Excursion guide

Geofaredagen 2023 Sogndal

Høgskulen på Vestlandet

Statens vegvesen

Sogndal-Byrkjelo

October, 20th 2023 8:00-16:00

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This excursion brings us to a number of localities where different landslide and avalanche deposits can be studied (Fig. 1). We will discuss both exogenic and endogenic processes that contributed to shaping the landscape of western Norway.

Schedule

When	***Where***	***What***
08.00	Sogndal Skysstasjon	Departure
08:30	1 Frudalen	Snow avalanches on road (examples from 2022)
09:15	2 Supphelledalen	Glacier lake outburst flood in 2004
10.00	3 Kjøsnesfjorden, Lunde	Bedrock structures (exfoliation pattern) Landslide and avalanche history, road projects
11.00	4 Jølstravatnet, Svidalsneset	Drainage history Jølstravatnet Extreme precipitation induced landslide event 2019
11.30	Svidalsneset	Lunch
12:30	5 Votedalen	Bedrock structures (landscape forming faults) “Aa ura” Landslides and avalanches harming the road
13:30	6 Byrkjelo, Vora	Vora rock avalanche deposits
14:30	Byrkjelo	Driving back
16.00	Sogndal Skysstasjon	Arrival

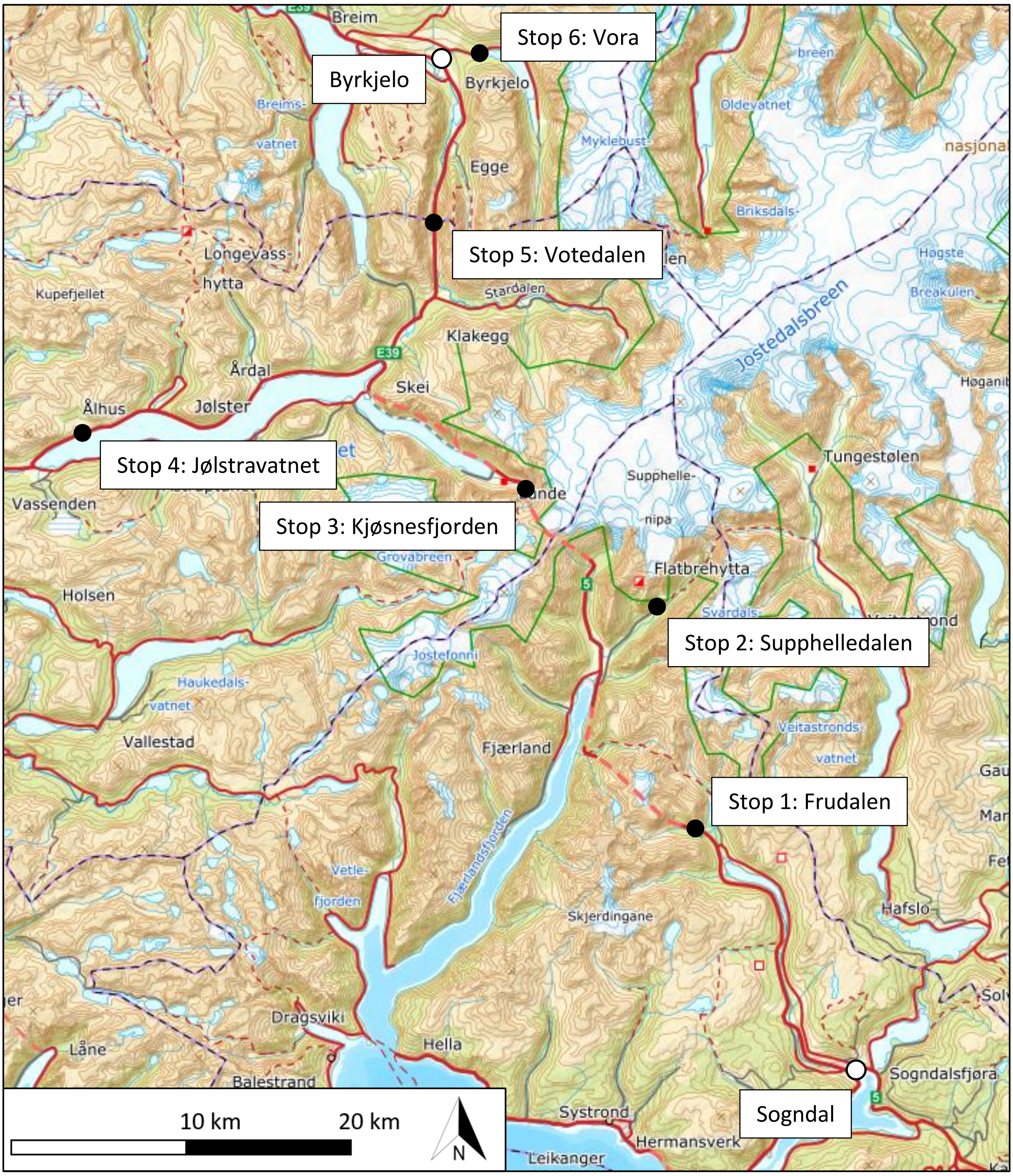

Fig. 1: Overview of the excursion route, including a total of six stops.

Introduction

The bedrock along the excursion route is dominated by high-metamorphic gneisses and magmatic rocks of the Western Gneiss Region, which forms part of the Precambrian Baltican basement. The Baltican basement is tectonically overlain by mainly phyllitic rocks of the Fortun-Vang nappe and by plutonic rocks of the Jotun nappe complex (Fig. 2). All our sites are located in the Western Gneiss Region.

The rock types of the Baltican basement can be summarized into three main units: (1) Gabbroic to granitic gneiss, in parts migmatitic gneiss, (2) middle- to coarse-grained granite, and (3) coarse-grained monzonite, partly transformed to augengneiss (Fig. 2). The basement gneisses have an (intrusion) age of ca. 1600 Ma, whereas the granite and the monzonite intruded at ca. 980-950 Ma, at a late stage of the Sveconorwegian orogen.

