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Formation of active composite faults in the Swiss Alps: the complex interplay of tectonics, gravitation and postglacial unloading

M. Ustaszewski (1), **A. Hampel** (2), A. Pfiffner (1)

(1) Institute of Geological Sciences, University of Bern, Baltzerstr. 1-3, 3012 Bern, Switzerland, (2) Institut für Geologie, Mineralogie und Geophysik, Ruhr-Universität Bochum, Universitätstr. 150, 44801 Bochum, Germany

(Andrea.Hampel@rub.de)

Active faults in the central Swiss Alps are describe by several authors (Eckhard et al. 1983, Renner 1982). These faults cluster along the valley flanks of the Upper Rhine, the Urseren, the Upper Rhone, and the Bredretto valley. These areas were therefore chosen for an investigation of postglacially active lineaments. Our study revealed a more complex and composite origin of these lineaments than originally thought. We therefore propose the term "composite fault" for these features. Composite faults have a tectonic origin, but subsequent gravitational movements exceed the tectonic displacement by far. They are characterized by a strong morphologic expression, uphill facing fault scarps, displacements on the fault scarps varying from 50 cm to more than 10 m, important displacement variations along strike, the parallelism of the lineaments and the regional trend of the Alpine schistosity, and a postglacial age derived from their intersection with moraine ridges and debris screes. Displacements on composite faults may be caused by gravitational movements, recent crustal tectonics, and postglacial unloading effects. To test if postglacial unloading may be responsible for the uphill-facing scarps observed in the studied valleys, we constructed a finite-element model of a rheologically layered lithosphere. In its center the topography of the Urseren valley and seven vertical fault planes are included. Slip on these fault planes is controlled by a Mohr-Coulomb criterion. After reaching an initial isostatic equilibrium, the model sides are fixed in the horizontal and vertical directions and a pressure representing the ice is applied. In different experiments, the load is then removed

within 1 ka, to 10 ka, respectively. The model results show that slip on the faults is initiated as soon as the unloading begins. The scarps that form on the model surface are uphill-facing scarps on both sides of the valley. Maximum scarp heights of 2.5 m and 1.1 m are attained on the northermost and southernmost fault planes, respectively; the other scarps are between 0.5-0.8 m high. All scarps reach their final height within the last few hundred years after unloading. The deglaciation rate plays only a minor role on the final scarp height. Our models show that deglaciation of the Alps after the LGM is able to cause differential uplift between the valley flanks and the thalweg, provided the valley is incised into rock units with steeply dipping foliation. Weaker mechanical properties in the core of the valley additionally favour the formation of the scarps. In contrast, valleys incised in more homogeneous rock units and/or rocks with shallow dipping foliation may show large-scale gravitational movements (e.g. Prättigau, Rhone Valley downstream of Leuk) but consistently lack uphill facing scarps. From our observation and modelling results we conclude that active composite faults in the Swiss Alps from in response to glacially induced differential combined with large-scale gravitational movements. Crustal tectonics may play an additional role at various stages.