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MANNEN-BØRA: LARGE GRAVITATIONAL ROCK-SLOPE DEFORMATION IN ROMSDALEN (WESTERN NORWAY)

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Romsdalen is a typical heavily over-deepened U-shaped glacial valley that characterises the extreme alpine relief of Western Norway (Norway, northern Europe; Figure 1). Romsdalen is characterised by the highest density of past rock slope failures and four large gravitational rock-slope instabilities on the southern slope of the 30 km long valley threaten the community and are currently under study (Figure 1). They developed in intensively tectonized high-grade metamorphic rocks and mostly Precambrian gneisses. A first detailed structural mapping carried out in 2006 at each of the sites allowed us to assess the feasibility of failure as well as to determine the type of slope deformation (Henderson and Saintot, 2007).

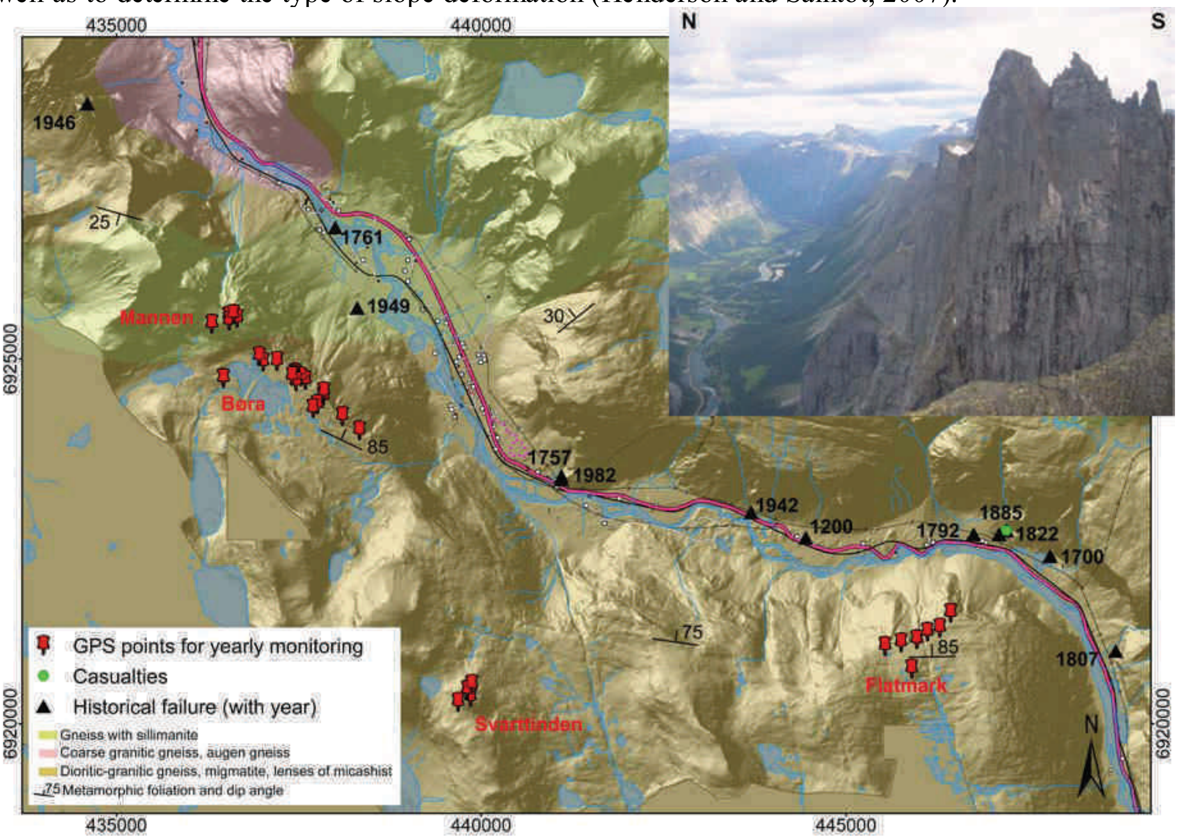

Figure 1. Geological map of Romsdalen on a 5 m resolution Digital Elevation Model and photograph to show the typical shape of the over-deepened glacial valley. Romsdalen is characterised by the highest density of past rock slope failures and by four current large gravitational rock-slope instabilities: Flatmark, Svarttinden, Børa and Mannen.