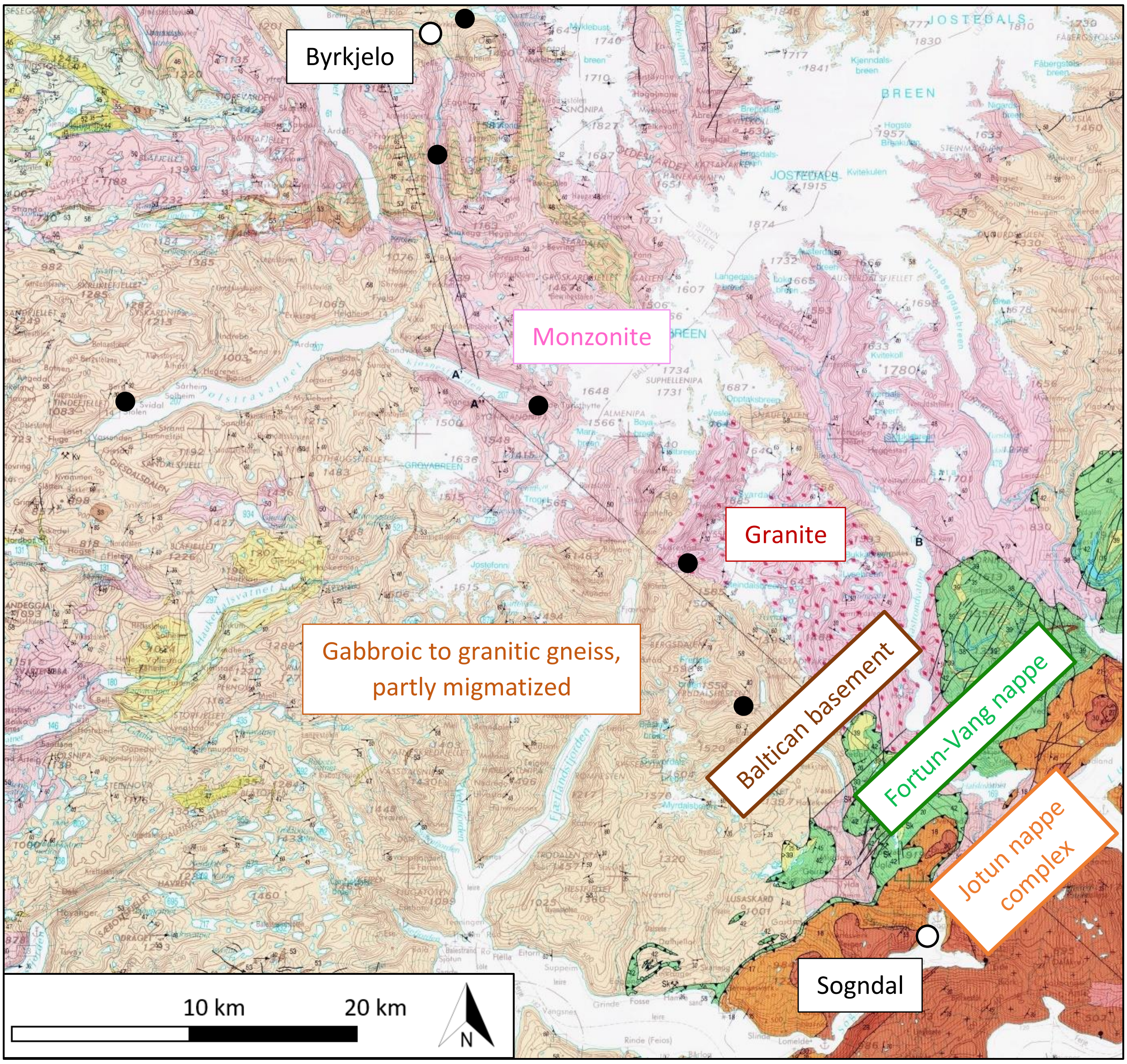

Fig. 2: Bedrock geology map (map sheet Årdal, 1:250 000 by Lutro & Tveten, 1996) highlighting the main tectonic units in the region (lower right corner) and the dominating rock types along the excursion route. Black dots represent excursion stops.

The Quaternary geology along the excursion route is characterized by deeply incised U-shaped valleys and fjords and post-glacial deposits in the valley bottoms. Glaciofluvial and fluvial sediments were deposited on top of till and in places also on marine clay (see marine limit on map of Fig. 3) in the bottom of larger valleys. The valley flanks are characterized by abundant and often thick landslide and rock-slope failure deposits.

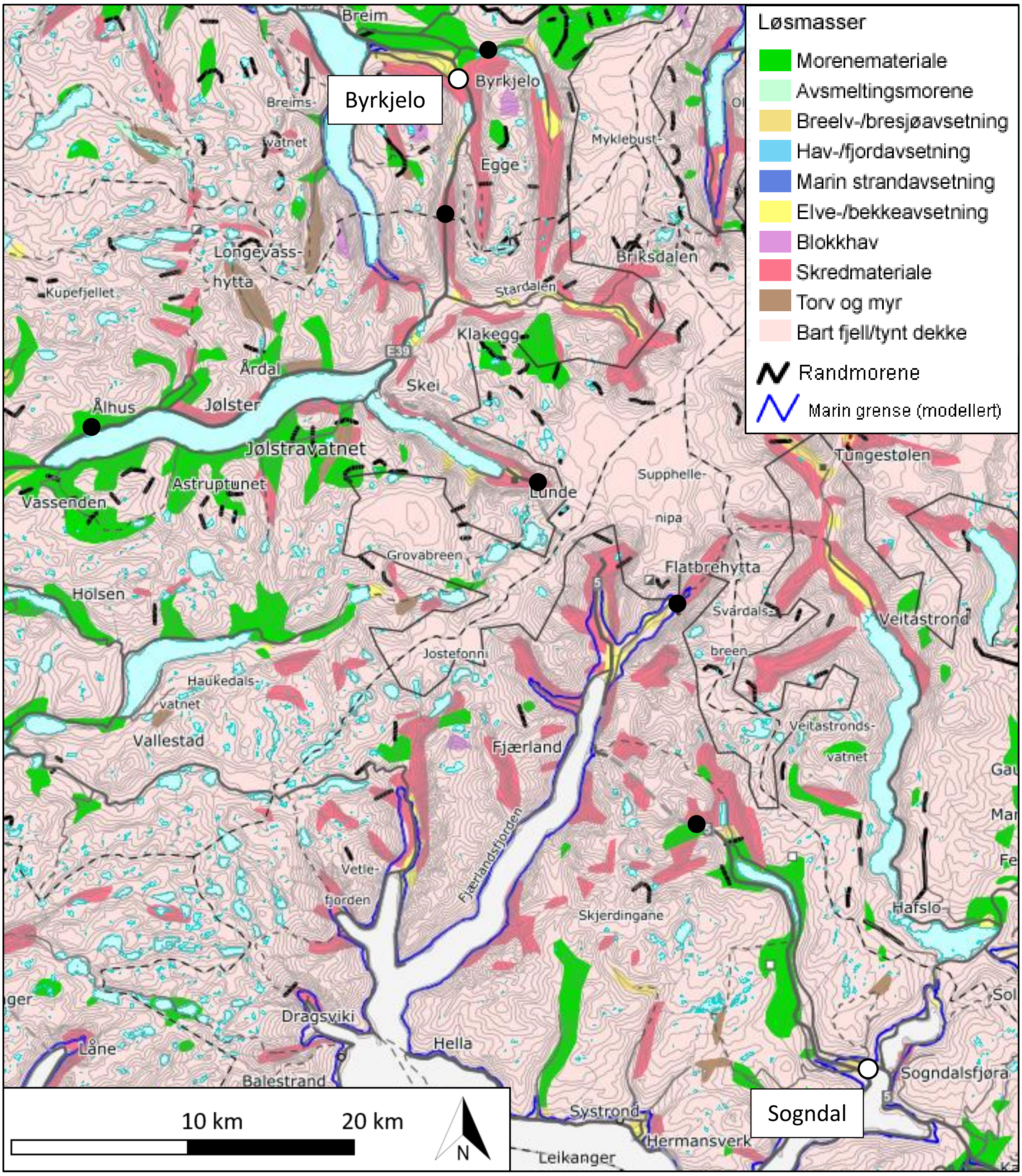

Fig. 3. Quaternary overview map ([ngu.no](ngu.no)). *Black dots represent excursion stops.*

Stop 1 – Frudalen

On the late evening of February 9th, 2022, the RV5 road between Sogndal and Fjærland was struck by an avalanche (Fig. 4). Due to bad weather conditions Statens Vegvesen (SVV) decided not to start clearing the road that evening. When the conditions started to get better the next morning, SVV flew in to the area. Just one hour before the helicopter arrived, all electricity in the Frudalstunnel was lost. A new avalanche had occurred, crossed the road and crushed the technical building for the tunnel (Fig. 4). A new technical room is now built inside the tunnel. These events were not the first endangering the road and traffic. Avalanches activity during and after road and tunnel construction resulted in a protection dam only a few hundred meters down the road from these recent events (Fig. 4a).

