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Rock avalanches - distribution and frequencies in the inner part of Storfjorden, Møre og Romsdal County, Norway.

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REPORT

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Summary:

Past landslide deposits store valuable and important information that can be used for geohazard analysis. This includes data on frequency of events, run-out distances and dynamics of rock avalanches. Investigations of rock-avalanche events also give possibilities for back-calculation (modelling of avalanches), such as conditions for sliding in potential unstable slopes.

A complete swath bathymetry data set from the inner parts of Storfjorden and its tributary fjords has been studied. Based on this data set and seismic data, rock-avalanche deposits on the fjords bottom have been mapped. An inventory of avalanche debris distribution and volumes has been compiled. A relative chronostratigraphy is elaborated, and slides are tentatively put into this frame based on seismostratigraphic position and freshness of surface morphology. In many cases it is difficult to distinguish between large rock- avalanches with volumes more than 100 000 m^3, and rock fall and alluvial cones. Hence the number of avalanches may be higher than listed in the inventory.

A total of 108 rock-avalanches have been mapped. Twenty five events occurred during the deglaciation (12 500-10 000 ^{14}C years BP) and the deposits from these avalanches constitute 522 mill. m^3, or 89 %, of a total avalanche volume of 587 mill. m^3 registered in the fjords. 5 out of these 25 avalanches contribute 79% of the total debris volume. Twenty-one slides are equal to or larger than the 1934 Tafjord Slide, but only six of these occurred during the Holocene. The frequency of rock-avalanches was very high during the Younger Dryas and Preboreal periods, i.e. from 11 000 to 9000 ^{14}C years BP with approximately 45 recognised slides. After that, we see a more or less even distribution of rock-avalanches throughout the Holocene, with 5-8 slides per 1000 years. The largest avalanche deposit is found in Sunnylvsfjorden, below Blåhornet, slightly north of the Åknes Slide, which is presently active.

The rock-avalanche activity is highest in Geirangerfjorden with a frequency of one slide every 350 years. The slides are, however, smaller than in other fjords. In Tafjorden the frequency is one slide every 650 years, in Synnylvsfjorden one slide every 1300 years and in Storfjorden from Stordal to the mouth of Sunnylvsfjorden, the observed slide frequency is one every 3000 years. The present data clearly shows that the Storfjorden area has a high frequency of large rock-avalanche events, and that there is a need for geological investigations to map unstable and active rock slopes in the fjord areas.

Keywords: Marine geology	Multibeam bathymetry	Reflection seismic
Rock-avalanche	Morphology	Chronostratigraphy
Slide frequencies	Geohazard	Seismic stratigraphy

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Appendix 1. Slide inventory. Database over registered rock-avalanches on the fjord bottom in the inner part of the Storfjorden and tributary fjords, Møre og Romsdal County.

1. INTRODUCTION

The inner fjord area of Møre og Romsdal County is an area of many rock avalanches, both in historical and geological time. In historical time, at least 12 large avalanches have occurred in the inner Storfjorden area, with 68 people killed by tsunamis (Blikra et al. 2006).

To understand rock-avalanche hazard, it is of fundamental importance to map slides in the geological record and to analyse slide frequency. The stratigraphic succession below the sea bed store valuable and important information that can be used for back-calculation (modelling of avalanches). Such calculations provide fundamental information about the conditions for sliding in potential unstable slopes. Slide morphology and extent of rock-avalanche deposits are also important for calculating run-out distance and dynamics of rock-avalanches, which are important for hazard analysis.

Rock-avalanche deposits onshore can be mapped from aerial photos, but if several slides are stacked on top of each other they can hardly be separated and dated. Hence, slide frequency calculations based on sub-aerial photos may be faulty.

Slide deposits on the seafloor can be recognized from swath bathymetry, and sediment stratigraphy can be mapped from seismic data. In fjords, there is frequently continuous sedimentation of minerogenic and organic debris from rivers, abrasion, slides and biogenic production. Sediments usually drape the seafloor and, depending on the sedimentary processes, have acoustic properties that can be recognized on reflection seismic records. Hemipelagic sediments (deposited from suspension) and slide deposits have different acoustic signatures and can, given sufficient seismic resolution, be separated. Hemipelagic sediments may occur between different slide units. Marine sediments contain organic matter that can be radiologically dated, and cores through seismic reflectors can be used to date events. If sedimentary conditions remain stable in a fjord system, seismic reflectors can be traced over long distances and can thus be used to correlate and date slides in different parts of the fjord.

The inner part of Storfjorden is completely covered by swath bathymetry (compiled since 1997), and is also covered by a dense seismic grid and a few dated cores. Based on these data, rock-avalanche deposits on fjord bottom have been mapped, and a slide inventory including area and volume of slide deposits has been made. A relative slide chronostratigraphy has been established based on seismostratigraphic position and surface morphology (ruggedness) of deposits. A rugged surface indicate little hemipelagic deposition since the avalanche and a young age of the event.

In many cases it is difficult to distinguish between rock-avalanches, with volumes more than 100 000 m^3, and rock fall and alluvial cones. Hence the number of avalanches may be higher than listed in the inventory.

The fjord areas have been mapped by NGU and Sjøkartverket over a period of several years. Financial support has been recieved from Møre og Romsdal County, NGU, Statens naturskadefond and the Åknes/Tafjord Project. This report is financed by the Åknes/Tafjord Project, the International Centre of Geohazard (ICG) and NGU. A preliminary version of this work was published by Blikra et al. (2006).

2. METHODS

2.1 Swath bathymetry

Complete swath bathymetric coverage, below the 20 m depth contour, was acquired during a joint cruise by the Norwegian Hydrographic Service (SKSK) and NGU in 1997. The survey was performed with a Simrad EM 1002 multibeam echosounder.

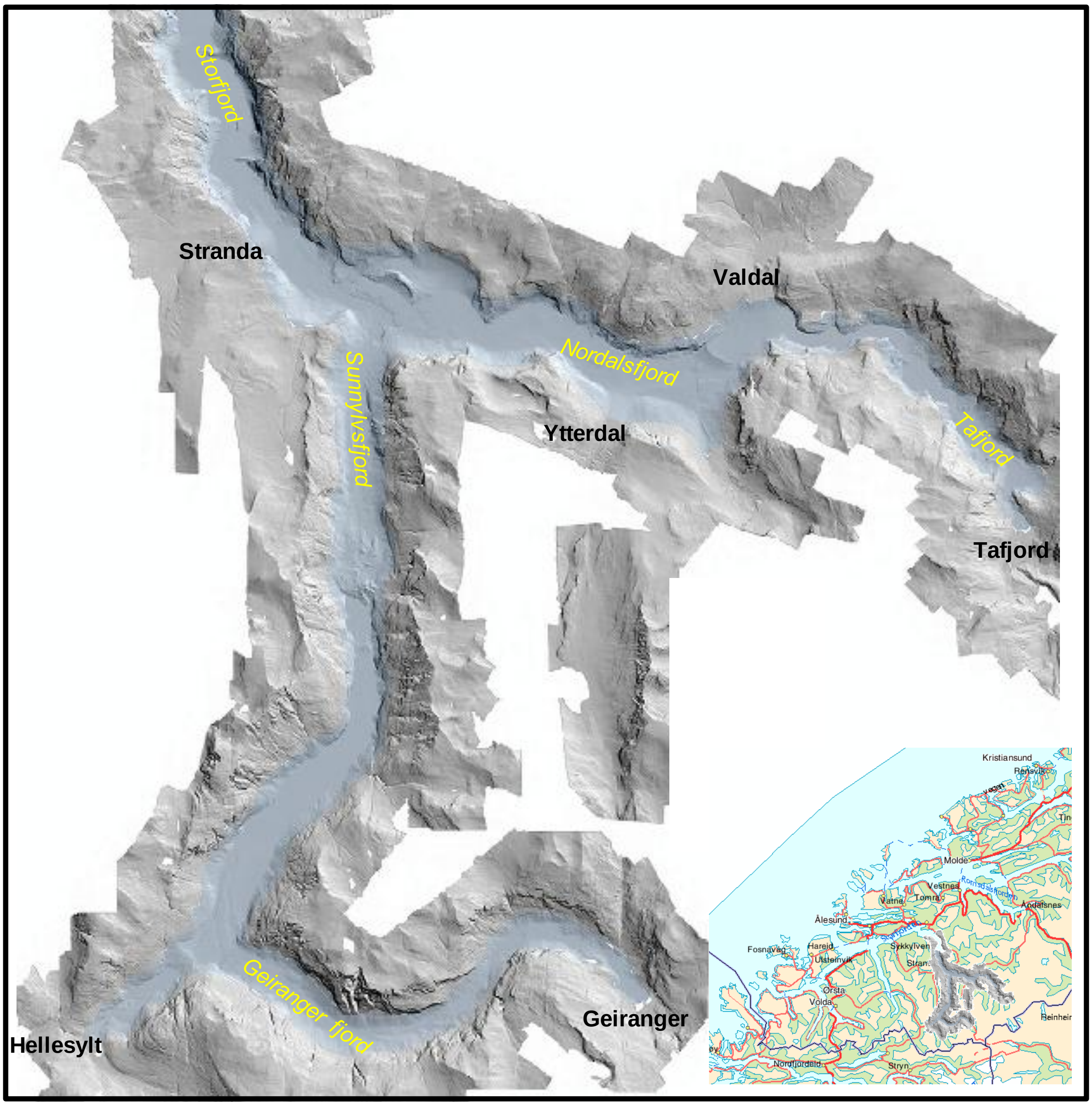

Figure 1. Swath bathymetry (blue) combined with LiDARdata for topographic elevation (grey). Grid cell size for topography is 1 m and for bathymetry 3 m.

In 2006, NGU mapped the areas shallower than 20 m, using a GeoAcoustics Geoswath 125 Mhz interferometric sonar. The data have been combined into a digital elevation model (DEM) (Fig. 1).

2.2 Reflection seismic

Ca. 950 km of high-resolution seismic data have been obtained on several cruises since 1986. Several seismic sources have been deployed, including 5-15 cubic inches airgun and Sleevegun, surface towed boomer and very high resolution parametric sonar (TOPAS). The airgun works on low frequencies (100-1500 Hz) with relatively high penetration, the boomer has medium frequencies (300-3000 Hz) and lower penetration, and TOPAS has a chirp function with frequencies between 2 and 6 kHz and low penetration.

