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Rock-slope failure activity and *geological crises* in western Norway

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In Norway a compilation of terrestrial cosmogenic nuclide (TCN) ages of rock-avalanche deposits suggests a close link of rock-slope failures related to deglaciation. Although ages spread over several thousand years at the end of the Late Pleistocene, 50% of all documented events occurred within 1000 years after deglaciation. It is therefore likely that debuttressing triggered most of the events. The same data set suggests that 25% of the events occurred during a period stretching until the Holocene thermal maximum (HTM). These events might be interpreted as possible reactions to additional factors such as the thawing of high-altitude permafrost.
An example of a geological crisis following deglaciation and before the HTM are seven lobate rock-avalanche deposits mapped under the slope of the Vora mountain (1450 m asl.) in the Nordfjord area of western Norway. Three events of this rock-slope failure cluster date within a short time period of 2000 years, where modelling studies indicate that high-altitude permafrost was present.
After the HTM rock-slope failures are distributed temporally and spatially rather evenly throughout the Holocene and western Norway. But there are two independent local clusters with frequent rock slides during a short time span. (1) At the active Mannen rock-slope instability several rock-avalanche and rockslide deposits were mapped on the valley bottom. Stratigraphic relations combined with TCN dating suggest that at least one event occurred when the valley bottom was below the marine limit. TCN ages of further four lobes cluster around 5.2 ka BP, which does not coincide with any other rock-avalanche occurrence in the region. The top of the north facing 1295 m high unstable slope concurs with the currently estimated permafrost boundary. Preliminary TCN ages of the sliding surface indicate that larger parts of the mountain did not become active until the climate maximum. It is likely that due to structural complexity not allowing for any easy kinematic failure process, it required several thousand years of rock-slope deformation prior to the multiple failures.
(2) The youngest independent rock-avalanche cluster is historic with 5 rock avalanches sourcing from Ramnefjellet in 1905, 1936 (three events), and 1950 entering into Loen lake in western Norway. Subsequent displacement waves killed 61 people in 1905 and 73 people due to the first failure in 1936. The back scarp does not exceed 850 m elevation and lies hence below the present day and Little Ice Age permafrost limit. It is therefore unlikely that permafrost dynamics contribute to this sequence of rock-slope failures.
Local clusters or a *geological crisis* by rock-slope failures seems to be related to different main factors, such as glacial debutressing, influence of ground thermal regime changes (Mannen) and probably more disconnected to major climate variability (Loen). For an integrated risk management it is therefore important to understand that large rock-slope failures do not necessarily have to occur in single events but can occur over several decades or centuries and thus complicate severely land use management after catastrophic events.