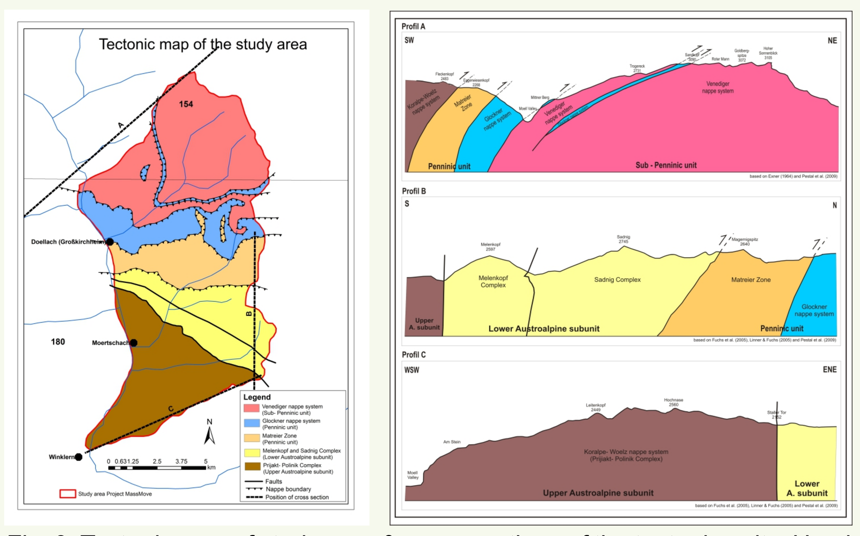


Fig. 3: Tectonic map of study area & cross sections of the tectonic units. Used nomenclature based on Pestal et al. 2009 (Melzner et al. 2012).

The southern half of the study area comprises the **Austroalpine unit**, which can be differentiated into a *Lower and Upper Austroalpine sub-unit* (Fig. 3).

The largest fragment of the *Lower Austroalpine sub unit* is composed by the *Melenkopf* and *Sadnig Complex* (covered by Permian to Triassic metasediments). The Prijakt nappe is part of the *Upper Austroalpine Koralpe-Wölz nappe system*.

The lithology of the Prijakt nappe is characterized by high-grade paragneiss and micaschist with layers of orthogneiss,amphibolite and eclogite (Fig. 4).

## Results

### Structural and lithological aspects

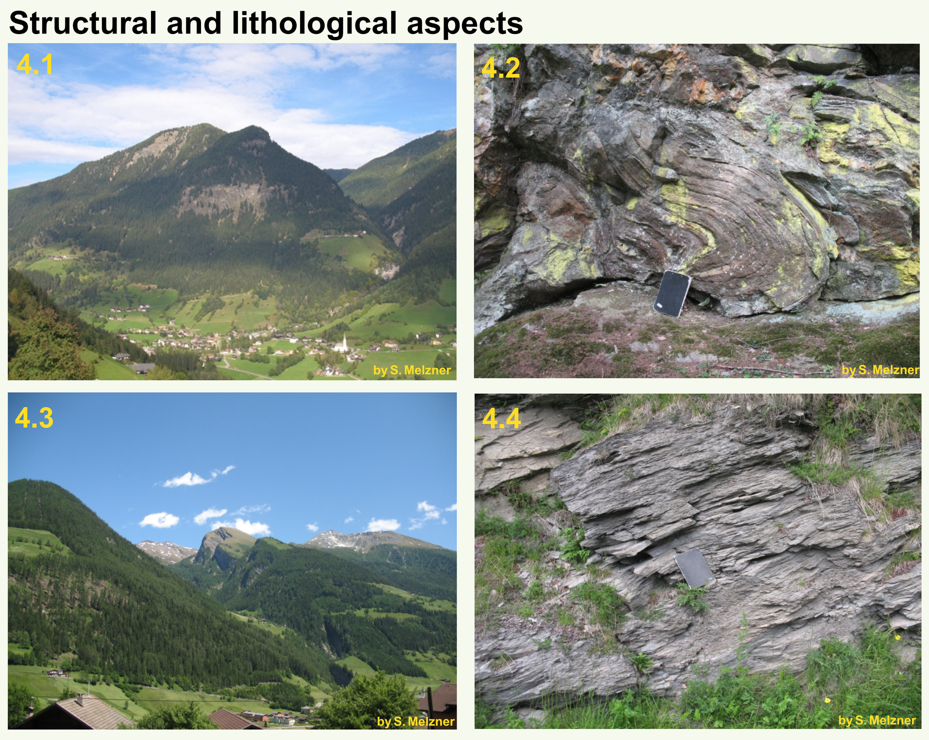


Fig.4: Tectonic and structural settings within the study area. Fig. 4.1 & 4.2 Upper Austroalpine sub-unit (Prijakt- Polinik complex); 4.3. & 4.4 Sub-Penninic and Penninic unit (Glockner nappe system & Matreier Zone) (Melzner et al. 2012).