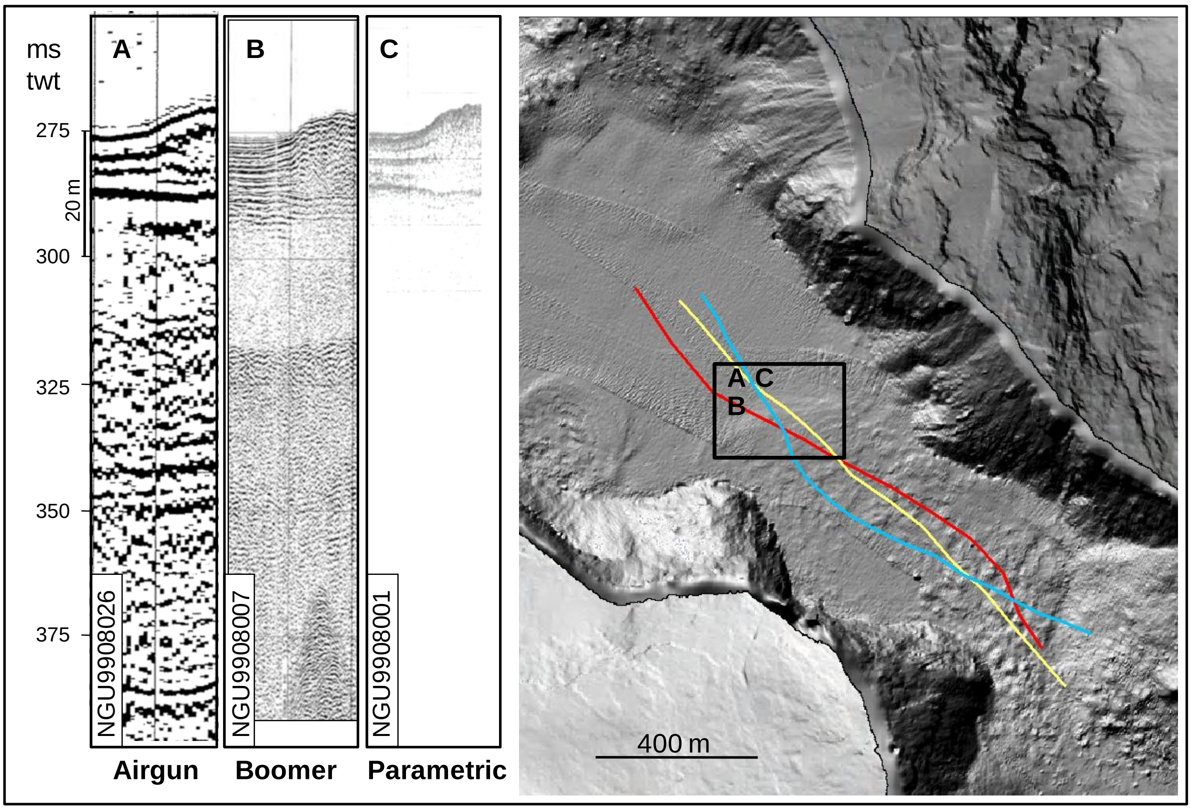

Figure 2. Examples of seismic records from three different sources in an area next to Heggurda in Tafjord. The airgun data has typically a vertical resolution 3-5 m, the boomer c. 1 m and the Topas 0.1-0.5 m. The uppermost layers are best resolved with the parametric source, while the airgun and boomer more clearly define the deeper structures. This demonstrates how a variety of sources can be complementary.

Table 1. Source, sweep and grid line distance for seismic lines used in report figures.

Seismic line	Area	Source	Sweep	1 grid line
9908001	Tafjord	Topas	125 ms	10 m
9908006	Tafjord	Topas	125 ms	10 m
9803007	Tafjord	Boomer	250 ms	20 m
9908026	Tafjord	Sleevegun	500 ms	40 m
0004020	Geirangerfjord	Sleevegun	500 ms	40 m
0004021	Sunnylvsfjord	Sleevegun	500 ms	40 m

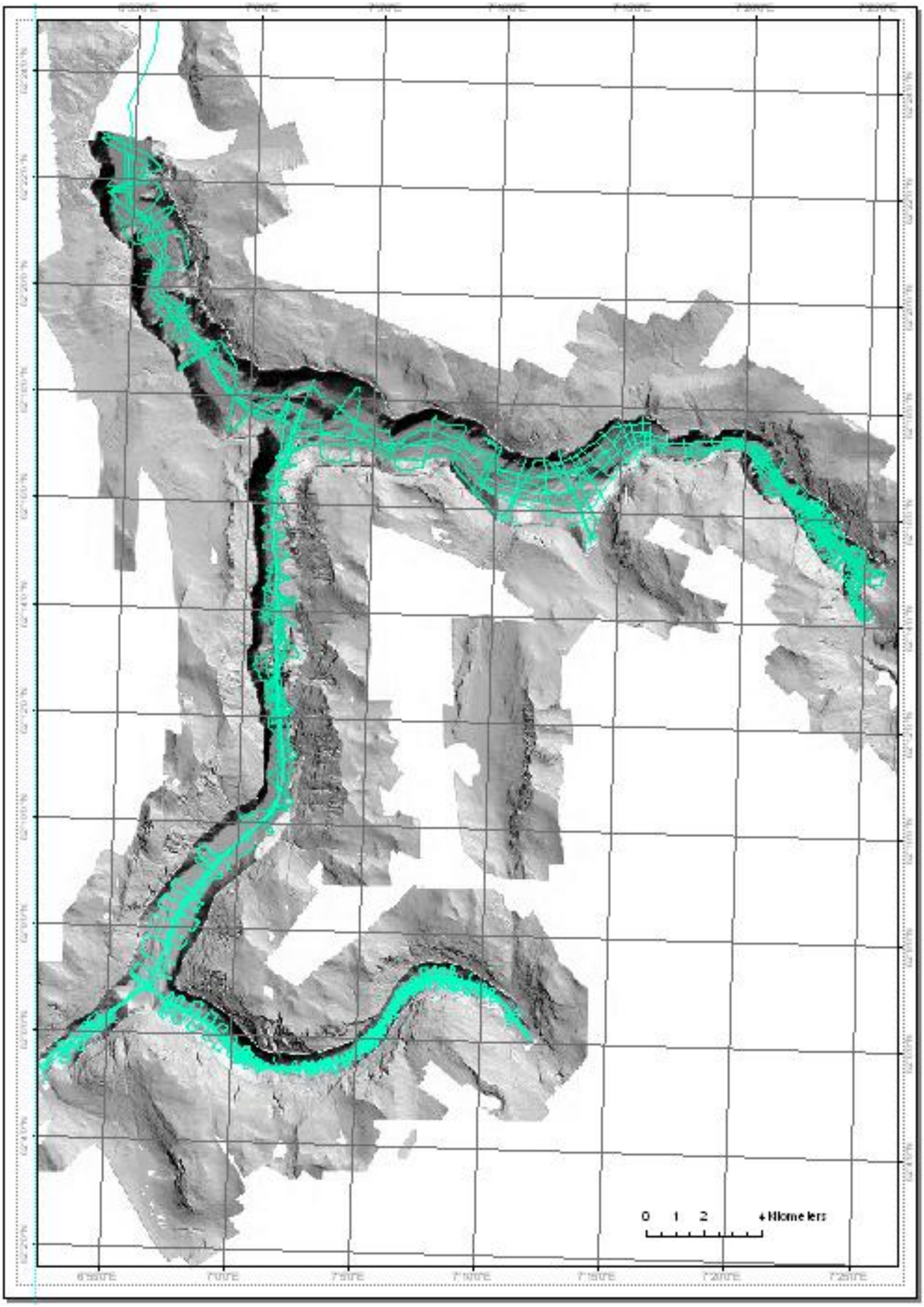

Figure 3. Location of seismic profiles.

3. DEGLACIATION HISTORY AND CHRONOLOGY

A relative chronology for the fjord sediments has been made based on one dated core, seismic stratigraphy and regional geological history. Ages are given in ^{14}C years BP.