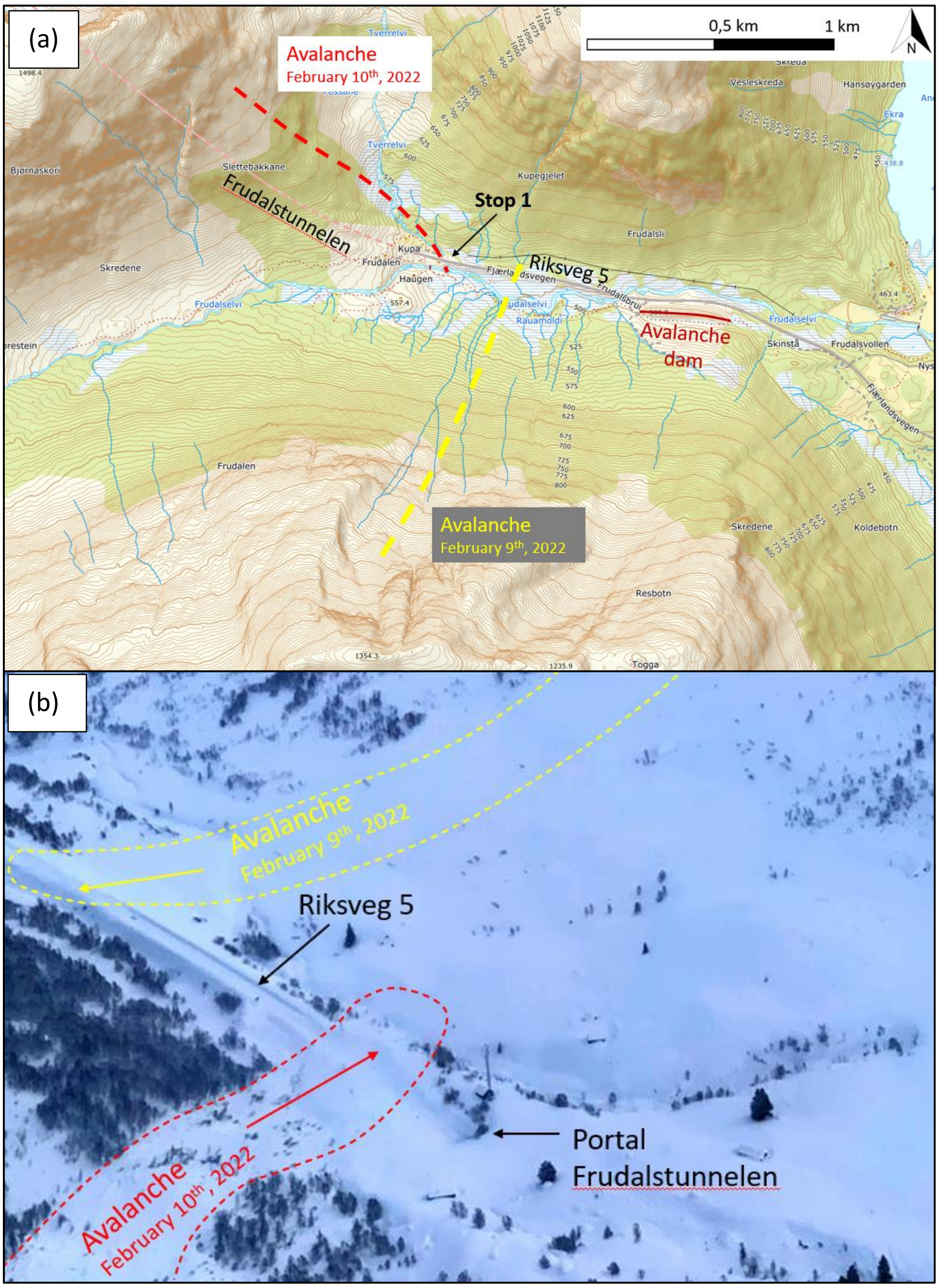

Fig. 4. (a) Map of Frudalen showing the trace of avalanches that crossed the road on February 9th and 10th 2022. (b) Helicopter photograph capturing the situation in front of the entrance to Frudalstunnelen on February 10th (picture by SVV).

Stopp 2 - Supphelledalen

At this location we visit the deposits of a glacial lake outburst flood (GLOF) that happened on May 8th, 2004. This outburst developed from rapid breaching of an end moraine which caused the sudden drainage of a naturally dammed lake between the moraine and the glacier.

Usually, during summer the lake drains through channels below the glacier to the east and down to Supphella (Fig. 5). Heavy rain combined with warm temperatures and associated snow melting filled the moraine-dammed lake during late April and early May 2004. At this time of the year, the drainage system through/below the glacier had not been established yet. As a result, the lake got filled up until it spilled over at the lowest point of the moraine ridge. The water immediately eroded into the unconsolidated moraine and the lake emptied as an outburst flood.