Svarttinden (Figure 2) is a translational rockslide of 7 Mm^3 with a basal plane that developed along an old foliation-parallel brecciated fault zone. A previous failure occurred to the east along the same basal plane. A vertical epidote-rich fault forms the border between the failed slope and the current instability. Because of the occurrence of well-developed basal sliding plane and of a previous failure along the same plane, the site is monitored by yearly GPS monitoring from 2006. No displacement is however detected until now.

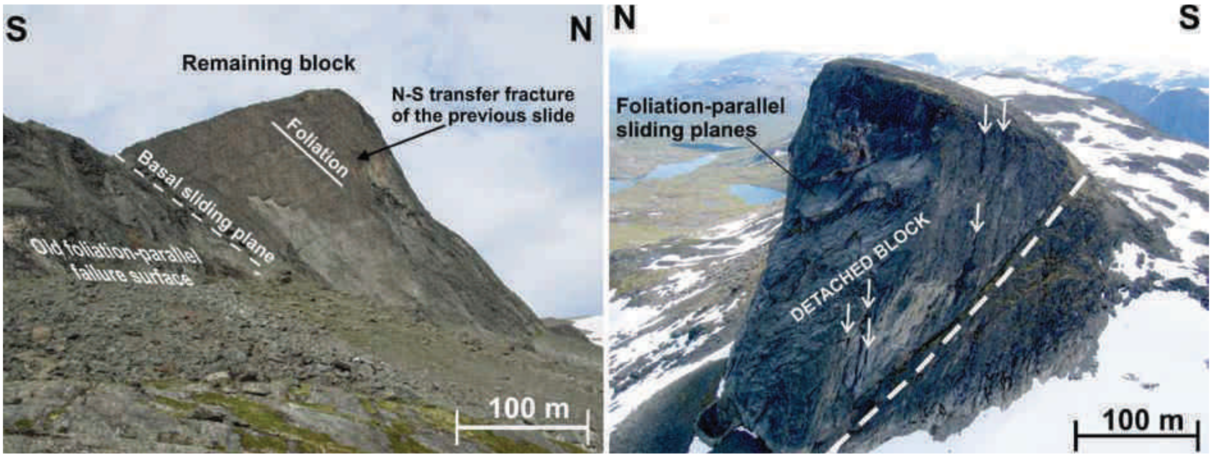

Figure 2. Svarttinden, a large translational rock-slide.

Flatmark, Børa and Mannen (Figure 1) show the same prevailing structural development at the edge of plateaus. Large dislocated blocks with volume from 2 to 25 Mm^3 detach from the steep cliff along the sub-vertical and slope-parallel opened metamorphic foliation (Figure 3). The intense dislocation of the detached blocks would correspond to a collapse above a basal valley-dipping plane (Figure 3). Systematic terrestrial Lidar scans of the collapsed blocks were carried out at Flatmark, Børa and Mannen in order to obtain a 3D model of the blocks and to better visualize the structures. Repetitive terrestrial Lidar scans is also planned in the aim to detect displacements. At Flatmark, few gravitational structures are observed inward the plateau at the back of three large lose blocks whereas, at Børa and Mannen, meter- to decametre-wide open cracks clearly developed away from the cliff inward the plateau. The lose blocks are monitored for several years by GPS yearly measurements and no movement are detected at Flatmark whereas displacements at the rate of 0,5 to1,5 cm/yr are recorded on 3 lose blocks at Børa and of 4 cm/yr on a large collapsing block at Mannen. It ensues from these two observations that there is a link between the occurrence of widespread gravitational deformation affecting the plateau far from its edge and the detected high rates of movements of blocks at the edge i.e. larger is the amount of gravitational deformation, larger is the activity along the slope. Further investigations were therefore required to better understand the deformation at the active side of the slope.

At Børa, on the plateau, a palaeoglacial valley trends parallel to the cliff and to the foliation (Figure 4). The ice-river is assumed to have partly contributed to the destabilization of the sub-glacial bedrock (at the back of the present-day cliff) by a partial opening of the foliation. The final destabilization at the edge of the plateau and the collapse of blocks was coeval with debuttressing subsequent to ice retreat in the Romsdalen valley. Electric resistivity profile on the plateau pictures highly drained rocks, i.e. the dislocated mass, versus water-saturated bedrock. The drained rocks at Børa are a surficial layer of about 5 m thick. However, the large opened cracks observed in the plateau (Figure 4) can be followed at more than 20 m depth.

