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Unravelling detailed kinematics of DSGSD morphostructures (Moosfluh, Swiss Alps)

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The Great Aletsch Glacier (Swiss Alps) is experiencing a remarkable retreat with rates in the order of 50 meters every year. In the current glacier tongue area, where several pre-existing landslides have been partially or completely unloaded from the glacier ice mass during the last 150 years, various types of landslide reactions (in terms of type, size and velocity) can be reconstructed and observed. In particular, a deep-seated gravitational slope instability located in the area called "Moosfluh" has shown during the past 20 years evidences of slow but progressive increase of surface displacement. The moving mass of the Moosfluh DSGSD affects an area of about 2 km2 and entails a volume estimated in the order of 150-200 Mm3. This DSGSD in gneissic rocks affects the entire slope and extents several 100 meters beyond the ridge separating the Aletsch from the Rhone valley. The slope morphology is complex and many ridges and depressions striking parallel to the slope have been observed and mapped in the past. Some of these ridges correspond to glacial trim lines, and could be dated as Egesen and Little Ice Age glacial re-advance stages. Other slope parallel structures were explained as up- and down-hill facing scarps, i.e. internal rupture planes, and most uphill facing scarps oriented parallel to the Alpine foliation were interpreted as toppling phenomena. However, most these structural and kinematic interpretations remained hypotheses, as all morphostructures were covered by soil and vegetation and no borehole displacement data were available, excluding direct verification of morphostructural interpretations. This is in fact a typical situation for many Alpine DSGSD, where observed phenomena developed slowly over long periods of time and can have many different structural and kinematic origins.

In late summer 2016, an unusual acceleration of the Moosfluh DSGSD was observed in the central part of the landslide. Compared to previous years, when annual ground deformations were in the order of few centimeters or decimeters, in the period September-October 2016 maximum velocities have reached locally 1 m/day. Between middle of September and middle of October, when displacement rates decelerated again, some sectors of the slope were displaced by up to 50 meters. During this period we monitored the evolution of the Moosfluh instability with two robotized total stations, several permanent GNSS stations and time-lapse cameras. Detailed mapping on ground surface and with helicopter based photogrammetry allowed to study internal deformation phenomena in detail, and to explore and unravel the displacement characteristics of all observed morphostructural features.

We can show that slope parallel ridges and depressions have various structural origins. New uphill facing scarps in bedrock or soil cover, which formed between September and October 2016, are caused either by toppling with block rotations of up to 17 degrees, throws of several meters and slope parallel extensions of several tens of meters, or by antithetic normal faults. Many antithetic faults show slumping of the hanging wall block, are listric in shape and belong to asymmetric graben structures. Lateral transition from the central rapidly moving sectors into less deformed landslide mass is accommodated along steeply dipping transform faults or en-echelon sets of tensile fractures. Displacements along most of these features were quantified in terms of slip vectors (throw and heave), horizontal extension or rotation. Comparison with surface displacement vector fields derived from total station measurements and digital image correlation allows to assess and explain local variations in strain fields and to develop a semi-quantitative kinematic model of the entire DSGSD including its structures at depth.