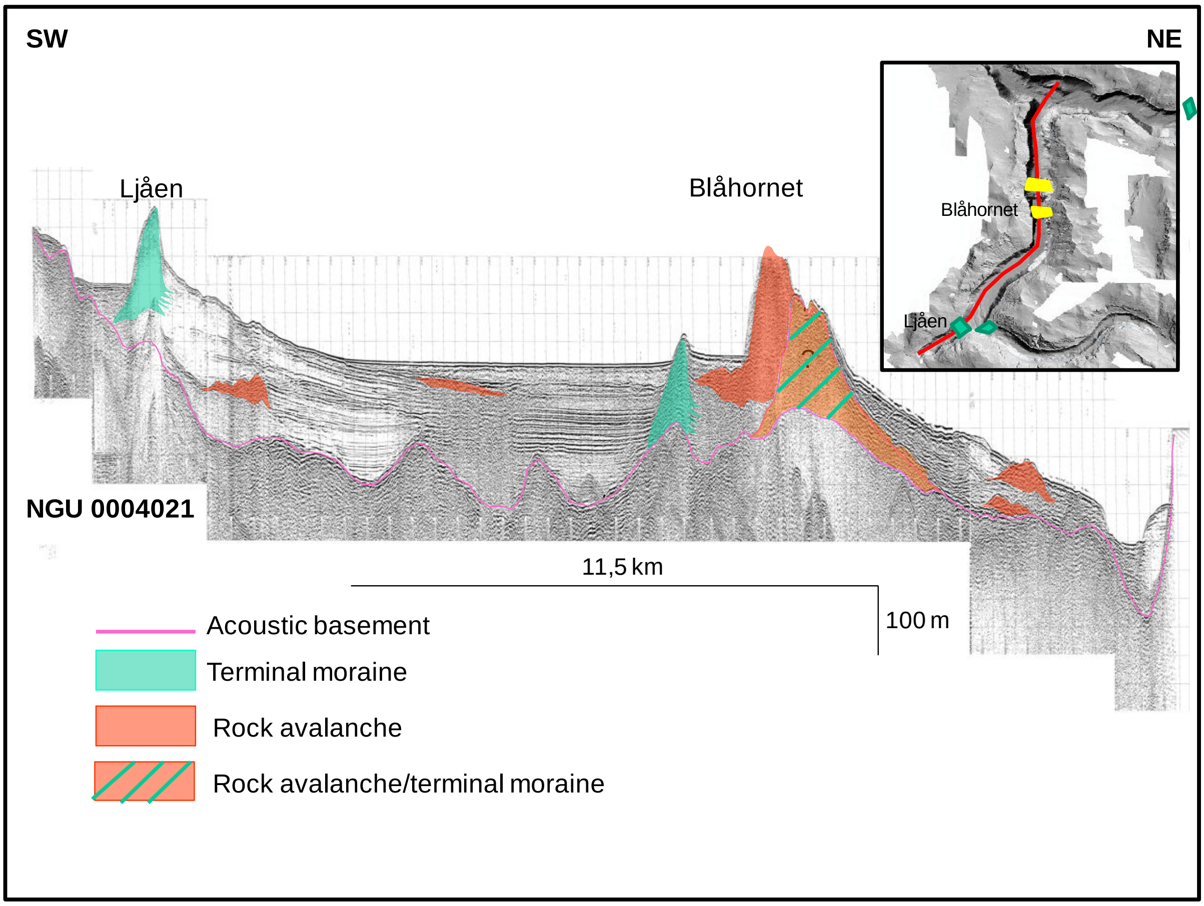

Figure 4. Interpreted sleeve gun profile along Sunnylvsfjorden (for location, see Fig.1). Approximate position of the profile is indicated by the red line on the inset figure. Green on inset figure: position of Younger Dryas re-advance end moraines; yellow marks glacial stops during the deglaciation below Blåhornet.

The deglaciation reached the inner parts of the fjords in this area during the Bølling/Allerød periods 13 000-11 000 ^{14}C years BP (Fareth 1987, Larsen et al. 1995, Aarseth et al. 1997). During the deglaciation, around 12 000 ^{14}C years BP, the glacier front had one or two halts at Blåhornet in the central part of Sunnylvsfjorden. From there the glacier retreated, probably with several short-lived still stands in Geirangerfjorden during the Allerød. In the following, cold Younger Dryas (YD) period 11 000-10 000 ^{14}C years BP, the glaciers readvanced and prominent terminal moraines were deposited. In Storfjorden, these moraines are found at the mouth of Geirangerfjorden (Korsfjorden), in Sunnylvsfjorden just south of Ljåen and in Nordalsfjorden at Linge (Fig. 4, inset). The maximum readvance stage has been dated to c. 10 500 ^{14}C years BP (Fareth 1987). The retreat from the YD terminus was rapid and the fjords were probably ice free around 10 000 ^{14}C years BP. During the retreat, thick beds of glaciomarine sediments were deposited in the deeper basins in the inner fjord arms like Geirangerfjorden and Tafjorden.

A seismic profile from the central part of Sunnylvsfjorden (Fig. 4) has been interpreted according to this history. A thick wedge of pro-glacial sediments from the YD advance to Ljåen/the mouth of Geirangerfjorden lies on top of acoustically laminated sediments from the Allerød, as indicated by the blue dotted line representing the approximate 11 000 ^{14}C years BP seafloor. Deep channels on the surface of this wedge, in front of the terminal moraines, witness about huge volumes of glacial melt water during the latest part of the advance. Distal sediments from the meltwater flow fill the central basin towards the Blåhornet moraine(s). The top of the fill facies is indicated by the orange dotted line. Sediments above this line are 3-5 m thick and were deposited during the Holocene (last 10 000 ^{14}C years). Locally, in basins directly in front of the largest rivers or where slides have deposited debris on the sea floor, the Holocene unit can be thicker. An upward shift in seismic signature from chaotic with diffractions to transparent or acoustically laminated, usually characterizes the Late Glacial-Holocene boundary.

In Tafjorden we have one dated core (Bøe et al. 2004). At c. 0.9 m depth in the core the age is c. 3000 ^{14}C years BP. The core (P 0103026) is shown in Figs. 5 and 6 together with Topas and boomer profiles crossing the core locality.

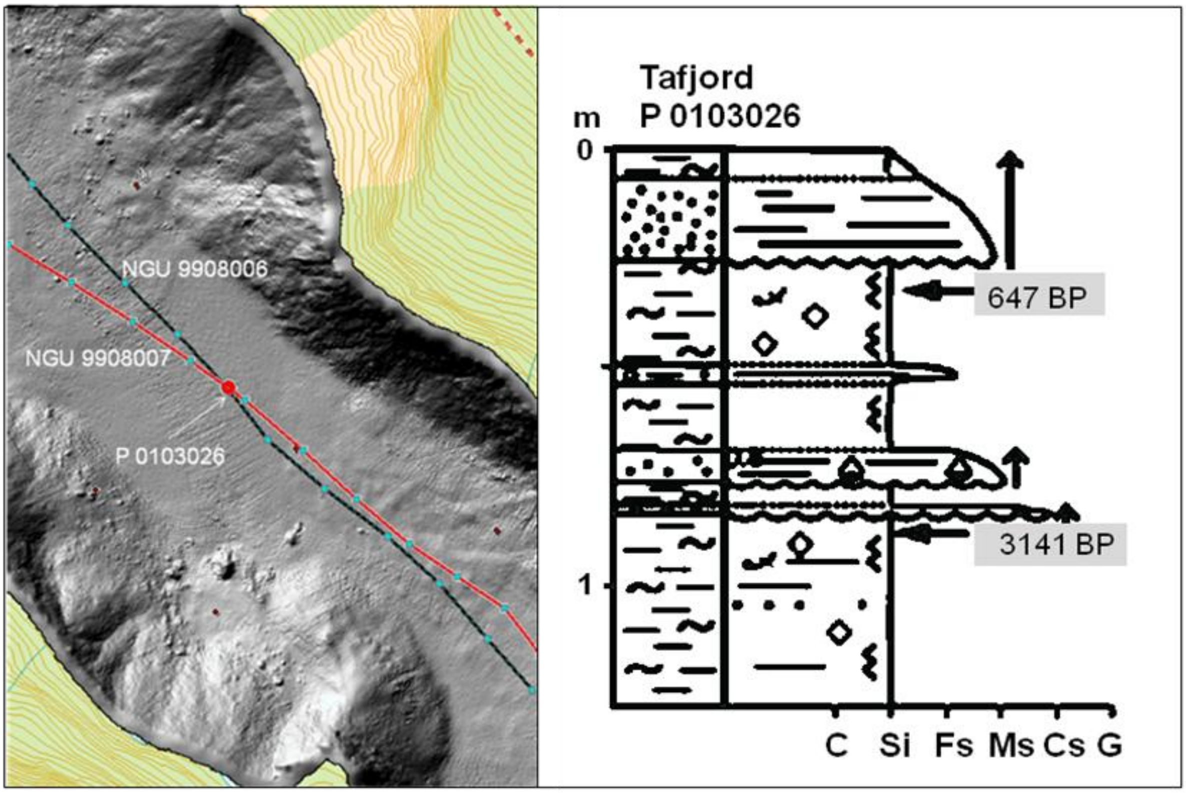

Figure 5. Position of dated core and seismic profiles are shown in Fig. 6. The dots on the seismic lines mark vertical grid lines on the seismic profiles. The core log is from Bøe et al. (2004). The ages are given in calendar years. The corresponding reservoir corrected ^{14}C ages BP, are 690±55 and 2900±70.

With the assumption that sedimentation rates were higher in the first part of the Holocene, with little vegetation and easily erodible sediments onshore, we estimate the thickness of Holocene fjord sediments to be c. 6 m at this locality. This fits well with the seismic records as shown in Fig. 6. For interpretation of ages of rock avalanches embedded in the Holocene unit, the seismic stratigraphy has been divided in time slots (Fig. 6). Seismic reflectors in

Tafjorden can be traced over long distances, and we do not think that this correlation introduces large errors.