### Upper Austroalpine sub-unit

Several ductile and brittle deformation phases during the Alpidic Orogenies have resulted in various fault systems that extert a major influence to the local anisotropy within the Prijakt-Polinik complex (Fig. 4):

- A considerable number of different discontinuity sets; each set is associated with a high degree of dispersion in its orientation (dip direction/dip angle) (Fig. 6).
- Significant faults are frequently associated with high degree of separation and wide spacing (Fig. 7).
- Deep tension structures that follow the main fault systems, which may cause large volume rockfalls (Fig. 9).
- Rapid lithological transitions and changes in the amount of fracturing (Fig. 5).

### Geotechnical properties of lithological units

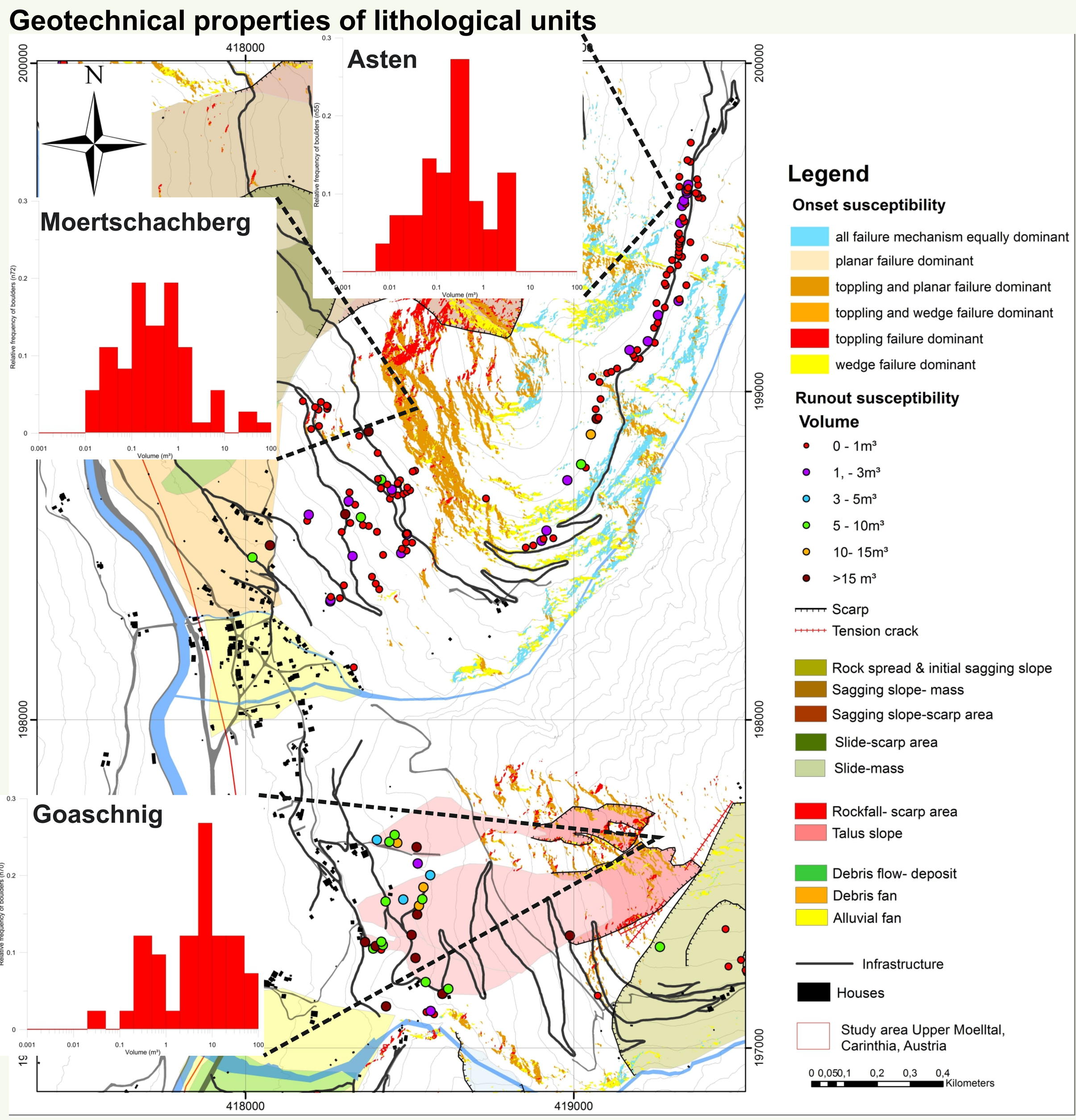