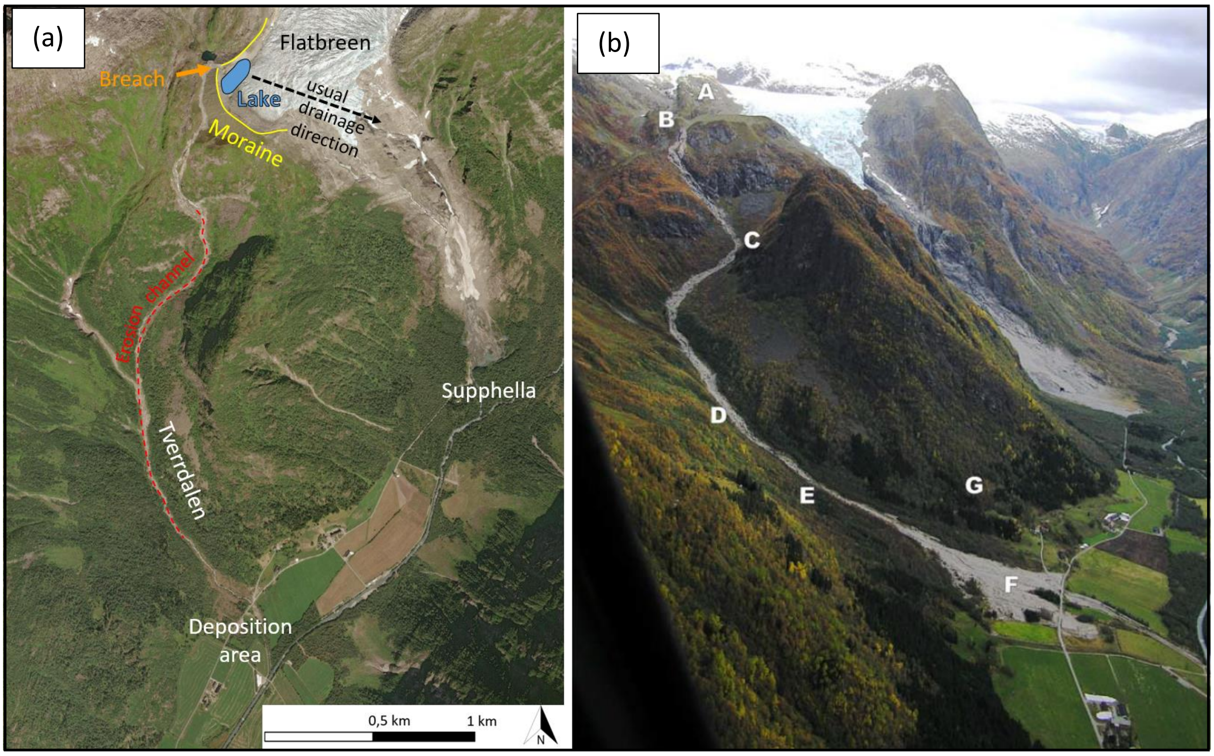

Fig. 5. (a) Orthophotograph over the area affected by the glacial lake outburst in May 2004. Meltwater drained from the glacier through Tverrdalen. Normal drainage route is through the ice fall towards Supphella. (b) Overview image after the 2004 GLOF (picture taken by A. Elverhøi, from Breien et al., 2008).

Facts and numbers from the outburst in 2004 (for details see Breien et al., 2008):

- c. 1,000 m elevation difference between moraine ridge and valley bottom.
- c. 3 km travel distance between moraine ridge and valley bottom.
- c. 15 minutes after breaching, the area in the valley bottom was flooded and inundated by mud (Fig. 6).
- c. 25.000 m^3 of the end moraine was eroded.
- c. 240,000 m^3 of sediment in total were involved in the debris flow.
- c. 100,000 m^3 of water drained in the outburst.
- after c. 45 minutes the outburst flood was over.

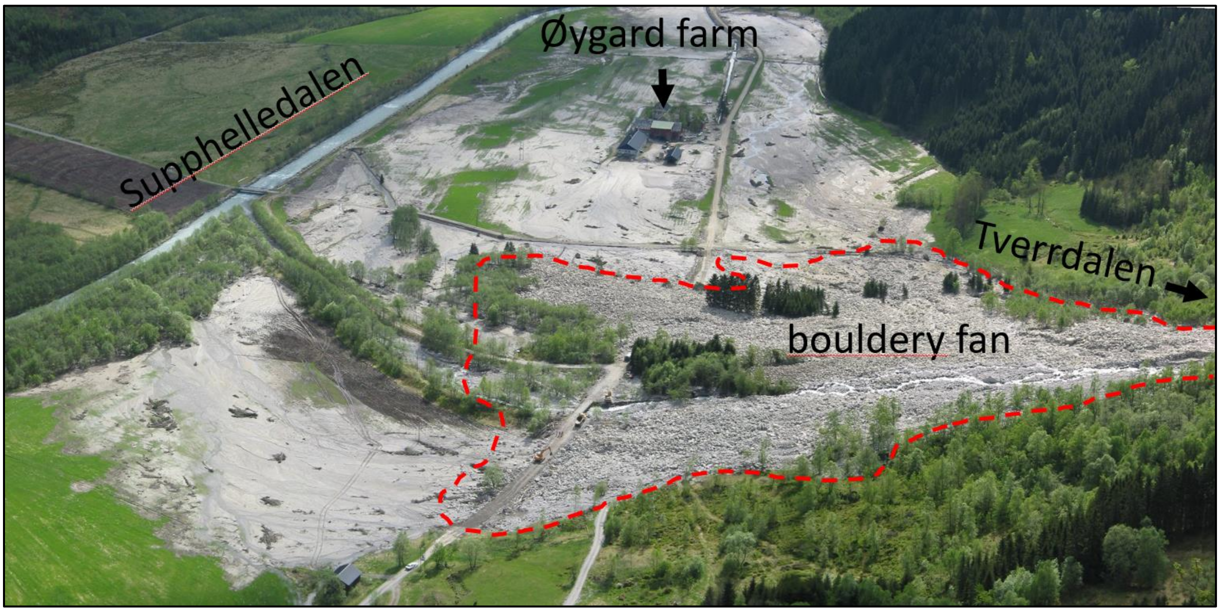

Fig. 6. The situation in the Supphelledalen valley some weeks after the event (Picture: K. Kristensen). The bouldery fan shows pronounced vertical inverse grading and poor lateral sorting. Most of the farmland at Øygard was covered by sand and silt.

Today there is still a naturally dammed lake (Fig. 7) rarely reaching up to the 2004 erosion level in the moraine ridge. The lake level varies depending on meteorological factors and subglacial drainage paths, and it still usually drains beneath the glacier towards Supphella (Fig. 4a).

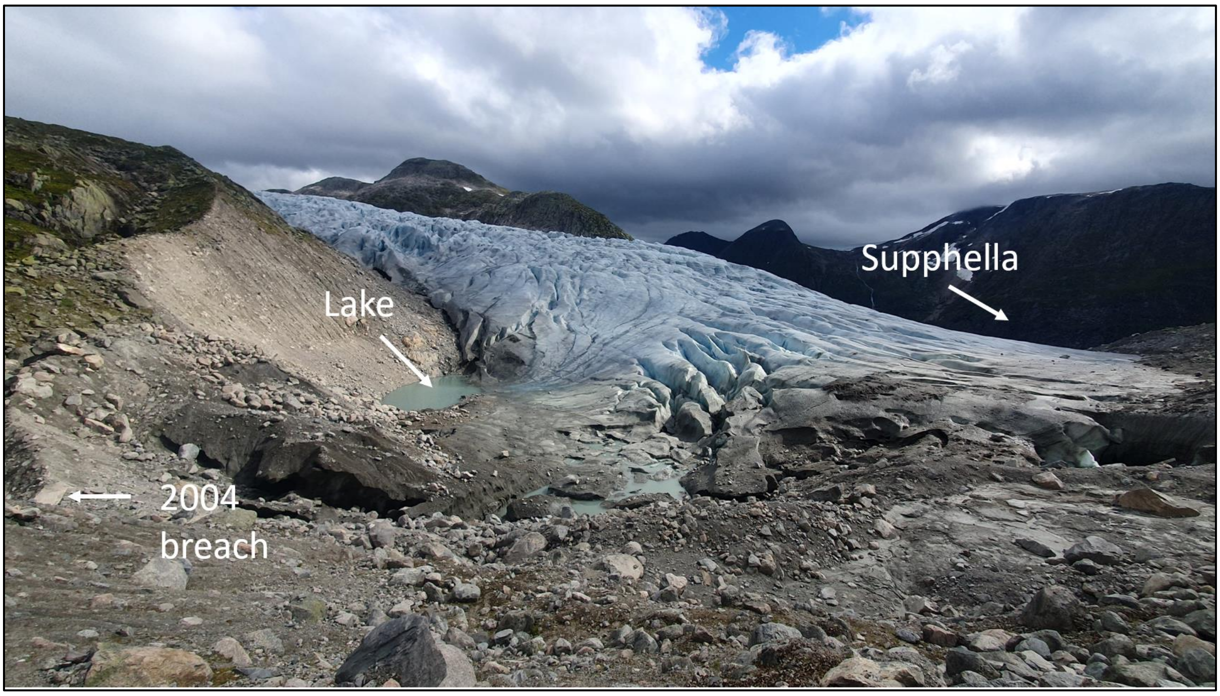

Fig. 7. Situation at Flatbreen in August 2023 during low water level (Picture: T. Scheiber) – the lake is significantly smaller than in 2004.