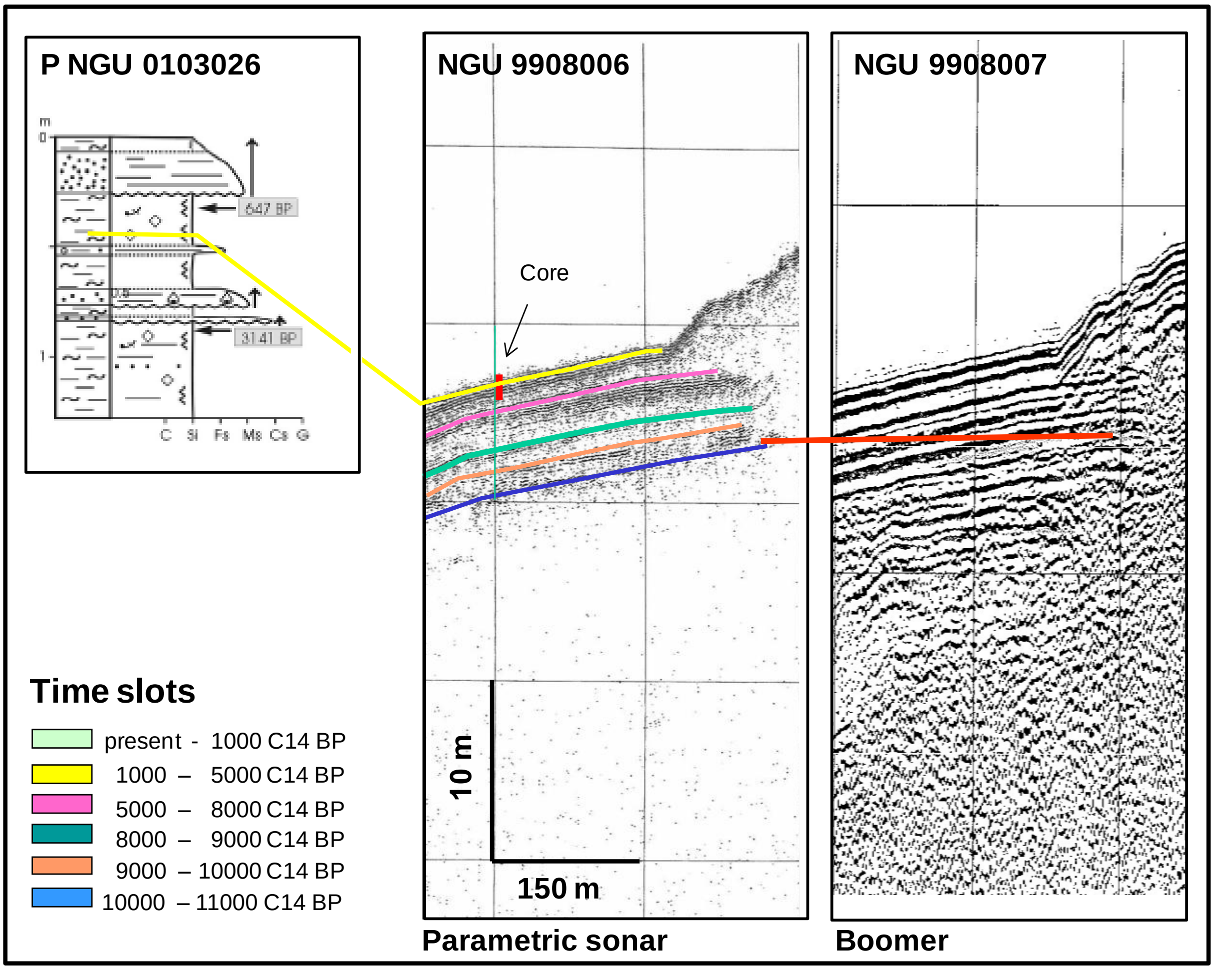

Figure 6. In core P0103026, acoustically laminated hemipelagic sediments alternate with more sandy, turbiditic layers initiated by rock-avalanches. About one third of the core comprises turbidites. That shows that the Holocene succession is thicker in fjord areas with frequent slide events.). The ages are given in calendar years. The corresponding reservoir corrected ^{14}C ages BP, are 690±55 and 2900±70.

Based on the stratigraphy in Sunnylvsfjorden and Tafjorden, a chronology has been proposed for the whole fjord system. Ages are relative, but contemporaneous events can be traced from fjord to fjord.

It is assumed that sediments in the fjords inside the YD terminal moraines were removed by erosion during the re-advance, and that all deposits seen on the seismic records are younger than 10 600 ^{14}C years BP. However, it is possible that older slide debris (e.g Allerød) has survived glacial erosion, and is misinterpreted as till or bedrock.

4. INTERPRETATION AND MAPPING OF ROCK AVALANCHES

The Holocene succession is less than 6 m thick (Fig. 6). Therefore, debris from large avalanches can be recognized as morphologic elevations of the sea floor, even if they are buried by younger sediments. Young avalanches have a rougher surface morphology than old ones, and a first interpretation of slide events and relative ages was based on their morphology (Fig. 7). This was followed by interpretation of the seismic records. On the seismic data, a rock-avalanche debris lobe will have a chaotic seismic signature in contrast to the transparent or acoustically laminated hemipelagic deposits above or below it. In some cases, it may be difficult to see through avalanche deposits in seismic data. Normally, fjord sediments show regular acoustic lamination. Seafloor sediments may however, be deformed by rock avalanches, and deformation features again draped by younger sediments. Deformed sediments and irregularities in the acoustic lamination hence point to rock-avalanches.

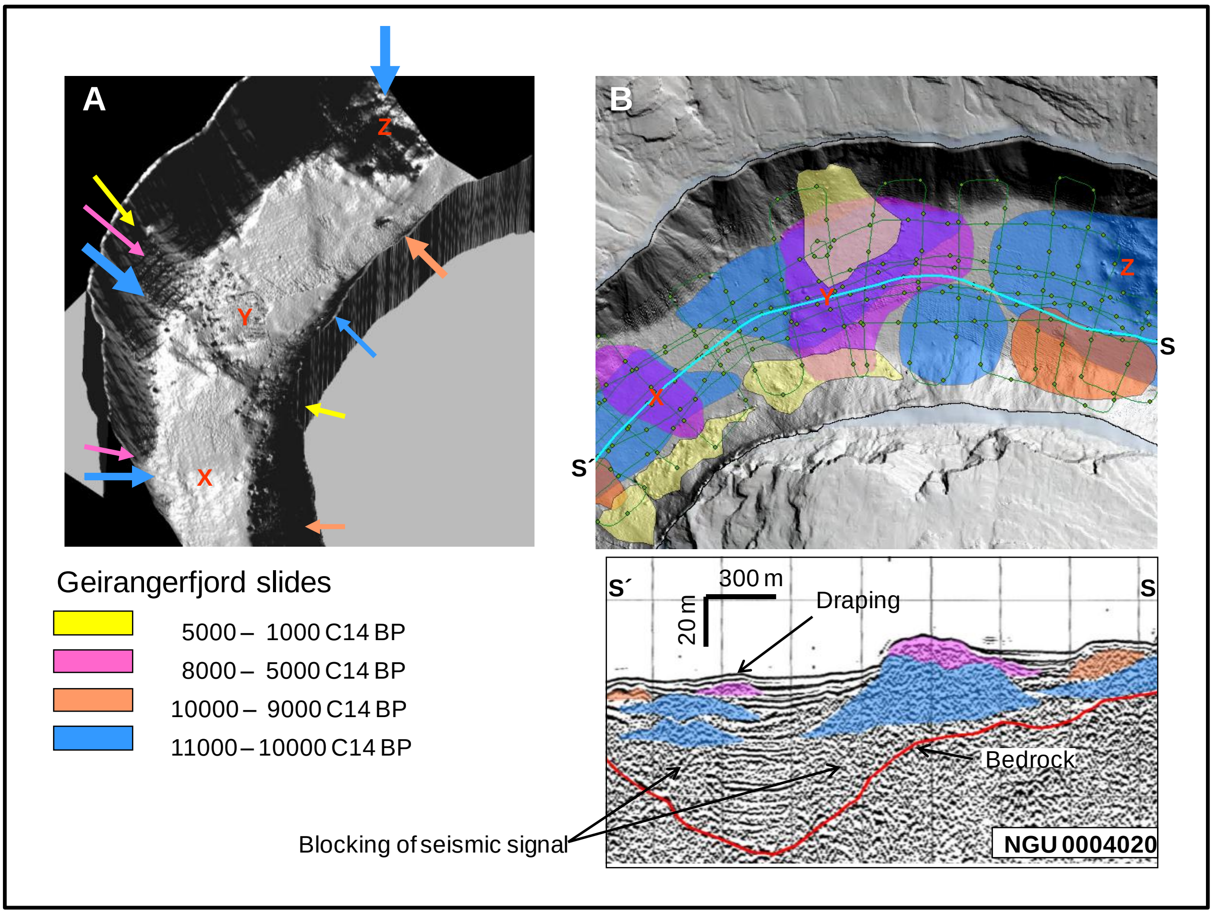

Figure 7. Morphologic and seismic interpretation of rock-avalanche deposits and age estimates of slides in Geirangerfjorden. The shaded relief image (A) demonstrates how younger avalanches have rougher morphology than older, deeper buried ones. The colour and size of the arrows indicate the source, age and size of different avalanches. Seismic lines (green) and deposition areas of avalanches are shown in B. The seismic diagram shows stratigraphical interpretation of slides. Note how the rock-avalanche deposits block seismic energy.

A dense grid of seismic lines with different resolution and penetration has enabled identification of stratigraphic position of slide deposits and to adjust areal extent of slide lobes. It has also enabled estimation of thickness of debris lobes and estimation of volumes of slides. If several slides are from one, or a nearby source area, the combination of seismic with different resolution makes it possible to map individual slide lobes and to place them chronologically. Since the hemipelagic sedimentation has been rather slow and the slide activity high, it is not always possible to observe fine grained deposits between the lobes. Therefore there are uncertainties as to whether deposits reflect one or several events. Rock-debris commonly blocks acoustic energy and if avalanche deposits occur close to bedrock it is difficult to discriminate between bedrock and rock-avalanche deposits. This has implication both for the number of mapped slide events and for the estimated volumes of single events.

Fans along the fjord sides (Fig. 7 B) can be colluvial fans, rockfall cones, rock-avalanche deposits or a combination of these. In cases where the fans lie outside distinct creeks or gullies and flow patterns can be seen on the fan surface, we have interpreted them as colluvial fans. If they lie beneath marked slide scars or where the soft sea floor sediments are deformed due to the fan, we have interpreted them as rock avalanches. In many cases it is difficult to distinguish between rock avalanches with volumes of more than 100 000 m^3, and rockfall and colluvial cones. Hence the number of avalanches may be higher than listed in the inventory (Appendix 1, Table 2).