Fig. 5: Comparison of the rockfall boulder volumes in the areas of Goaschnigkopf, Moertschachberg and the Asten Road. Although these three areas are all located in the Prijakt-Polinik complex, there are significant differences in terms of their mapped boulder volumes due to factors such as higher number of faults (Asten), rapid changes and selective weathering (Moertschachberg) and deep tension structures (Goaschnigkopf)

### Failure mechanisms

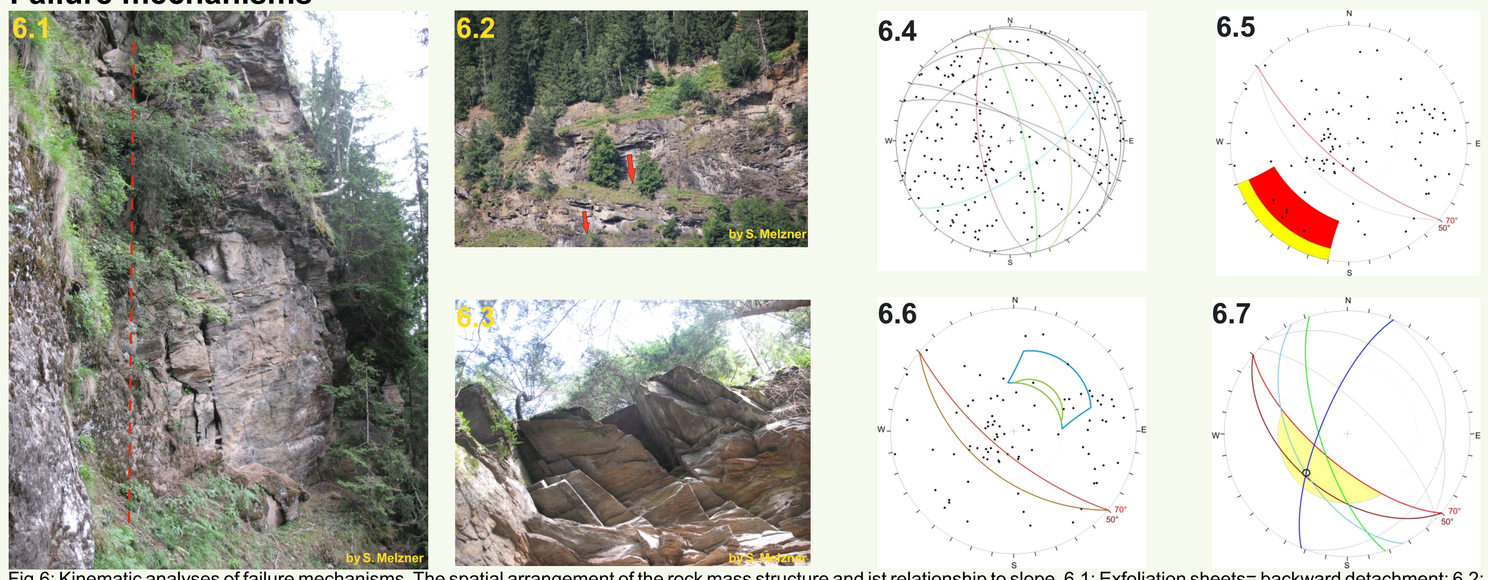


Fig.6: Kinematic analyses of failure mechanisms. The spatial arrangement of the rock mass structure and ist relationship to slope. 6.1: Exfoliation sheets= backward detachment; 6.2: Steeply dipping faults= sliding planes; 6.3: foliation= roof (upward detachment) of rock blocks; 6.4.=clusters of some of the frequently measured discontinuities in the field; 6.5=Failure mechnism „toppling"; 6.6= Failure mechanism „sliding along one plane"; 6.7= Failure mechanism „wedge failure on two intersecting discontinuties" (Melzner et al. 2012).