In November 2022, a rainstorm caused a sudden lake level rise and another spillover of the lake towards Tverrdalen with only little erosion at the 2004 breach. On November 12th, a debris flow from Tverrdalen again caused significant damage to the fields and the road along Supphelledalen, resulting in the isolation of the innermost farm (Fig. 8). If or to what extent the overflow of the lake has contributed to the triggering of the debris flow remains to be solved. The SKRED and BRE research groups at HVL have recently installed a time-lapse camera and a lake-level pressure sensor to monitor the lake level fluctuations at Flatbreen.

Fig. 8. Debris flow deposits from Nov. 12th 2022 (sognavis).

Stopp 3 – Kjøsnesfjorden, Lunde

This stop is situated directly at the western entrance of the Fjærlandstunnel. From this location we have a spectacular view down a glacially carved valley with landslide deposits along the slopes. The Kjøsnesfjorden lake level is at c. 200 m a.s.l. and the surrounding mountains are up to 1,600 m a.s.l. The mountain slopes are very steep and characterized by smooth slope-parallel rock slabs (Fig. 9) representing the surface expression of exfoliation fractures.

Fig. 9. View towards Kjøsnesfjorden (Picture: P. Snook)

Until 2009, the main road was in open air along the north-eastern side of Kjøsnesfjorden, a road section frequently affected by different types of mass movements (Fig. 10). Since Fjærlandstunnelen opened in the mid 1980's, a lot of mitigation measures have been installed to make the road safer. One of them is the 2.6 km long Støylsnestunnel, built in 2009. On November 9th 2022 the Kjøsnestunnel, which is a prolongation of the Støylsnestunnel and represents an 8.5 km long bypass of the entire lake Kjøsnesfjorden, was opened (Fig. 10). However, there are still areas prone to snow avalanches, and the last three winters two avalanches closed the road for some time. One from the northern mountain side reached over the deflection dam near the SE entrance of Kjøsnestunnel, and one very large avalanche from the southern side crossed the valley a bit further up the road by Lunde (Fig. 10).

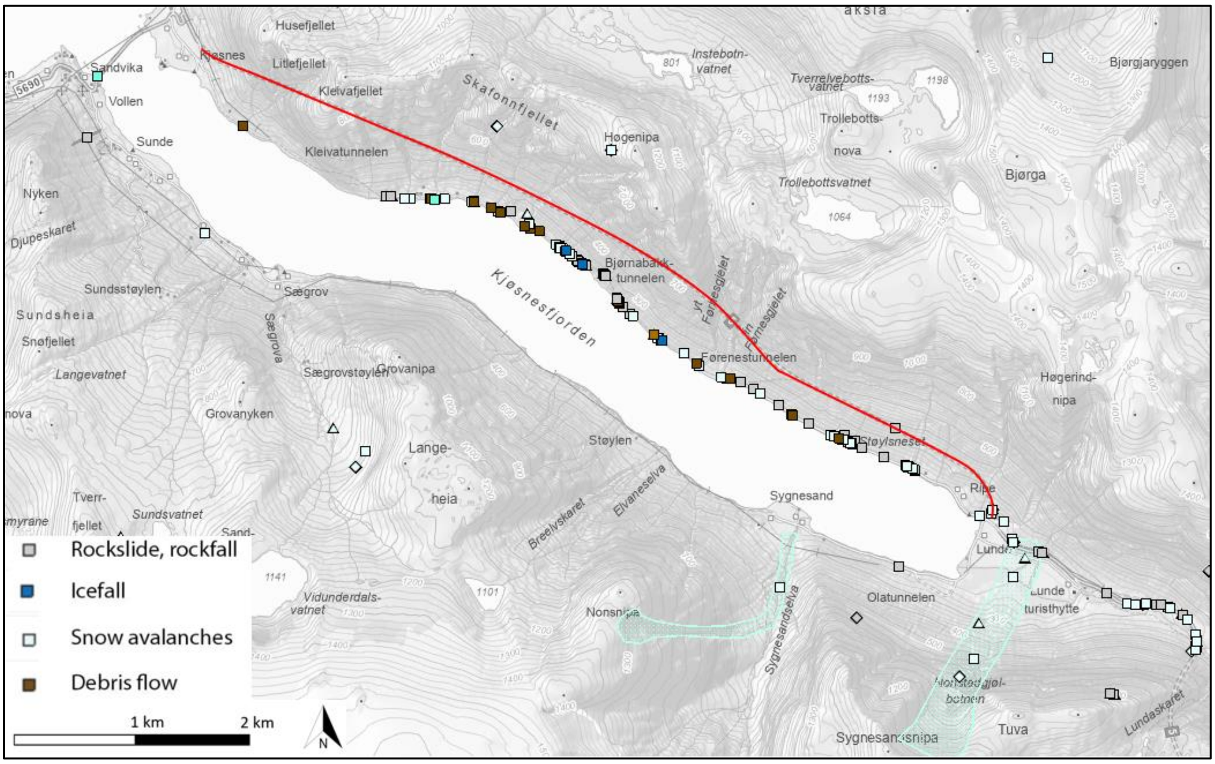

Fig. 10. Historical slide events along Kjøsnesfjorden (from Skredregistrering.no). The red line shows the new Kjøsnestunnel bypassing entire Kjøsnesfjorden. The turquoise polygon in the lower right represents the area affected by a large snow avalanche on March 23rd 2020.

Stop 4 – Jølstravatnet, Svidalsneset

The drainage history of Jølstravatnet

Jølstravatnet is a 22 km long lake with a fascinating drainage history. A study by Klakegg and Rye (1990) shows that the drainage direction of the lake has changed several times since deglaciation (Fig. 11). During the retreat of the glaciers in the area, the lake was dammed up by a glacier that lay in lake Jølstravatnet. The lake drained across Vassenden towards the west (phase 1).

When this glacier retreated further into the Kjøsnesfjorden, the drainage direction shifted towards Breim in the northeast (phase 2). As a result of higher isostatic uplift in the east than in the west there was a period between 8350 and 6350 yr BP when the water drained both towards Breim (east) and towards Vassenden in the west (phase 3). Due to the continuous higher uplift in the east the drainage towards Breim ceased. Since 6350 yr BP the direction of the drainage and the outlet of Jølstravatnet has been stable.