4.1 Volume estimates

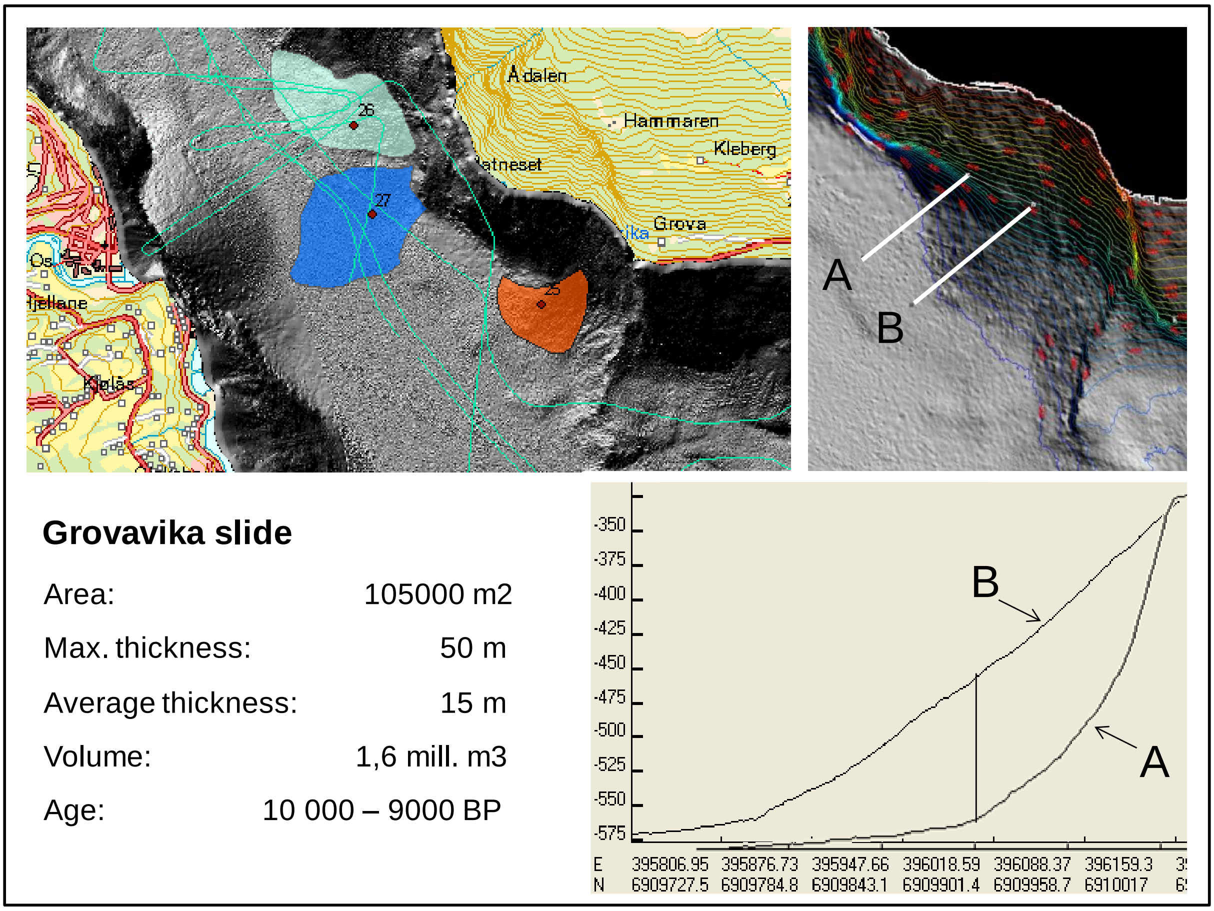

Figure 8. Example of the volume estimate of rock avalanche number 25. See text for explanation.

Fig. 8 gives an example of volume estimates of slide debris. A is a profile of the fjord side immediately north west of a rock-avalanche fan (slide no. 25) and is interpreted as an approximate profile of the bedrock beneath the cone. B shows the morphology along the thickest part of the fan. Combined they give the maximum thickness of the deposit. From this, an average thickness is found, which is multiplied by area of the fan to find volume. The thickness of fans partly buried in fjord sediments are interpreted from seismic records, e.g. slide 27 in Fig. 8.

5. SLIDE INVENTORY

Altogether, 108 rock avalanches have been mapped and volumes of 107 avalanches estimated. A database of all mapped events is presented in Appendix 1, Table 2 and contain position, area, seismic lines used for interpretation, maximum/minimum thickness, volume, age estimates, quality index and comments. The inventory does not give the source area for the avalanches, but the shape and position of the slide lobes gives strong indications for which fjord side the rock fell from. Many of the debris lobes lie underneath marked scars in the cliff and the source for the slide seems obvious (Fig. 8). However, in this report we do not try to fit the different slides to their source. This can probably be done with a great degree of certainty, but that task is left for later.

5.1 Rock avalanche volumes and frequencies

Out of 107 events, 25 occurred during the deglaciation (12 500-10 000 ^{14}C years BP, Table 2, Fig. 9). These events deposited 522 million m^3 of a total of 587 million m^3, or 89 % of the total rock-avalanche volume (Fig. 10). Of the slides during the Holocene (after 10 000 ^{14}C years BP), 53% of the events comprising 49% of the Holocene avalanche volume was deposited during the first millennium after the final deglaciation. The high frequency may be related to frost activity, melting of permafrost, exfoliation and strong earthquakes due to rapid isostatic rebound. Nineteen of the events have volumes smaller than 0,1 mill. m^3, i.e. not rock avalanches per definition. However, since it has been possible to identify these slides, they have been registered in the inventory and used in the statistics.

Table 2. Summary of the slide inventory.

Period : 1000 years BP	12,5 - 11	11 - 10	10 - 9	9 - 8	8 - 5	5 - 1	1 - 0
Number of events	6	19	26	5	16	30	5
Events per 1000 years	4	19	26	5	5	8	5
Total volume mill. m^3	354	168	31,7	6,7	3,9	15,5	7,6
Average volume mill. m^3	59	8,8	1,2	1,3	0,2	0,5	1,5
Volume per 1000 years	236	168	31,7	6,7	1,3	3,9	7,6

As seen from the table, the largest rock avalanches occurred during or immediately after the deglaciation. A similar pattern has been observed in Trondheimsfjorden (Bøe et al. 2003). Five of these slides – no. 39, 40, 2, 1, 51 (Figs. 16, 17, Appendix 1) – account for 79% of the total slide volume alone. For Sunnylvsfjorden/Nordalsfjorden deglaciation occurred at 12 500-11 000 ^{14}C years BP and the largest mapped rock avalanches in these fjords occurred during this period. The largest events, number 39 and 40, are found at Blåhornet in Sunnylvsfjorden, c. 4 km north of the slide risk area at Åknes (Blikra 2008). The controlling factors for the slide were probably similar to Åknes, with deep-seated slide planes along foliation planes, and large fractures cutting through.

In Tafjorden and Geirangerfjorden and the innermost part of Sunnylvsfjorden, the final deglaciation occurred between 10 500 – 10 000 ^{14}C years BP. According to size, slides number 3 and 4 are found in Tafjorden (at Heggurdaksla and Kallskaret). These are interpreted to have occurred as the ice withdrew during the Younger Dryas. Avalanches into ice free parts of these fjords during the Allerød may have been picked up by the readvancing glacier in the early stages of the Younger Dryas and incorporated into till and terminal moraine ridges. The moraine ridge across Korsfjorden, the outer part of Geirangerfjorden, has a wide, untypical shape for YD moraines, and it is possible that large numbers of Allerød rock avalanches are incorporated in the ridge and that the number of large slides during 12 500-11 000 ^{14}C years BP is higher than we have recognized.

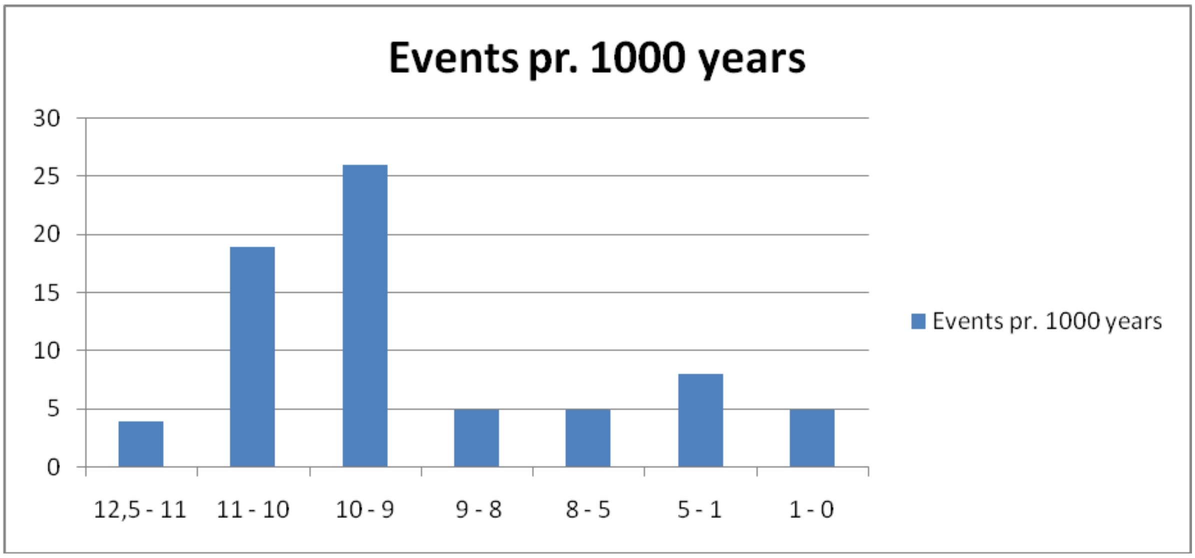

Figure 9. Number of rock-avalanche events per 1000 years.

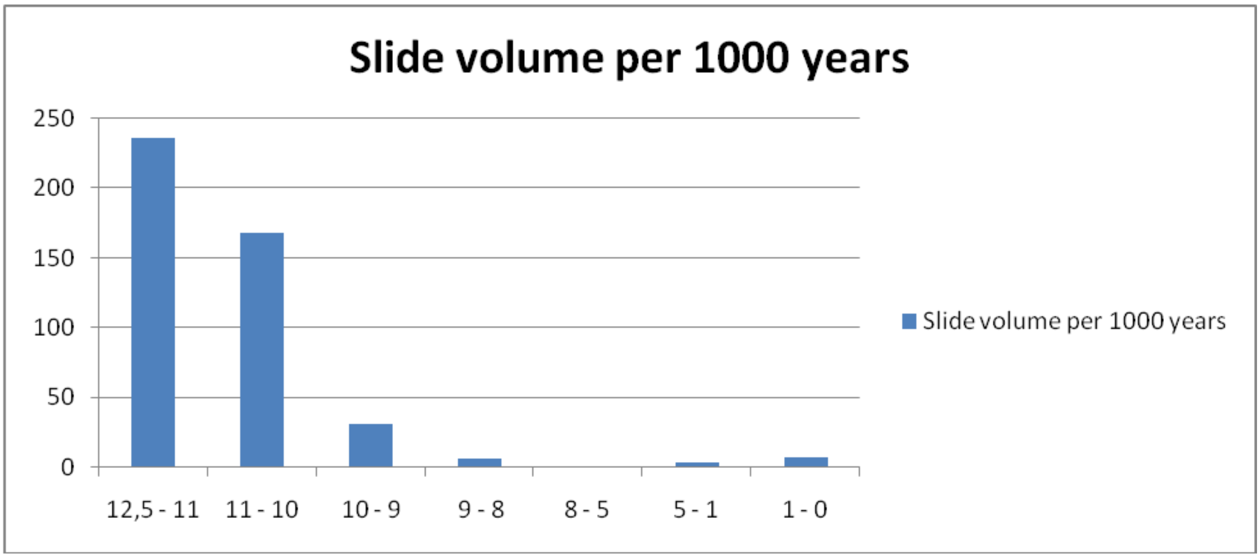

Figure 10. Rock-avalanche volumes per 1000 years.

