How much does a very active rock slope contribute to the sediment budget of an alpine glacier?

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Introduction

The ongoing glacier retreat since the mid of the 19th century has significant influence on rock slope stability in alpine high mountain areas. Due to oversteepening by glacial erosion, cold climate weathering processes and debuttressing as a consequence of stress redistribution, rock slopes adjacent to shrinking glaciers generally show an enhanced geotechnical activity. Regarding the glacier sediment budget, the rockfall material deposited on a glacier is particular important, because the debris material can be transported directly and without any intermediate storage. Therefore, gravitational mass movements contribute in a substantial way to the sediment budget of a glacier, especially as rockfall material can easily reach en- or subglacial areas through crevasses and thus affect the subglacial sediment transport and glacial erosion.

Here we present the first results regarding the geotechnical rock slope activity of "Schwarze Wand". The "Schwarze Wand" is located at 2400 - 2800 m.a.s.l., right above the tongue of the Gepatschferner, which is one of the largest glaciers in Tyrol (Austria) and contemporarily affected by a high retreat rate. The rock mass consists of strong foliated paragneisses which are dissected by large joint sets. These joint sets provide sliding planes, which favor slope failures. To monitor the rock slope activity at the "Schwarze Wand", multitemporal terrestrial laser scans were carried out in 2012 and 2013 to detect and quantify mass movements. Additional, high resoluted multitemporal airborne laser scan data (10 points/m²) are available to trace larger scale rock slope deformations. The investigations are conducted by the DFG- joint research project PROSA (High-resolution measurements of morphodynamics in rapidly changing PROglacial Systems of the Alps).

Our LiDAR data, as well as field observations, show an enhanced rock fall activity at the scarp in the last years which is assumed to be the consequence of an activation of a larger deep-seated gravitational slope deformation towards the glacier which comprises at least several 100 000. m³.

Study Area

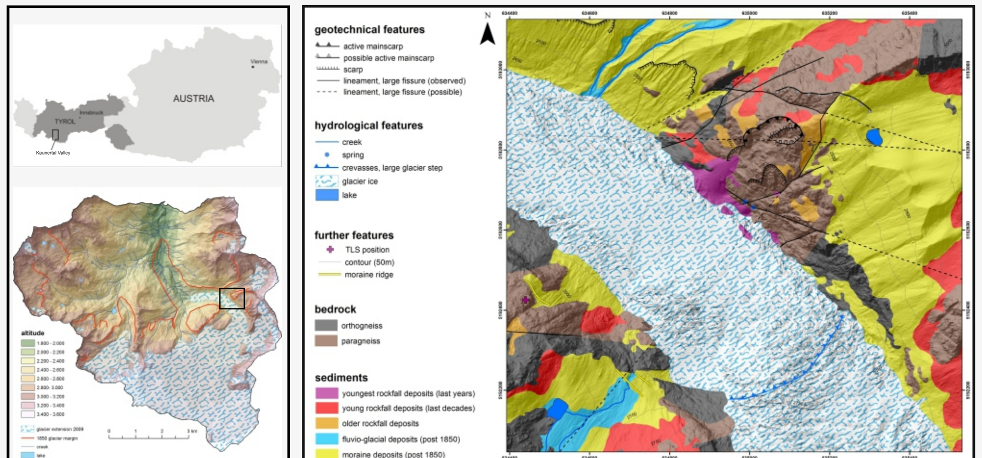

Fig. 1 Location of the study area in the Ötztaler Alps/Tyrol, The black box marks the study site "Schwarze Wand"**(A)**, geotechnical map of the study site "Schwarze Wand" and its surrounding; shaded relief from 10 m DEM **(B)**, (data source: www. tirol.gv.at, http://de.wikipedia.org/wiki/Datei:Datei:Austria map modern.png, http://alt.tirol-travel.com/img/karten/karte-von-tirol-nur-schweiz.png).