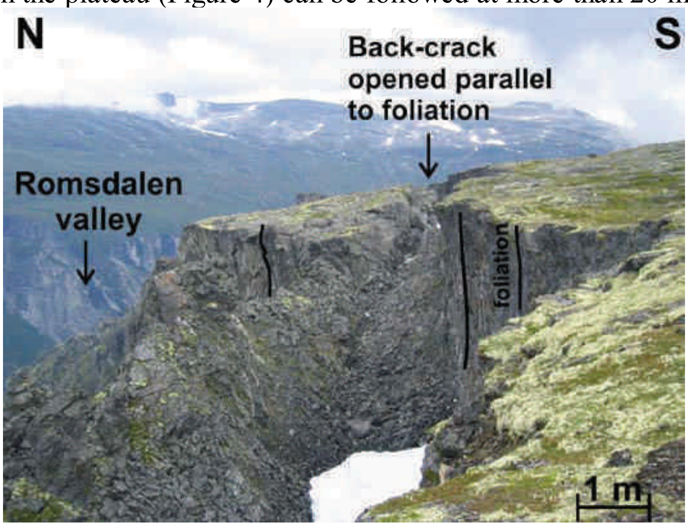

Figure 3. Left: Flatmark: lose block at the edge of the plateau. The main mechanism to detach the block is expected to be sliding on a basal valley-dipping plane and opening along the sub-vertical foliation

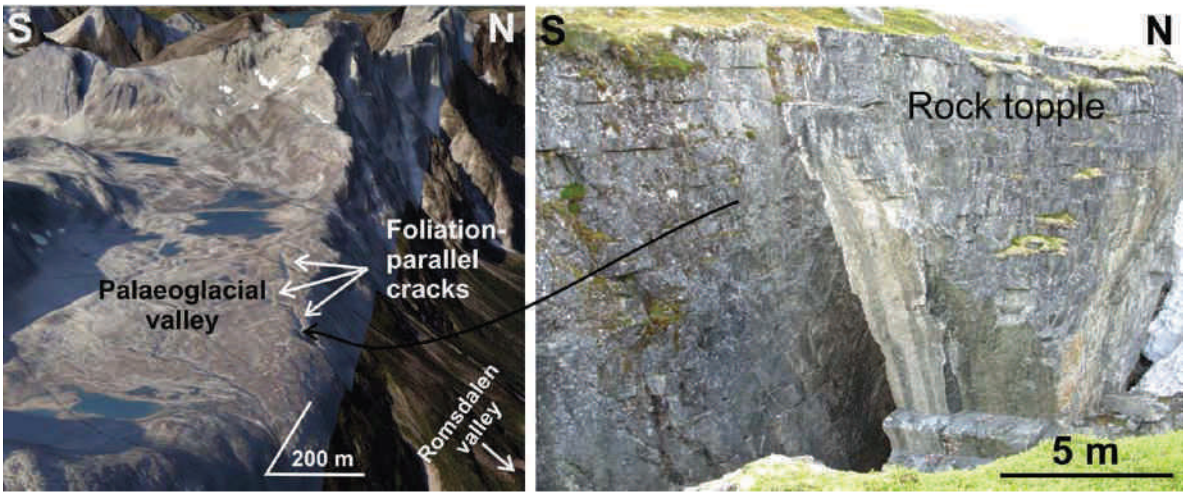

Figure 4. Left: view to the WNW of Børa slope instability (from www.norgei3d.no). Cracks developed parallel to steep foliation planes trending parallel to the cliff of Romsdalen valley. The palaeoglacial valley trends parallel to the cliff. The ice loading is assumed to have partly opened the steep foliation and to have therefore contributed to the destabilization of the edge of the plateau. The total destabilization occurred when the ice melted in the Romsdalen valley (From Saintot et al. 2010). Right: rock topple in a large back-crack in the plateau of Børa.