Since c. 9000 BP, the number of events has been 5-8 pr. 1000 years or one large event every 150 years for the fjord system as a whole. The rock avalanches were generally smallest between 8000 and 5000 ^{14}C years BP with a slight increase in avalanche size towards the recent (Fig. 10, Table 2). The data also demonstrates that there is no simple relationship between age and frequency of events. The concept of a general reduction in frequency from the deglaciation until today seems not to be real in this area. This means that there are possibly several controlling factors of importance for the generation of rock-slope failures.

6. SPATIAL DISTRIBUTION OF ROCK-AVALANCHES

The rock-avalanche activity is not equally distributed thoughout the fjord system. In Table 3, the slide inventory is broken down to separate stretches of the fjord and total values and Holocene values are given. Avalanche maps of the individual areas are given in figures 14-18.

Table 3. Rock-avalanches and volumes in different parts of the fjord system (for location see Fig. 1). The Holocene numbers cover the period after 10 000 ^{14}C years BP.

Fjord	Total number of events	Total volume mill. m^3	Average slide volume mill. m^3	Number of Holocene events	Holocene slide volume mill. m^3	Average Holocene slide volume mill. m^3
Geirangerfjord	56	40,6	0,7	44	19,1	0,4
Sunnylvsfjord	17	363,3	21,4	12	22,2	1,9
Tafjord	20	144,8	7,2	16	18,4	1,2
Nordalsfjord	4	6,6	1,6	4	6,6	1,6
Storfjord	11	31,7	2,9	6	22,9	3,8

Rock-avalanches are most frequent in Geirangerfjorden, with Tafjorden and Synnylvsfjorden as number two both totally and during the Holocene (Fig. 11, Table 2). In Nordalsfjorden and Storfjorden only four and six slides are registered, respectively.

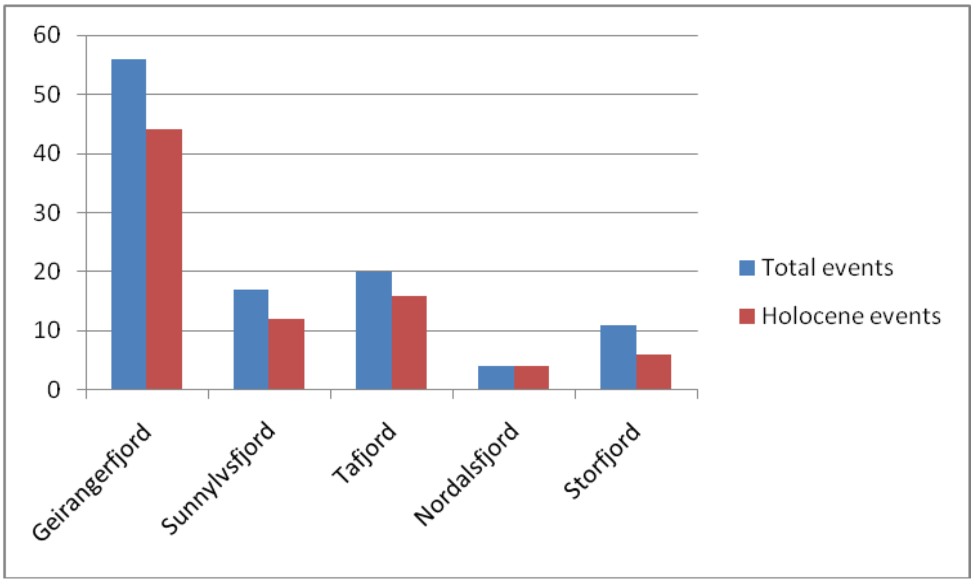

Figure 11. Number of events per fjord.

Fig. 12 shows that the majority of the avalanche debris are related to avalanches in Sunnylvsfjorden and Tafjorden during the deglaciation, while Fig. 13 shows that the volumes during the Holocene are almost equal for the different fjords with the exception of Nordalsfjord. The average size of the events differs, with the smallest slides in Geirangerfjorden and the largest in Storfjorden. Nordalsfjorden has only a few, relatively small events and they are all from Skrenakken, early in the Holocene (Table 4).

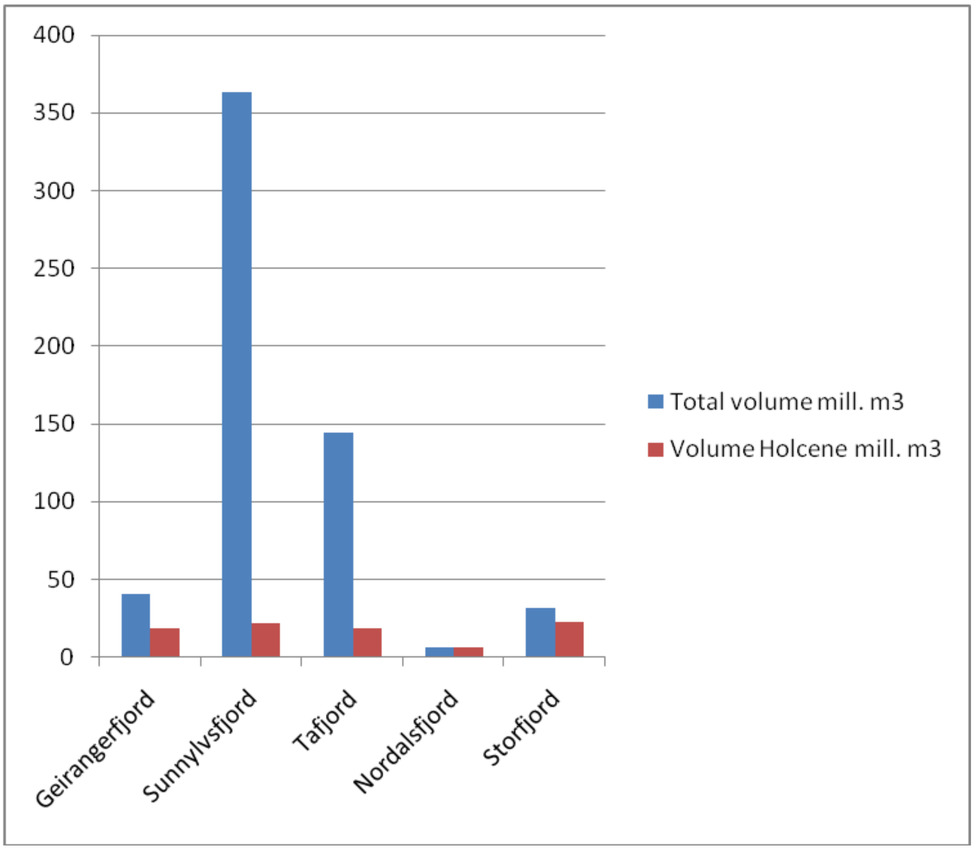

Figure 12. Rock-avalanche volumes per fjord.

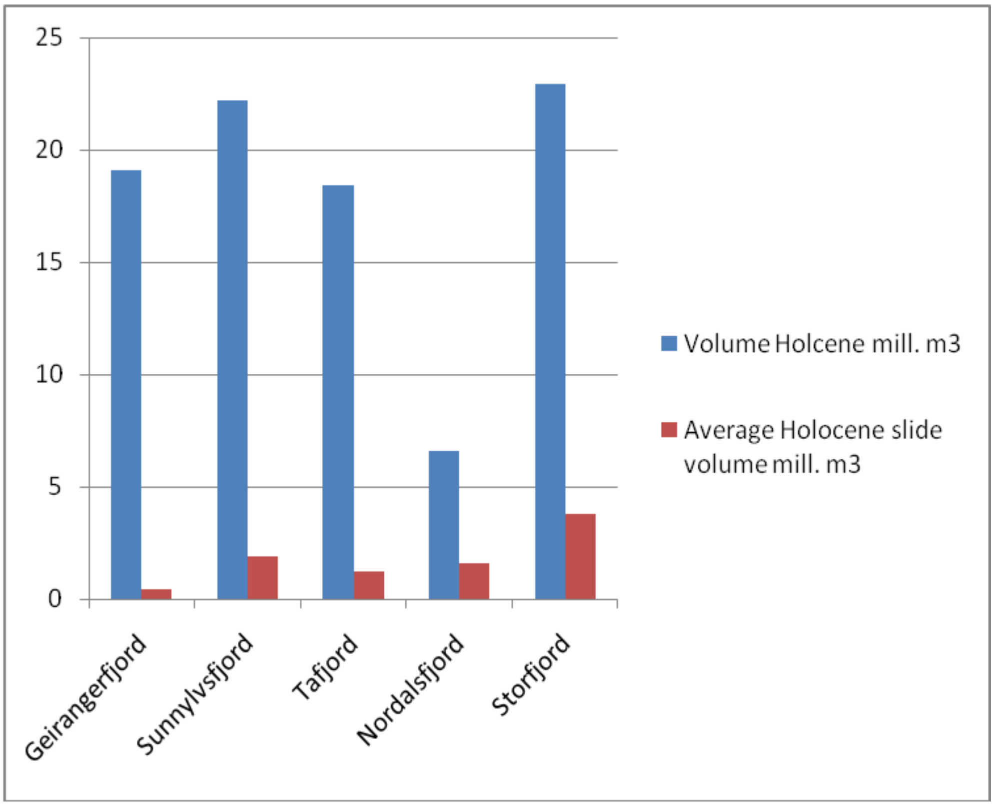

Figure 13. Total and average Holocene rock-avalanche volumes for the different fjords.

Table 4. Holocene events per. 1000 years and per fjord (total numbers for a period are given in brackets), average slide volumes, and frequencies for the last 9 000 ^{14}C years BP.