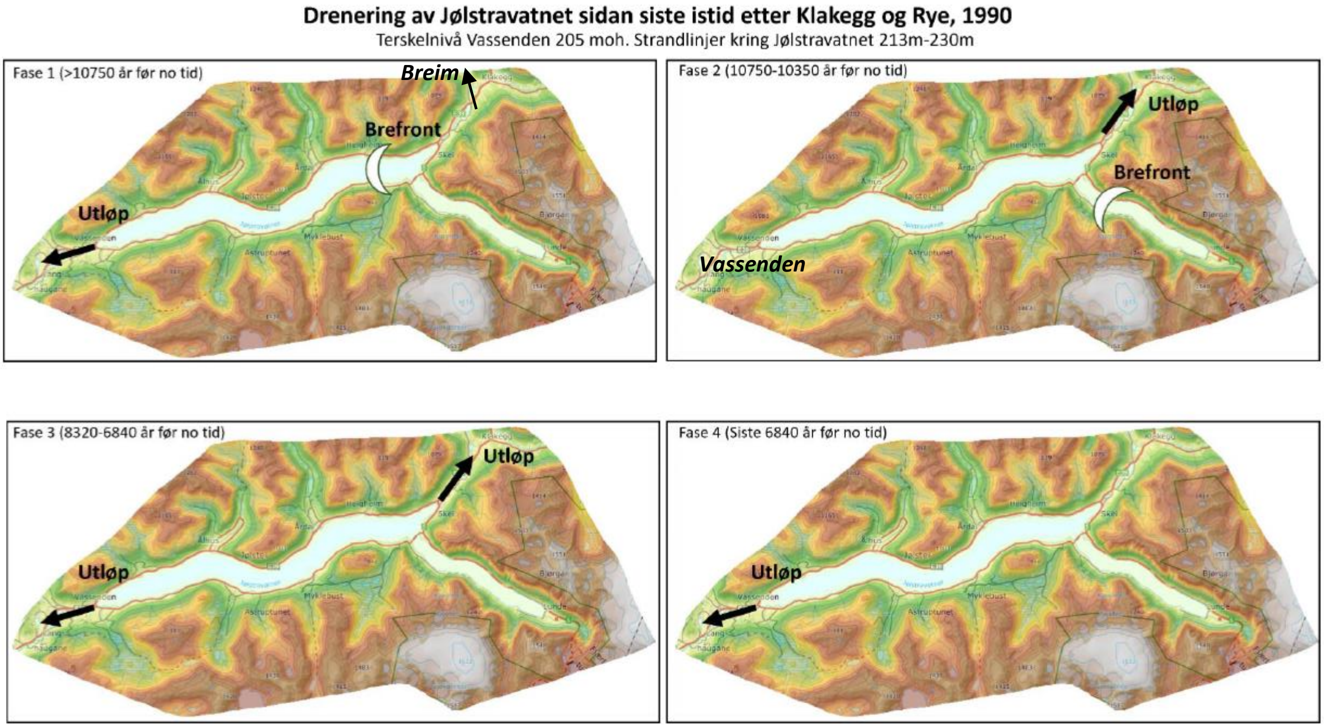

Fig. 11. Drainage pattern of lake Jølstravatnet since last deglaciation (after Klakegg and Rye, 1990).

Extreme precipitation induced landslide event on 30 July 2019

Thunderstorms resulting from warm summer temperatures and moisture have generally been a rare phenomenon in Norway. However, the Jølster area was hit by such a local thunderstorm on July 30th, 2019. This thunderstorm triggered more than 100 debris floods, flows and avalanches (Lindsay et al., 2022) within a radius of 10 km around Vassenden (Fig. 12). Locally, precipitation exceeded 60 mm during a three-hour time period, while it was dry in Lunde (stop 3, 20 km towards the west). The 24-hour precipitation records at nearby weather stations correspond to the one of a 200-year recurrence interval (Fig. 12).

120 debris floods, flows and avalanches were mapped in the Jølster area with 10 km radius around Vassenden (Fig. 12; Lindsay et al., 2022). The landslide events of July 30 caused extensive damage to public infrastructure and private property. One person died as the car was taken by a debris avalanche close to Årnes and swept into the lake Jølstravatnet (Fig. 13). We can still see the traces of this debris avalanche on the other side of lake Jølstravatnet.

Many of the Jølster event landslides started outside existing national susceptibility zones and in places not previously known for similar processes. The majority of 120 shallow landslide source areas share common characteristics: they are situated above or at the tree line, in thin to very thin soil, in contact with the bedrock or large boulders and in rather steep terrain (>30 degrees). Exposed bedrock cliffs above the starting areas are also a common feature and led to spontaneous waterfalls as water couldn't infiltrate and had to flow superficially.

The majority of shallow landslides were triggered 1-2 hours after the onset of the rainfall on dry ground. This together with restricted erosion in the landslide paths suggests that the soil in the source areas was not fully saturated, but instead failed due to locally high porewater as water infiltrated through open cracks.

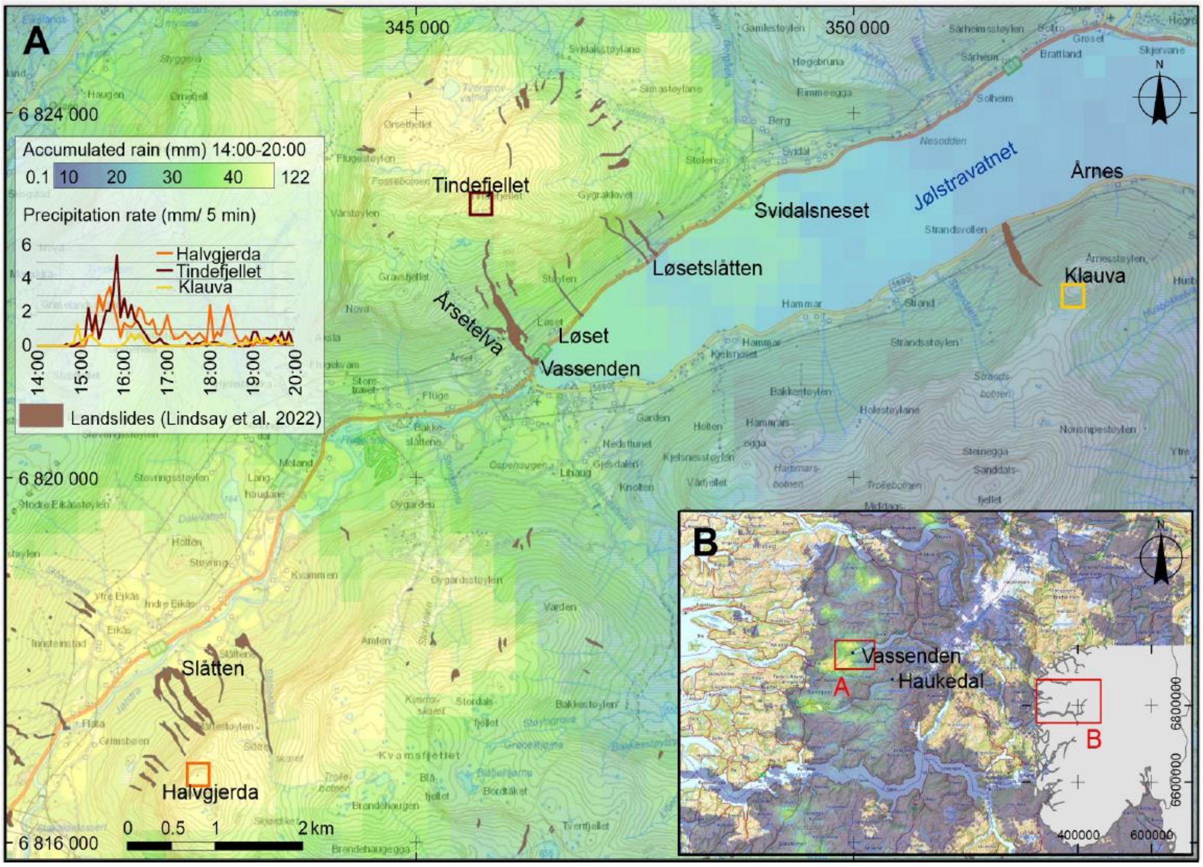

Fig. 12. Precipitation accumulated from 2 to 8 pm on 30 July 2019 based on weather radar shown for (A) the area around Vassenden and (B) western Norway. Areas of highest rain intensities show correlation with occurrence of landslides (Lindsay et al., 2022). The inserted graph shows precipitation rate in mm per 5 minutes for three selected locations at Halvgjerda, Tindefjellet and Klauva. Figure from Rüther et al., (2022).