### Sub-Penninic and Penninic units:

The northern part of the study area is characterised by predominately southwesterly dipping Sub-Penninic and Penninic units. In the area of southwesterly dipping slopes (Fig. 4), the so-called dip slope situation results in the absence of distinct cliffs. Potential rockfall source areas that lie orthogonal to the strike direction of the lithological units, areas of significant tectonic structures, or areas of deep-seated slope deformations (Fig. 8-15).

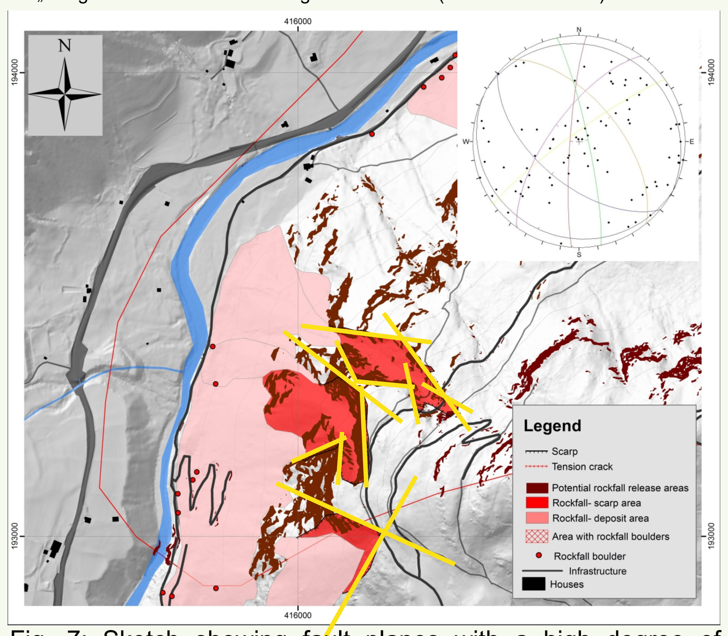


Fig. 7: Sketch showing fault planes with a high degree of separation (yellow lines) and pol plot of field mapping. These faults are the main cause of large volume rockfalls. Cliffs/scarps follow these tectonic structures, map scale 1:5.000 (Melzner, S. 2011).

### Deep-seated slope deformations

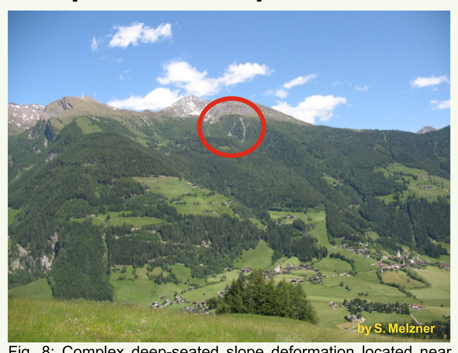


Fig. 8: Complex deep-seated slope deformation located near Moharspitz. Rockfalls occur within the scarp area (Melzner et al. 2012).

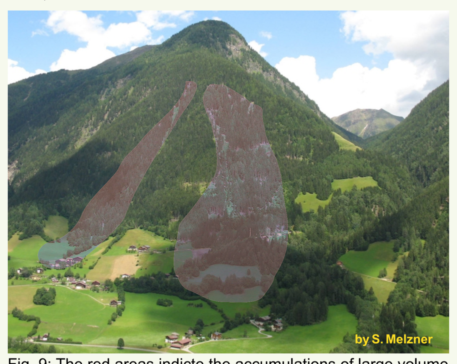


Fig. 9: The red areas indicte the accumulations of large volume rockfalls and rock avalanches (Melzner et al. 2012).

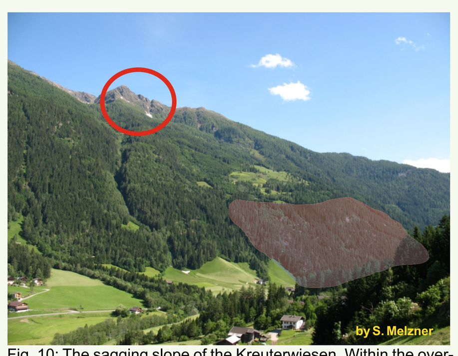


Fig. 10: The sagging slope of the Kreuterwiesen. Within the over-steepened toe (red area), displaced rock masses represent potential rockfall source areas that may result in large volume rockfalls (Melzner et al. 2012).