Fjord /Period (^{14}C years BP)	10-9	9-8	8-5	5-1	1-0	Av. size mill. m^3	Average frequency since 9000 ^{14}C years BP
Geirangerfjord	12	3	3 (10)	4 (17)	2	0,3	1/350 years
Sunnylvsfjord	5	1	1 (2)	1 (3)	1	2,7	1/1300 years
Tafjord	2	1	1 (4	1 (8)	1	1,2	1/650 years
Nordalsfjord	4				0	0	
Storfjord	3			0,5 (2)	1	2,9	1/3000 years

The earliest part of the Holocene had many rock avalanches compared to the rest of the Holocene (after c. 9000 ^{14}C years BP). Since then, the number of events per thousand years has been approximately constant for Geirangerfjorden, Sunnylvsfjorden and Tafjorden, while Storfjorden has little, but slightly increasing rock-avalanche activity over the last 5000 ^{14}C years BP. Nordalsfjorden has no rock-avalancehe activity during this period (Table 4).

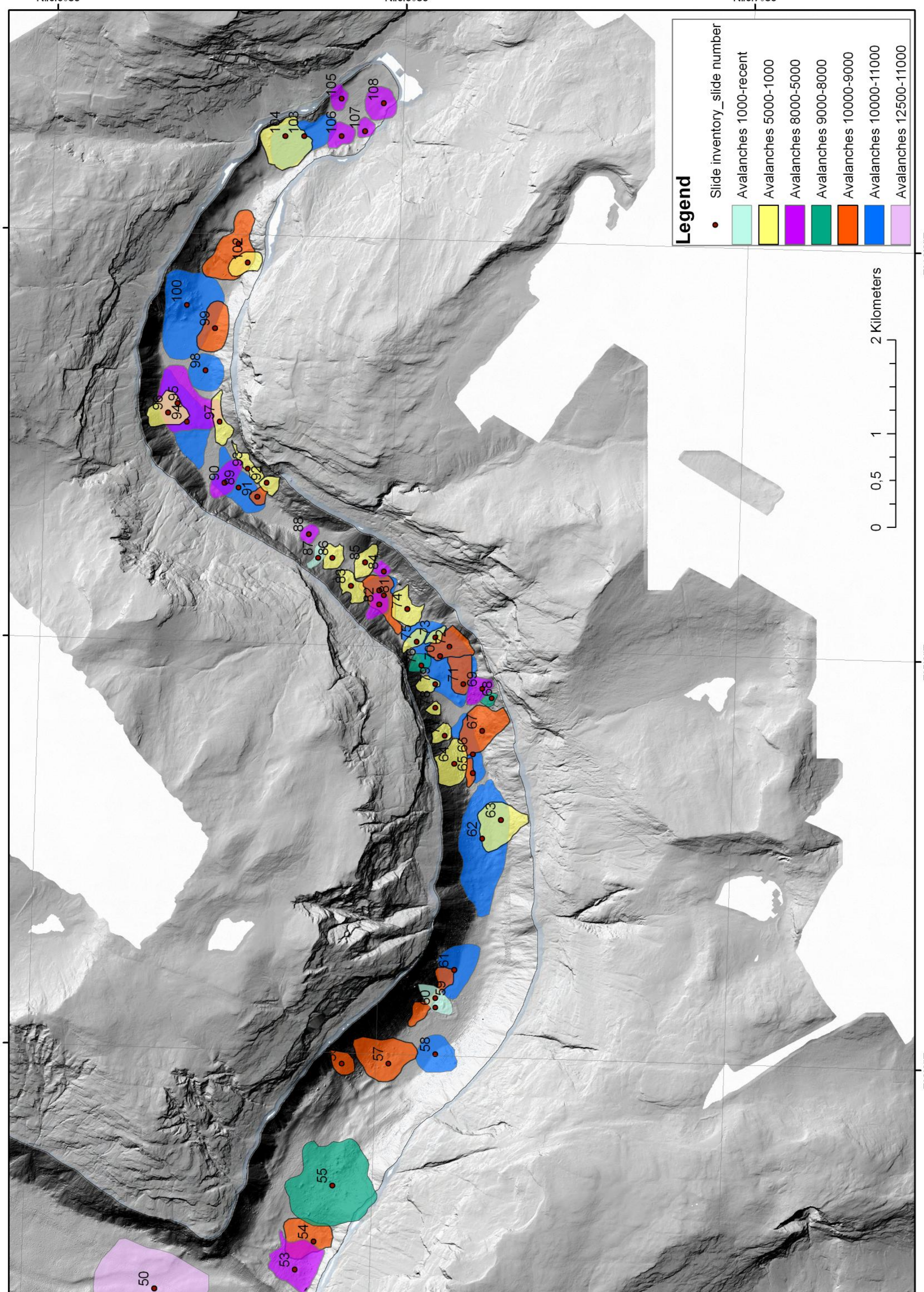

Figure 14. Rock-avalanches in Geirangerfjorden.

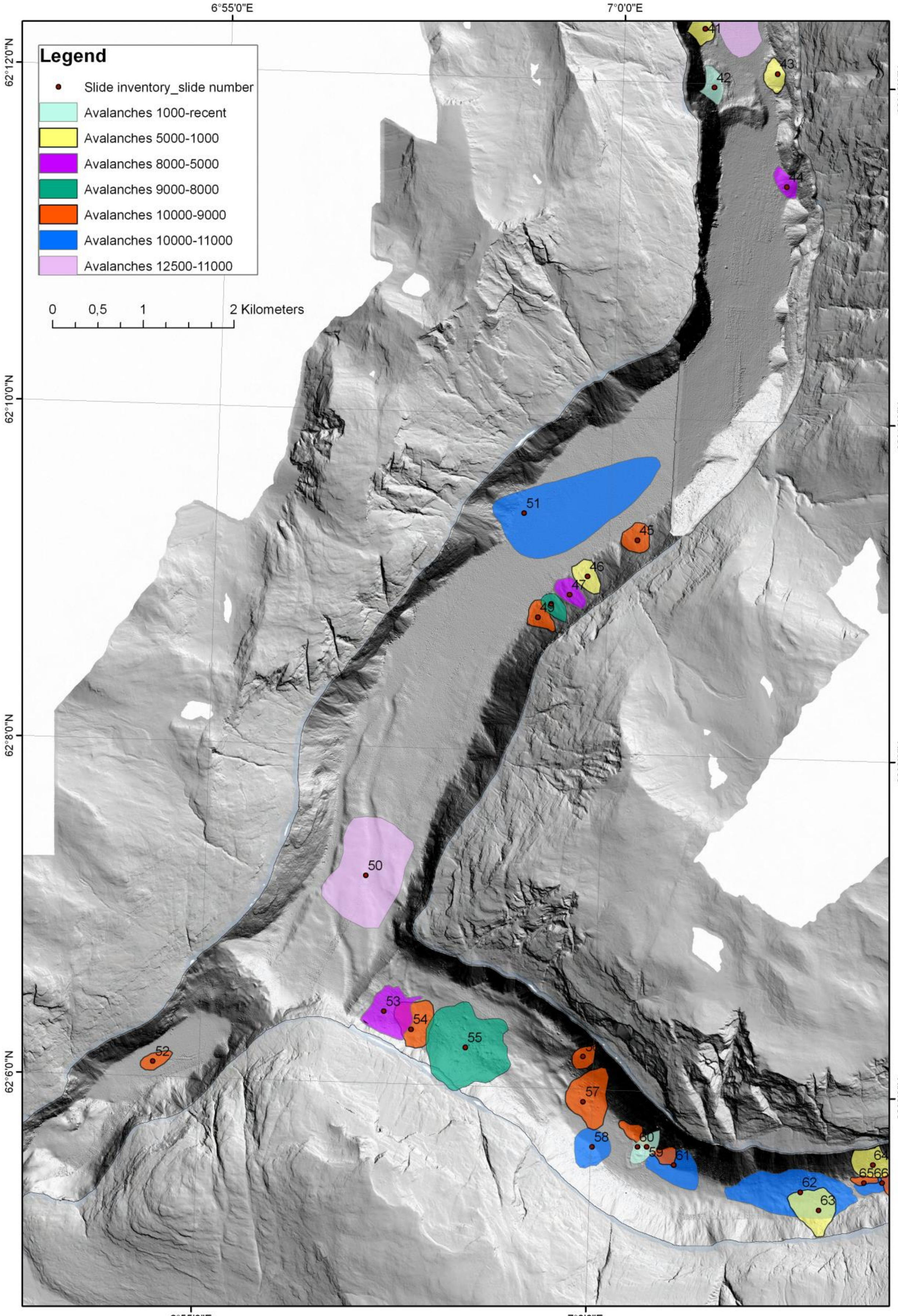

Figure 15. Rock-avalanches in the southern part of Sunnylvsfjorden.