The picture was taken in N-E-direction. The Scree slope extends over 90 meters of altitude from the apex to the base. Its contact line to the glacier measures 200 m. The enhanced rockfall activity started after 2010 and could be a consequence of the (re)activation of the large rockslide. The right picture (oblique view) illustrates a possible sliding plane (yellow arrows). However, the location of the sliding plane remains unclear. As the mountain ridge above the rockfall scar is highly dissected, a sliding plane could also be located deeper in the rock slope. This would increase the instable rock mass volume. The large fissure behind the scar (red arrow) may originate from former sagging activity.

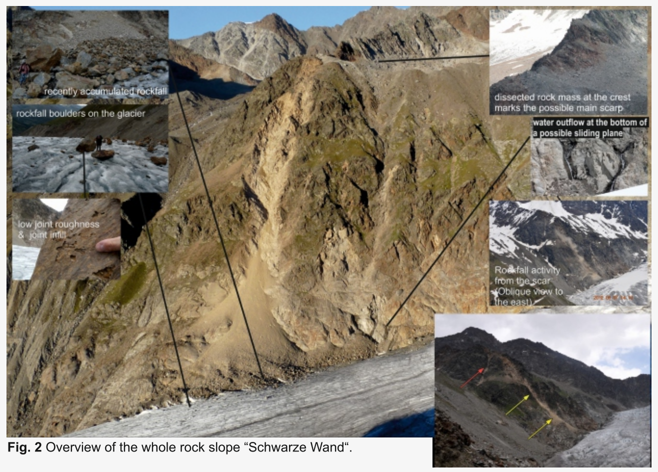

Fig. 2 Overview of the whole rock slope "Schwarze Wand".

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Workflow

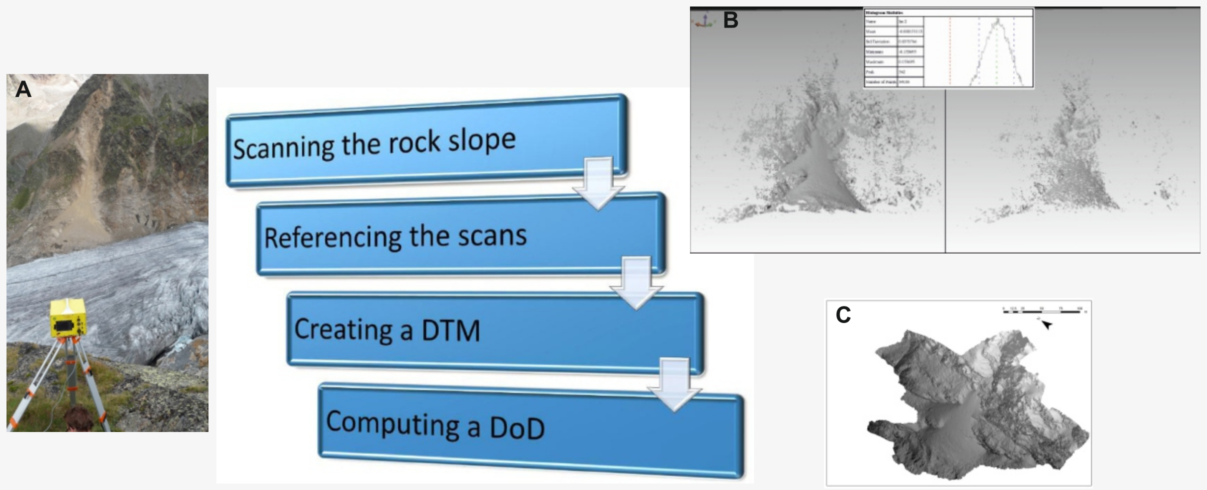

Fig. 3 Schematic Workflow for the determination of the sediment balance, **(A)** Scanning the rock wall using the terrestrial laser scanner ILRIS-3$_6$D, **(B)** Postprocessing and referencing of the scanner data using Polyworks software, **(C)** Creating a Digital Terrain Model (DTM) using ArcMap.