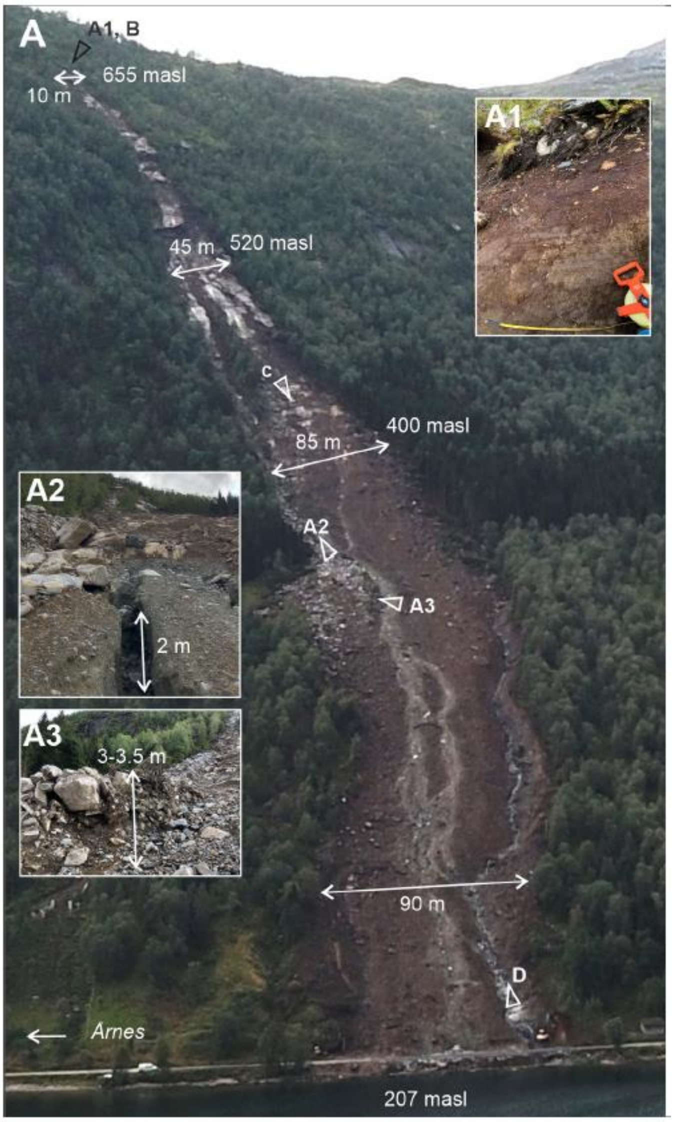

Fig. 13. Debris avalanche at Årnes (from Rüther et al., 2022)

Stop 5 – Votedalen

Votedalen is a short (12 km long), narrow, N-S trending valley characterized by very steep slopes and snow avalanche and rockfall deposits. While the valley bottom is rather flat and consists of fluvial deposits the average slope angle of the valley flanks is more than 40° (Fig. 14).

In the middle of the valley, we visit a textbook example of a rockfall cone, which has been listed as a geological heritage of Norway.

Despite several similarities with the valley visited in Kjøsnesfjorden (stops 3), the bedrock morphologies of these two valleys are very different. While the bedrock morphology in Kjøsnesfjorden is generally very smooth due to surface-parallel exfoliation pattern, a "staircase" morphology of the mountain slopes can be recognized, especially when entering the Votedalen from the south. Each vertical step corresponds to a fracture plane, which is genetically related to a larger N-S trending fault zone presumably following the valley bottom (Hestnes et al., 2022).

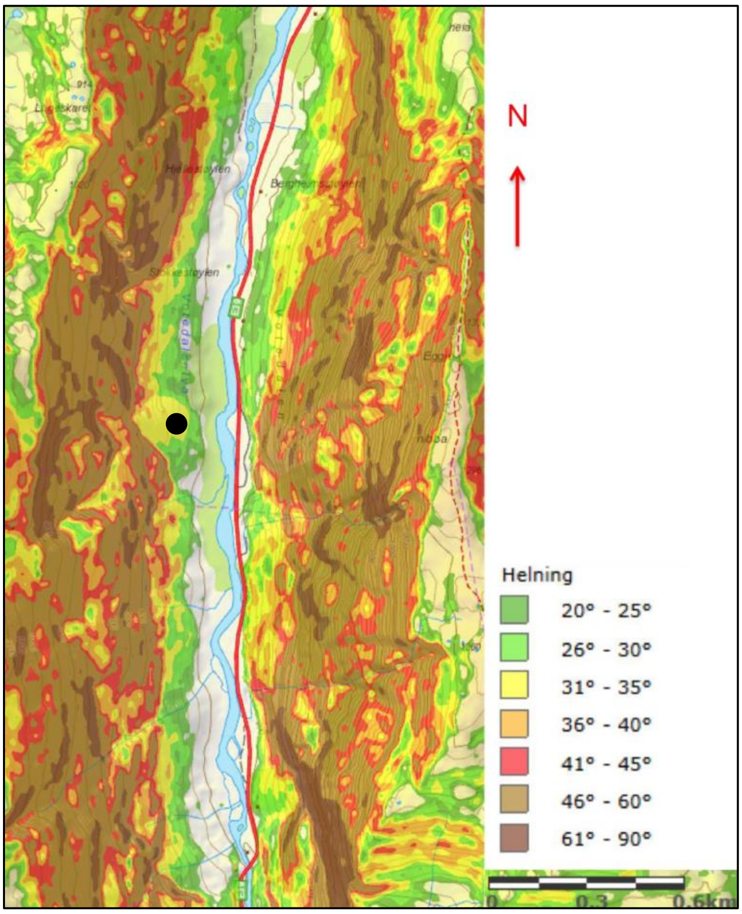

Fig. 14. Slope map of Votedalen. Black dot shows the location of the rockfall cone, called the "Aa-ura", named after the geologist Asbjørn Rune Aa who suggested it as a geological heritage, as road works started to destroy it.

While rockfall dominates during summer times, the road through Votedalen is particularly exposed to snow avalanches during winter. There are several protection measures along the east side, such as dams along the road. However, most of the big avalanches come from the western valley flank. On February 21st, 2020, a snow avalanche from the western side of the valley crossed the road, which wasn't closed at this time. One car was taken by the snow masses and transported c. 30 meters up on the other valley side (Fig. 15). There are some «grey numbers» in registration of avalanches that affect the road since the events don't always cross the river. Still the powder cloud and air pressure can be of great harm to the traffic.