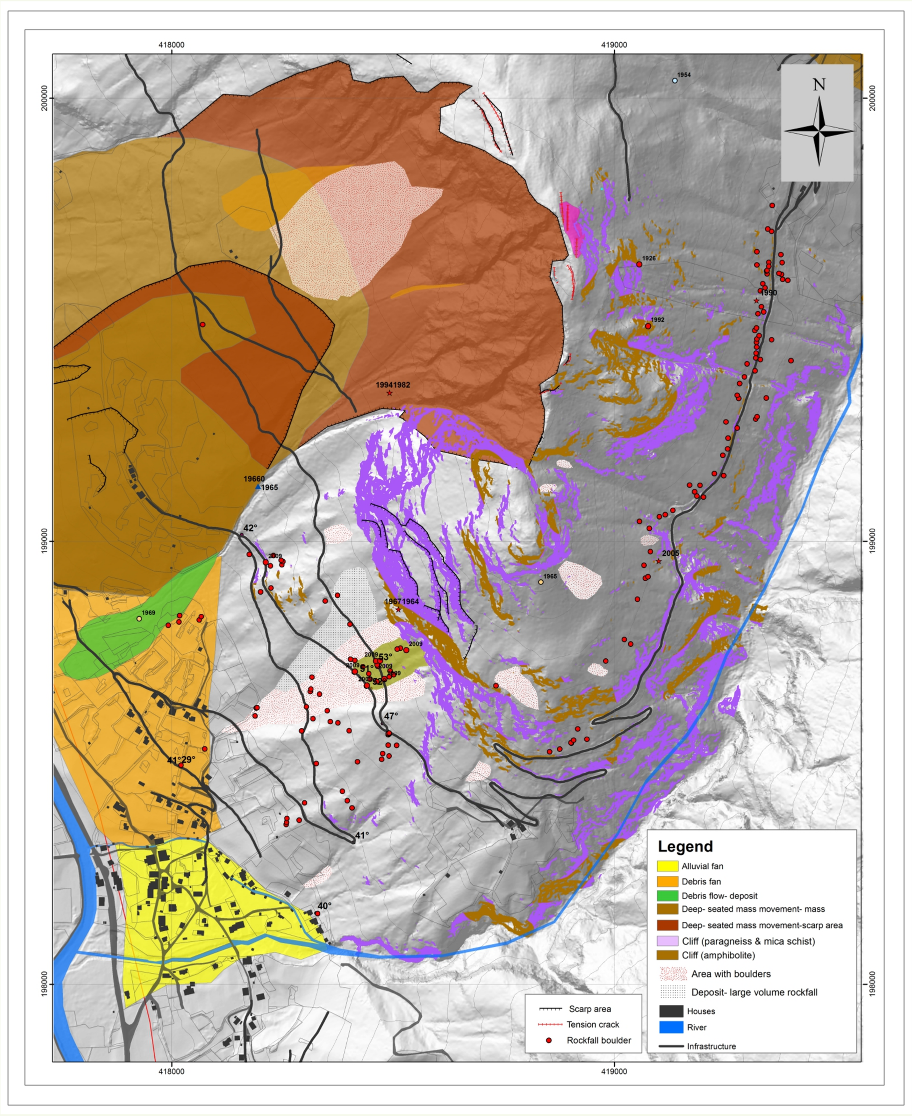


Fig. 11: Geotechnical map of gravitational mass movements in the Prijakt-Polinik complex, map scale 1:5.000 (Melzner, S. 2011).

