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How fractographic analyses uncover complex trends of modern and palaeo principal stresses

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Mode-I fracture surfaces can contain unique information about the fracture formation processes and the spatio-temporal state of stress in the form of fractographic markings. A special case of mode-I fractures are exfoliation (sheeting) joints. These joints are restricted to the uppermost 200 m below ground and occur as fracture sets subparallel to current and palaeo bedrock surfaces [1]. In the upper Aar region of southcentral Switzerland exfoliation joints were formed during distinct periods of the Pleistocene in crystalline rocks. At the slopes of inner U-shaped valleys moderately to steeply dipping (30–60°) exfoliation joint surfaces are exposed due to rock falls and rock slides and accessible for remote sensing. In a preceding study [2] we have measured on these exfoliation fractures the trends and plunges of so-called plumose (or plume) axes, which formed parallel to the maximum compressive principal stress (σ_1) (Figure 1A). This dataset describes the palaeo (Middle Pleistocene to Holocene) principal stress orientations within shallow bedrock at nearly 400 locations and in different geomorphological settings.

In order to confirm the inferred palaeo stress pattern, which suggests that near-surface stresses change their orientation systematically with respect to local topography, we analysed near-surface (<100 m below palaeo ground) stress tensors utilizing perfectly linear-elastic finite difference numerical modelling. Our basic models incorporate the current and assumed palaeo topography of the upper Aar valley and enabled us to test the effects of gravitational and contractional far-field isotropic and anisotropic strains on the trends of near-surface maximum principal stresses. Model calibration was carried out utilizing *in-situ* stress data and fracture-mechanical considerations.

Our numerical modelling results show principal stress trends that are similar to stress trends inferred from fractographic investigations (Figure 1B). We suggest to systematically record exfoliation joint fractographic data in engineering and research projects because these present a remarkable opportunity to increase our knowledge of palaeo and modern stress conditions in the uppermost few hundred meters where most engineering and mining projects are located. Acquiring such data is cost-efficient and the data represent geologically recent stresses of larger rock volumes compared to classical stress measurements in boreholes.

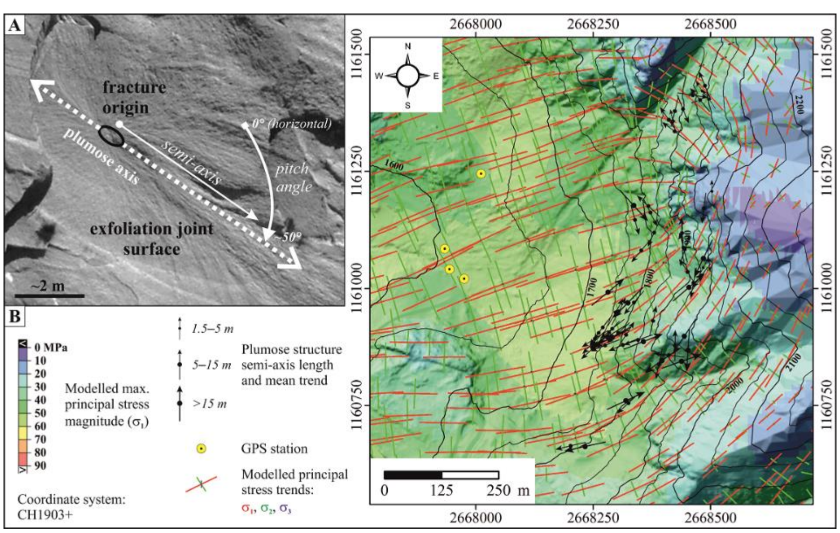

Figure 1: A) Example of an exfoliation joint plumose structure [1,2]. Dotted arrows mark the plume axis and major fracture propagation direction. The axis formed parallel to the

maximum compressive principal palaeo stress (σ_1). B) Comparison of fracture plume axes (black) and modelled σ_1 trends (red) within the U-shaped valley.

References:

[1] Ziegler M et al. (2013) Geomorphology 201: 344-362

[2] Ziegler M et al. (2014) Tectonophysics 626: 1-20