Slope Displacement

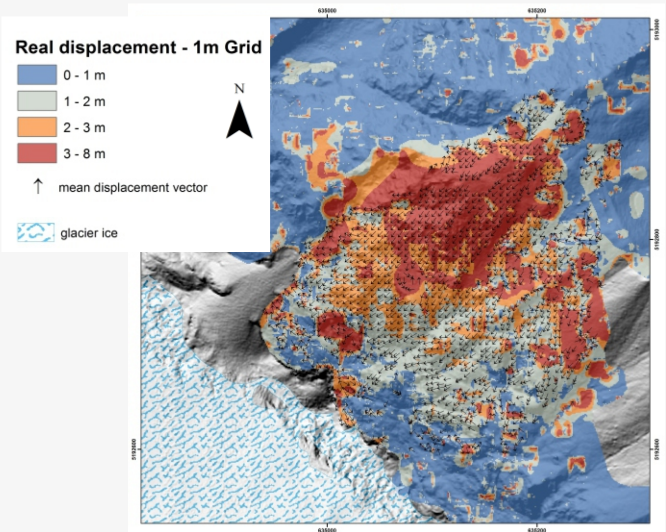

Fig. 4 Map of the rock slope displacement between 2006 and 2012.

The displacement of the large-scale rock slope deformation is assessed by the automatic comparison of two airborne LiDAR datasets (SAGA-GIS tool 'feature tracking' (Scambos et al. 1992)). The procedure is carried out on two congruent DEMs (2006 & 2012) with one meter cell size and is based on more than 100000 correlation points.

The large red area in the center is the most active part of the slope deformation with a displacement velocity of more than 3 meters in 6 years. Grey areas are missing correlation points, as they are talus slopes or moraine deposits, which are subject to discrete erosional processes which displace small isolated particles. These processes cannot be detected by ‚feature tracking'. Blue areas are considered as stable as they are lying close to the level of detection. Small isolated reddish areas result from biased points due to unfavorable slope geometry, i.e. sub-vertical slope steps, or the isolated movement of larger boulders.

Conclusion & Outlook

This study focusses on the sediment budget of a very active rock slope. During the investigation period in 2012 and 2013 the rock slope "Schwarze Wand" was surveyed three times, using a terrestrial laser scanner (ILRIS-36D, Optech Inc.).

Between Aug ´12 and Sep ´12 there is a net erosion of 557 m³. The comparison of the two latest data sets, Sep ´12 and Aug ´13, shows a net accumulation of 17489.3 m³. Within one year, about 35066 m³ of sediment were accumulated on the tongue of the glacier Gepatschferner. Based on experience in the field, we assume that the rockfall activity in 2012 was higher than in 2013. Our data confirm this assumption.

There is a striking discrepancy between erosion and accumulation (especially between Sep `12 and Aug ´13). Several explanations are assumed to be plausible.

1. The laser scanner does not capture the whole rock slope → the upper part, which is the most active area (see Fig. 4) was not recorded.
2. Due to shading effects of rock outcrops there is no data of the the area behind the outcrop.
3. We have to consider the bulk density of the material.
4. Glacier melting leads to mass loss at the base of the talus cone.

We can show that the rock slope "Schwarze Wand" contributes considerably to the sediment budget of the Gepatschferner. Further surveys of the rock wall will be carried out in the future. For this reason, it is important to be aware of the notes mentioned above. To avoid shading effects, the rock slope should be recorded from several positions far apart from each other.