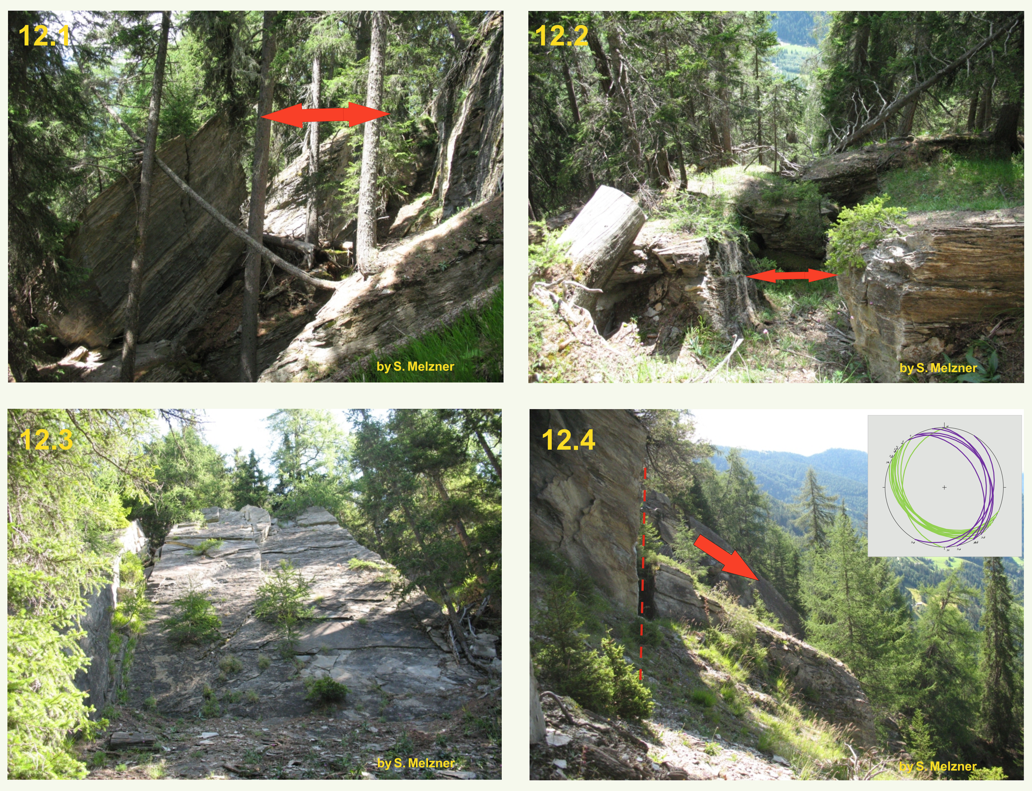


Fig. 12: Rockslide (initial stage) (Fig. 12.1) is characterised in its upper part by highly loosened zones and tension fissures (Fig.12.2) that strike slopeward. In the lower part it is characterised by overturning or folding of rock masses (Fig. 12.3) and releases of very large rock blocks at the front and along the sides (Fig. 12.4) (Melzner et al. 2012).

Figure 15 presents slope profiles of detailed investigation areas within the Austroalpine unit. In some places only a very short distance separates potential rockfall source areas from potential element at risk. In other areas with lower relief gradients, a far greater distance separates source area an potential element at risk. In case of the sagging slope of *Talzuschub Kreuterwiese* the oversteepened toe can be seen clearly.

Fig. 13: The dip slope situation in the southwesterly slopes in te Penninic units results in rockslides and sagging slopes (Melzner, S. et al. 2012).

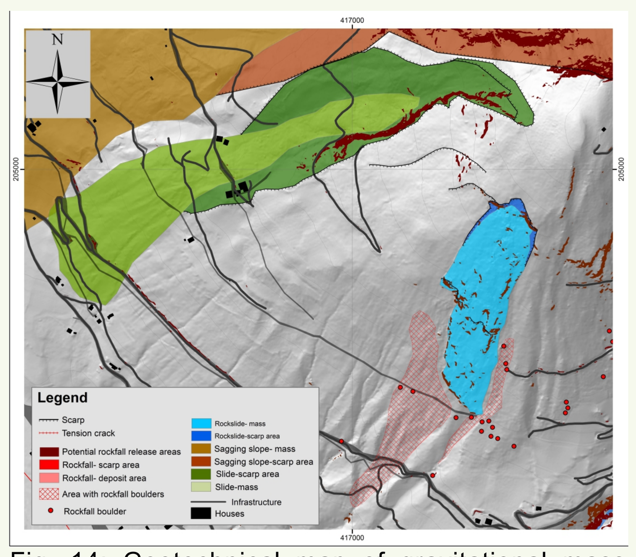


Fig. 14: Geotechnical map of gravitational mass movements in the Penninic unit (Glockner nappe system), 1:5.000 (Melzner, S. 2011).

