

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

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Several authors (Eckhard et al. 1983, Jaeckli 1965, Renner 1982) describe active faults in the central Swiss Alps. These faults cluster between 1900 m.a.s.l. and 2300 m.a.s.l. altitude along the valley flanks of the Upper Rhine valley, the Urseren valley, the Upper Rhone valley, and along 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/lineament” for these features.

Composite faults have a tectonic origin, but subsequent gravitational movements exceed the tectonic displacement by far. Composite lineaments are characterized by a) a strong morphologic expression, b) uphill facing fault scarps (Figure 1), c) displacements on the fault scarps varying from 50 cm to more than 10 m, d) very important displacement variations along strike (e.g. from 0.5 to 10 meters within 100 m), e) the parallelism of the lineaments and the regional trend of the Alpine schistosity, and f) a postglacial age which is derived from their intersection with moraine ridges and debris screes (Figure 1).

Displacements on composite faults may be caused by three different mechanisms: gravitational movements, recent crustal tectonics, and postglacial unloading effects. Large-scale gravitational movements (Deep Seated Gravitational Slope Deformations) use a preexisting discontinuity in the rock (like a tectonic fault or schistosity surfaces) as a gliding plane or decoupling horizon. In the valleys mentioned above, such discontinuities exist and make gravitational movements feasible. In contrast, these valleys lack a pronounced seismicity (e.g. Deichmann 2004) and surface uplift maxima are located to the east and west of them (Kahle et al. 1997). Nevertheless, a component of recent tectonics on the displacement can not be ruled out completely. In order to test if postglacial unloading may be responsible for the uphill-facing scarps observed in the studied valleys, we constructed a finite-element model representing a 1500-km-long and 100-km-thick lithosphere. The model lithosphere is divided into a 20-km-thick elastic upper crust, a 20-km-thick viscoelastic lower crust and a 60-km-thick viscoelastic lithospheric mantle. Based on a simplified topographic profile, the topography of the Urseren valley is included in the centre of the model. Seven vertical fault planes are incorporated into the model. Slip on the fault planes is controlled by a Mohr-Coulomb criterion. At the beginning of each experiment, the model attains isostatic equilibrium. Afterwards, the model sides are fixed in the horizontal and vertical directions and a pressure load representing the ice is applied. In case of the Urseren valley, the ice thickness during the Last Glacial Maximum is derived from the inferred location of the top of the ice at 2600 m.a.s.l. (Florineth & Schlüchter 1998, Jäckli 1965). For the regions

north and south of the Urseren valley, we vary the ice thickness between 400 m and 1000 m. The load is then removed within 1 ka, 2 ka, 5 ka and 10 ka, respectively, to investigate if the rate of deglaciation affects the formation of scarps.

The model results show that slip on the fault planes is initiated as soon as the removal of the load 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 northernmost and southernmost fault planes at 2175 and 2300 m.a.s.l. altitude, respectively. Scarps at lower altitudes are between 0.5-0.8 m high. All scarps reach their final height within the last few hundred years of the unloading phase. The rate of deglaciation plays only a minor role on the final scarp height. The differences between the experiments are in the range of a few centimetres only.

These 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 (lower Young's modulus) additionally favour the formation of the scarps. 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, Rhine Valley downstream of Ilanz, Val d'Hérens,...) but consistently lack uphill facing scarps. Differential uplift together with large-scale gravitational movements and presumably also crustal tectonics, lead to the formation of active composite faults in the Swiss Alps.

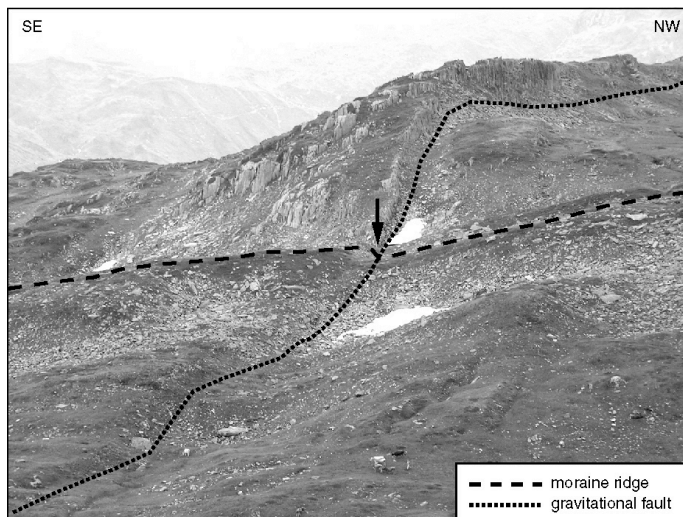


Figure 1: Uphill facing scarp of a composite fault (dotted line) cutting through a moraine ridge (stippled line) in the Bedretto valley. Arrow indicates intersection between the fault and the moraine. The latter is vertically displaced by 1.5 meters.

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