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DoD

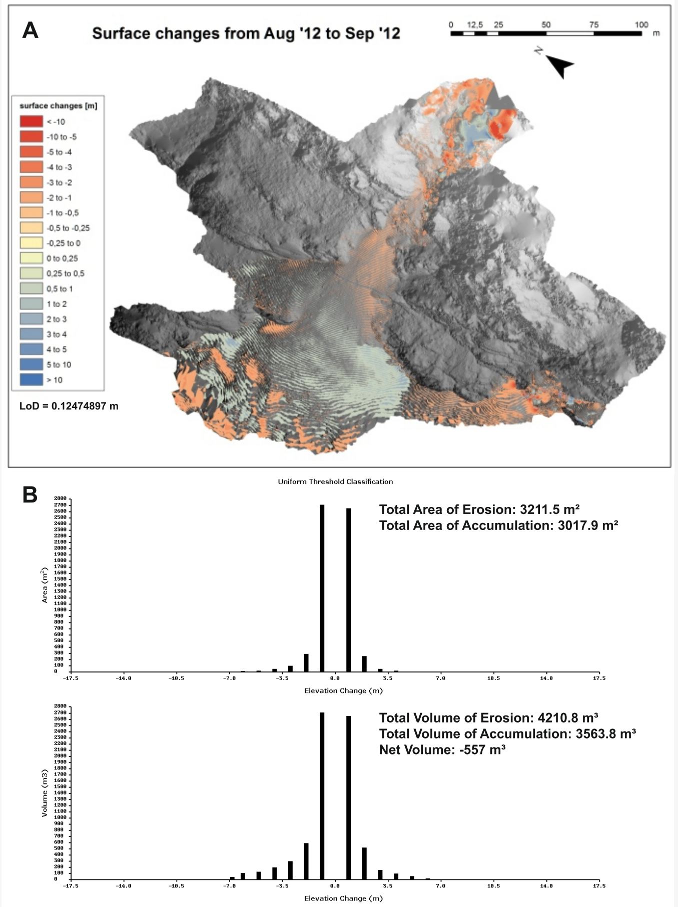

Fig. 5 DEM of Difference (DoD) for the period between Aug ´12 and Sep ´12 **(A)**, Histogram of the elevation changes with respect to the area/volume. Additionally, the sediment budget is shown **(B)**.

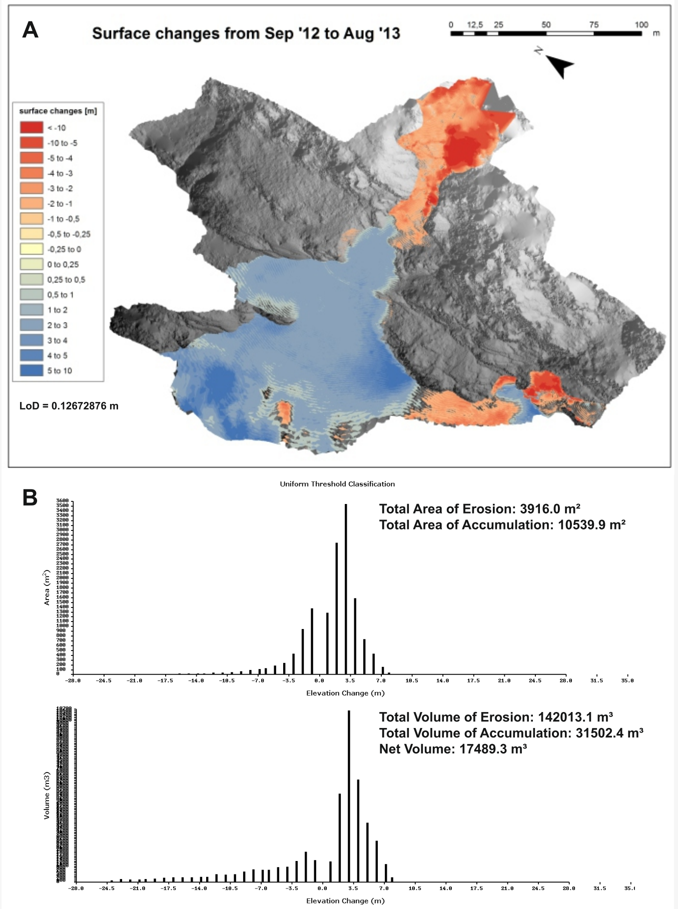

Fig. 6 DEM of Difference (DoD) for the period between Sep ´12 and Aug ´13 **(A)**, Histogram of the elevation changes with respect to the area/volume. Additionally, the sediment budget is shown **(B)**.

Reference: Scambos, T. A., Dutkiewicz, M. J., Wilson, J. C., & R. A. Bindschadler (1992): Application of image cross-correlation to the measurement of glacier velocity using satellite image data. Remote Sensing Environ. 42(3): 177-186.