At the site of Mannen, the western border of the instability is a nearly N-S trending vertical epidote-rich brecciated fault, largely opened under the gravitational forces. It also marks a clear limit between the unstable eastern zone where numerous secondary parallel pre-existing fractures are opened, and the more stable western zone where such structural grain is less developed (Figure 5a). The active 15 to 25 Mm^3 collapsing block of Mannen (Figure5b) is highly disrupted by the same system of presently opened fractures. The perpendicular fractures opened along the E-W steep foliation (Figure 5c). The main back-crack is localized on a narrow folded zone and opens perpendicularly to the axial surfaces of recumbent horizontal folds (Figure 5d). Several sets of moderately to shallow dipping joints were also measured and some of them are good candidates to define basal sliding planes (Figure 5c). The 4 cm/yr velocity recorded by GPS yearly measurements of the collapsing block of Mannen allowed to implement a permanent monitoring system of the moving part from 2009 (Dahle et al. 2008). Two lasers pointed on two reflectors are installed on the top of the block. A radar system permanently scans the whole slope of Mannen from the bottom valley. Clinometers and extensometers are also installed. The signals of all these instruments are sent to an emergency center in charge of analyzing them day after day.

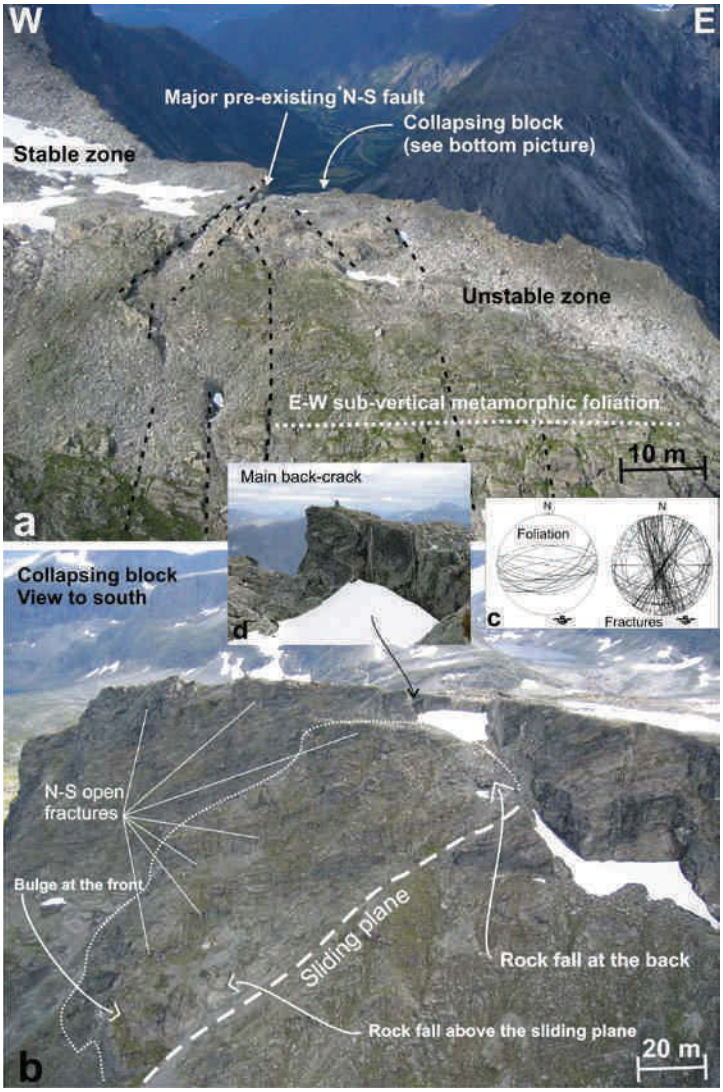

Figure 5. Mannen. (a) Photograph from helicopter of the unstable edge of the plateau at Mannen. The roughly N-S trending epidote-rich faults and parallel or nearly parallel fractures (black dashed lines) opened under gravitational forces (Henderson and Saintot 2007). A N-S main fault marks the limit between the unstable and stable areas. (b) Photograph from helicopter of the collapsing block of Mannen with an important set of N-S trending opened fractures. The dotted line is the unstable block limit in this plane view. (c) Stereonet of field data. (d) Photograph with view to the east showing the back-crack of the collapsing block opened perpendicularly to the axial surfaces of recumbent horizontal folds (white line). (From Saintot et al. 2010).

In 2008-2009, the Geological Survey of Norway acquired airborne Lidar data at 1 m resolution and the orthophotographs that cover the entire valley and slopes. Their detailed analysis is in progress. The 1 m to 5 m Digital Elevation Model was built from the airborne Lidar dataset (see background of Figure 1). On Mannen, orientation of structures was extracted from the 1 m resolution DEM and confirms the occurrence of a basal sliding plane (Figure 5).

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