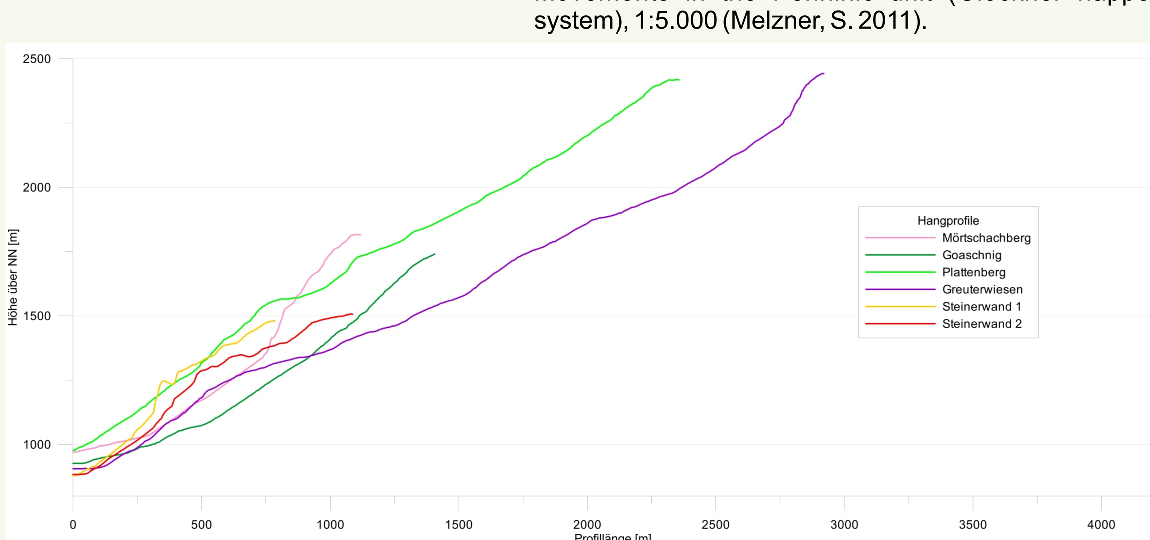


Fig. 15: Slope profiles in the Austroalpine unit (Melzner et al. 2012).


## Summary

The varying anisotropy affects the spatial distribution and extent of potential rockfall source areas within the study region (Melzner et al. 2012):

Due to the young landscape evolution an almost preserved, oversteepened glacial and postglacial relief can be recognized. Hence, nearly all of the lithological units form cliffs starting from 48 or 50 degree of slope inclination. However, more competent rock has greater proportions of steeper terrain than less competent rock.

Typically, steep cliffs occur within the Upper Austroalpine Prijakt-Polinik complex (Linner & Fuchs 2005). The lithological properties of this complex and the orientation of its mass structure (gently dipping from NW to NE) favour the development of significant rockfall source areas (Fig. 4). Field investigations demonstrated that these cliffs are generally very susceptible to rockfall due to the heterogeneous anisotropy of this lithological unit (Fig. 1). The heterogeneous anisotropy results in a range of failure mechanisms (Fig. 6) as well as considerable diversity in block size and shape (Fig. 5):

- Small-scaled transitions between competent and less competent rock together with the ongoing process of detachment along a few widely spaced discontinuties sets are likely to cause selctive weathering and subsequent susceptibility to comparatively large volume rockfalls.
- The number of faults increase from the Prijakt-Polinik complex towards the Melenkopf complex. This results in rockfall source areas that are very small but highly fractured and loosened.
- Some cliffs have been constructed from a sequence of scarps generated by several large volume rockfall events (Fig. 7 & 9). It is striking that the scarps follow the same orientation as some of the dominant fault planes, which occur with a high degree of seperation.

Several rockfall areas are associated with deep-seated slope deformations. These mass movement types shape the landscape in the Tauern Window and have their origin (in regard to mechanism, location etc.) in the varying anisotropy of rock. Depending on the mass movement type and ist stage of development rockfall either occurs within the scarp area, along/within the body or along the oversteepened front parts of the slope deformations (Fig. 8-15).

Due to the glacial and postglacial landscape evolution, many slopes are covered by moraine deposits or scree. The (re-)mobilization of boulders caused by erosion processes, mass movements or wind throw, are common processes. Such secondary rockfalls can be triggered nearly everywhere throughout the whole study area.


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