Fig. 15. Snow avalanche on Feb 21st, 2020. Pictures from NRK (left) and Bergens Tidene (right)

Stopp 6 – Byrkjelo, Vora

From Votedalen we drive through the village of Byrkjelo and up towards Myklebustdalen valley. On our way up we drive through a chaotic landscape with up to house-sized boulders, overgrown by trees and we observe lakes filling some of the depressions. This landscape is formed by very large rock avalanche deposits originating from the mountain Vora.

The Vora rock-avalanche deposits (Fig. 16) are interpreted as being the result of several rock avalanche events (11 according to Aa et al., 2007) since different rock-avalanche lobes are superimposed by each other (Fig. 17). The total volume of the deposits exceeds 100 million m^3. Based on radiocarbon ages from dust lamina in a sediment core, Aa et al. (2007) suggest that the oldest and biggest rock avalanche occurred more than 8000 years ago, and that rock avalanching has been ongoing throughout most of the Holocene, until 3600 cal. years BP. Schimdt hammer ages from the same authors suggest, that the largest rock avalanches happened from 10440–10960 to 8890–9450 cal. BP. While Hermanns et al. (2017) generally support the stratigraphy of the different lobes from Aa et al. (2007), their ^{10}Be surface exposure ages suggest about 2000 years older failure timings for the largest failures, between 12900 and 10800 years ago.

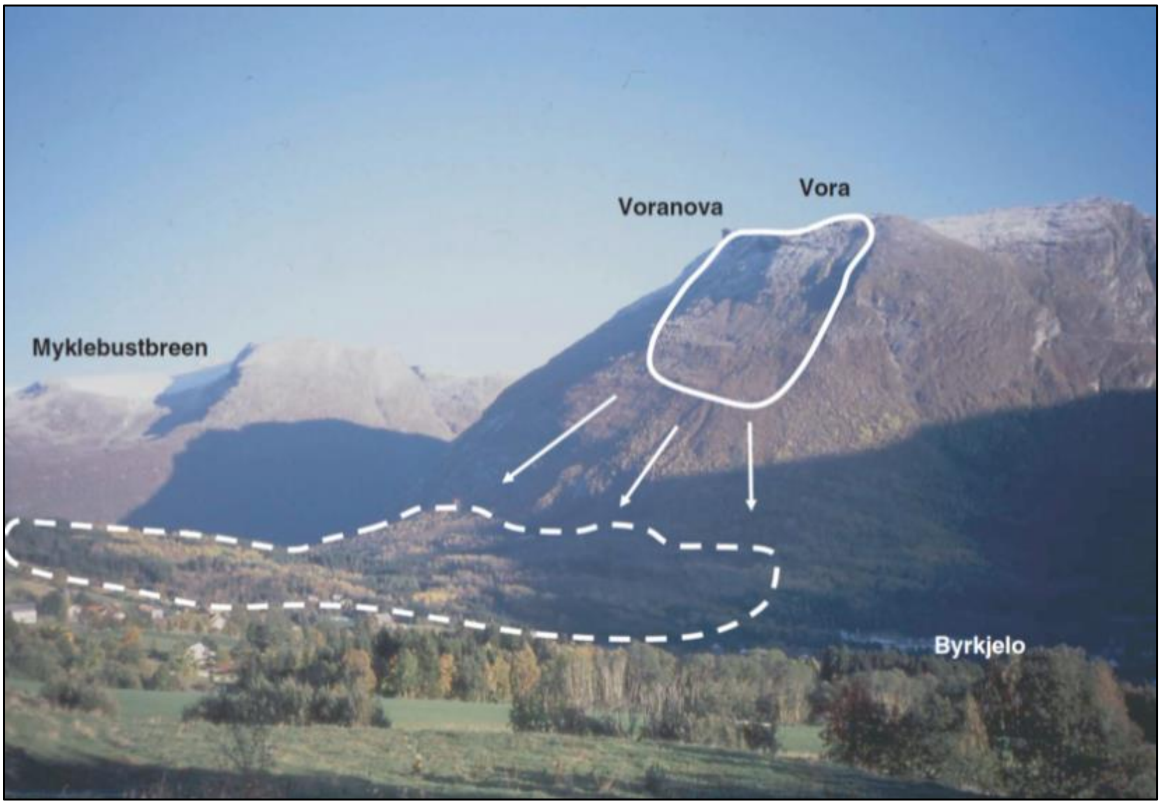

Fig. 16: North face of mountain Vora with source area and extension of rock avalanches indicated (from Aa et al., 2007).

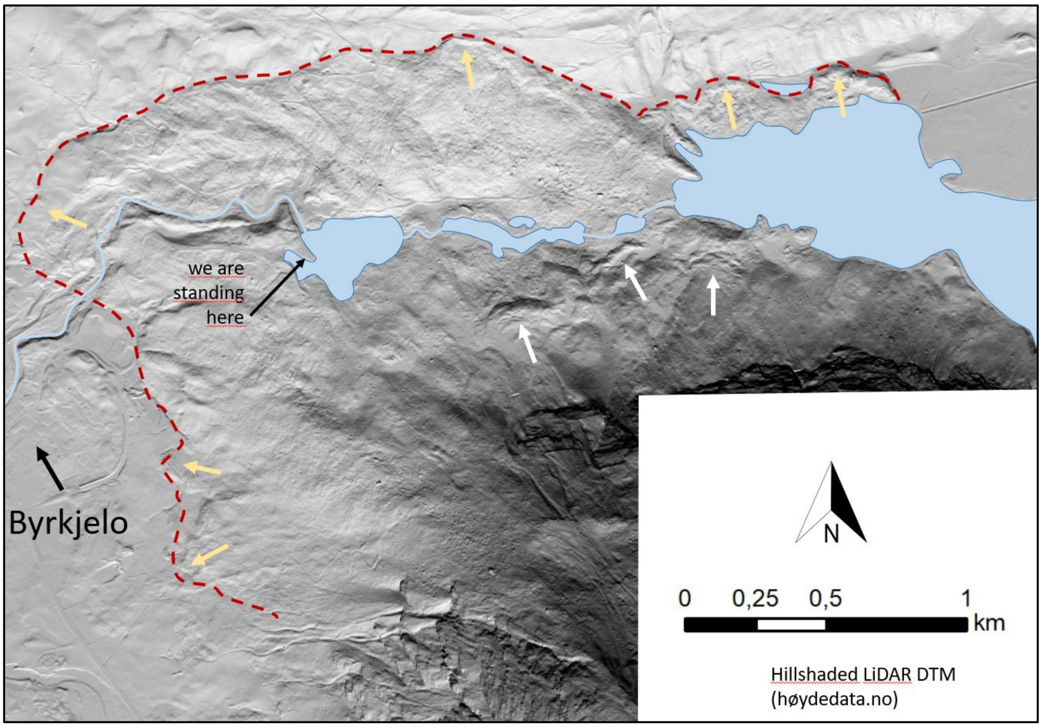

Fig. 17: Hillshaded digital terrain model (DTM) illuminated from the south. The red dashed line indicates the ouline of the rock avalanche deposits. Note frontal (yellow arrows) and internal lobes (white arrows).

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