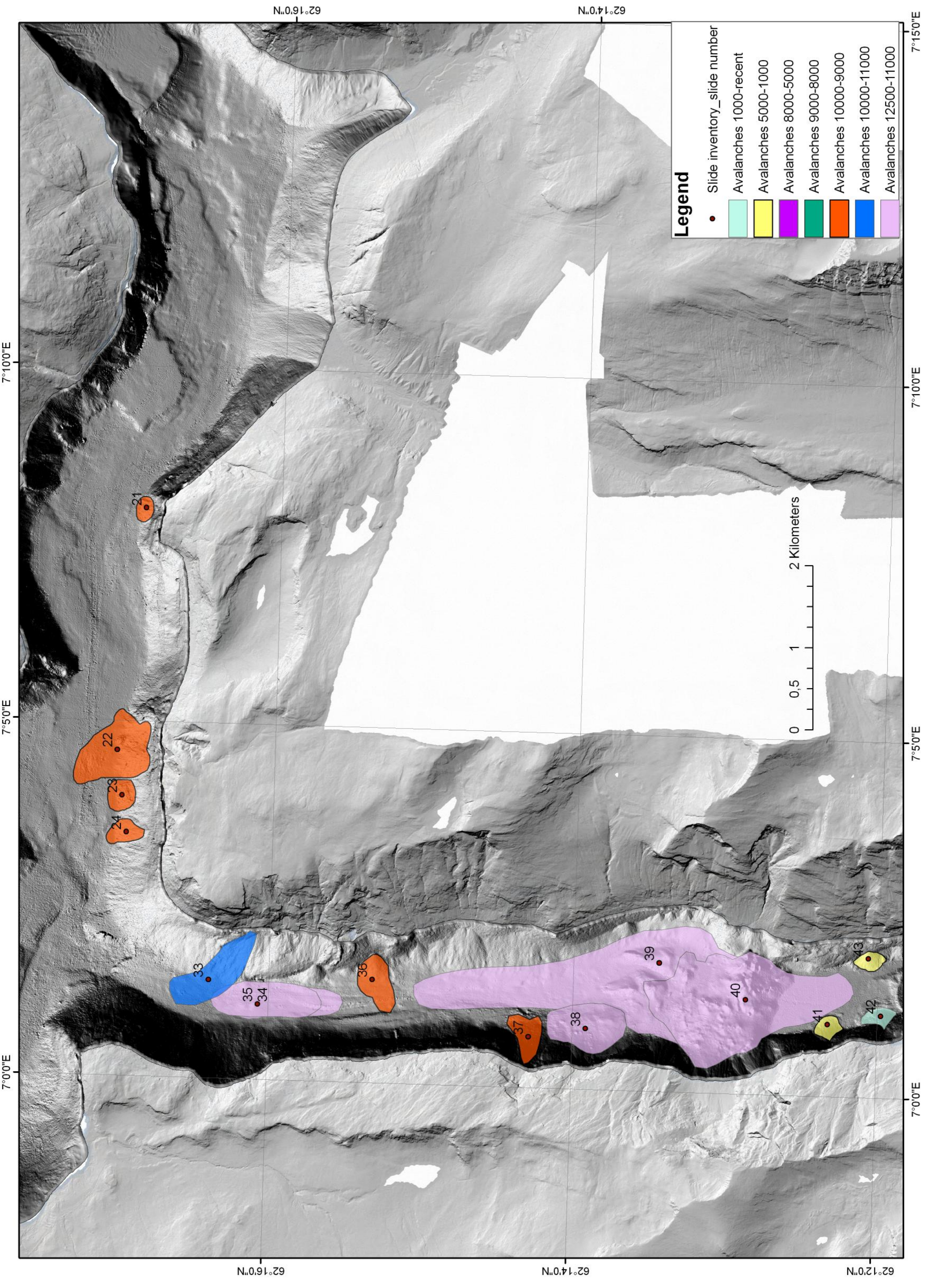

Figure 16. Rock-avalanches in the northern part of Sunnylvsfjorden and Nordalsfjorden.

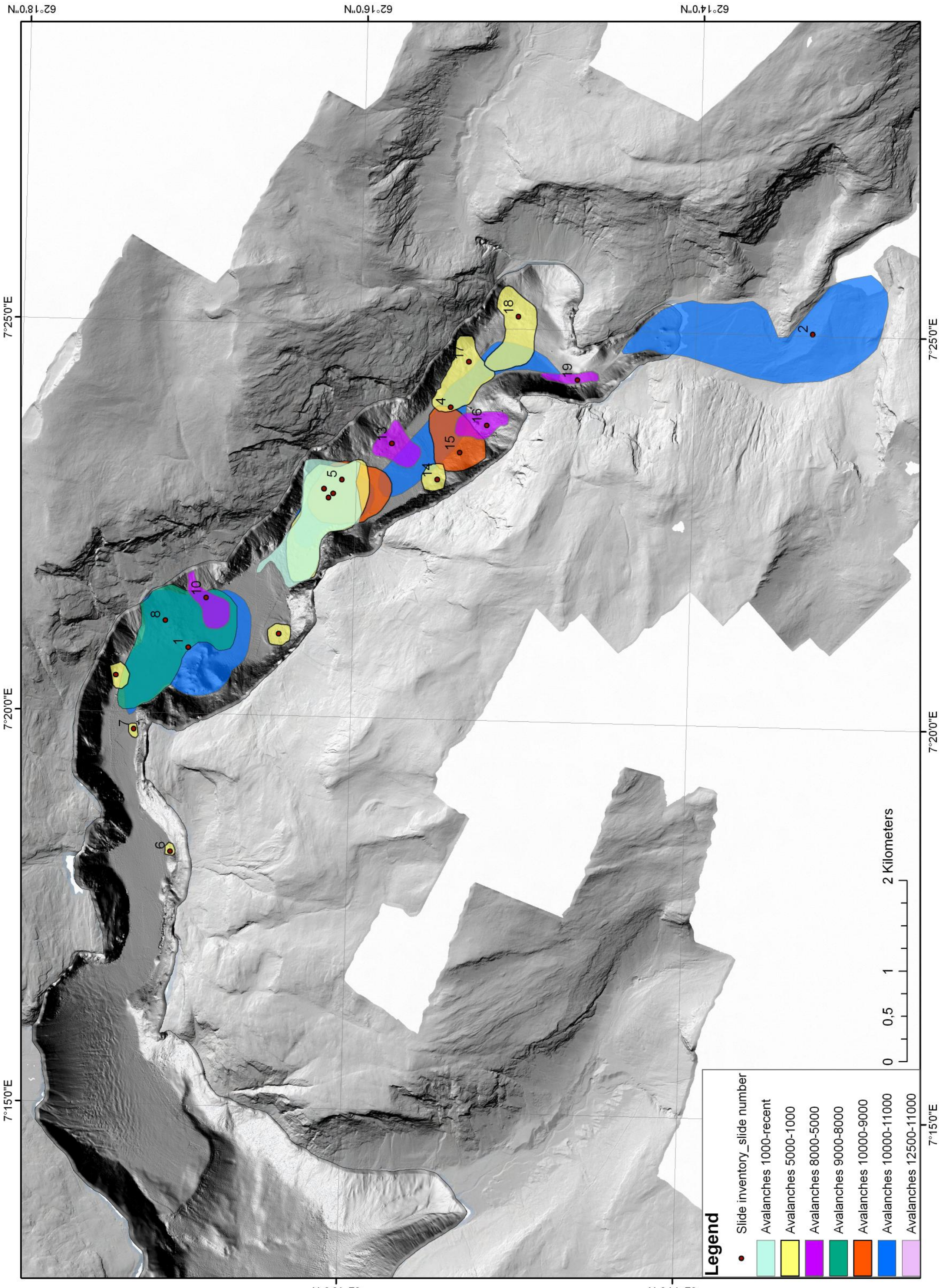

Figure 17. Rock-avalanches in Tafjorden.

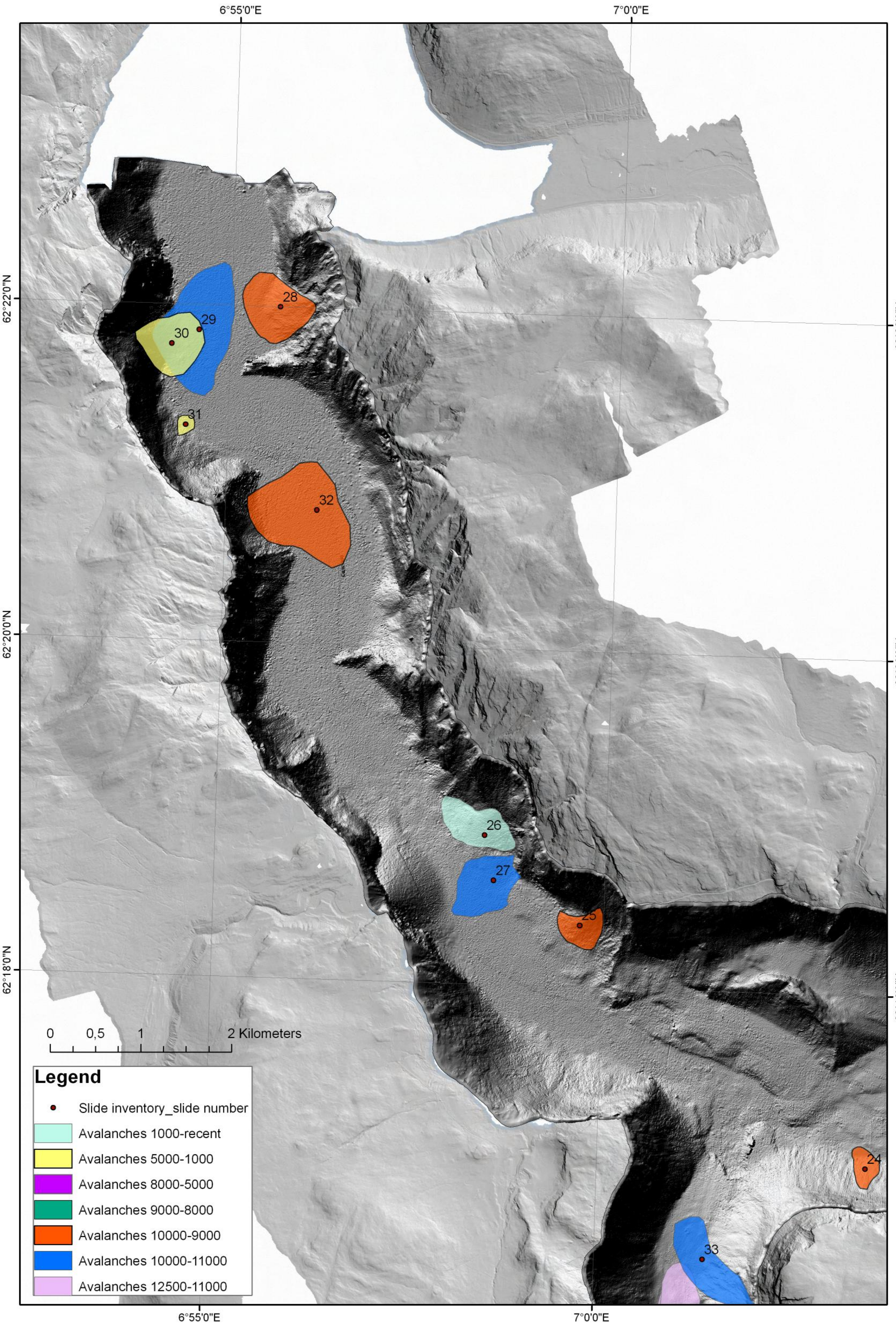

Figure 18. Rock-avalanches in Storfjorden.

7. CONCLUSIONS

In the inner part of Storfjorden, 108 rock-avalanche deposits have been mapped on the fjord bottom from swath bathymetry and shallow seismic data. The age of individual avalanches is based on one radiocarbon dated core, regional deglaciation history and seismic stratigraphy, and a slide inventory has been made.

Twenty five events occurred during the deglaciation (12 500-10 000 ^{14}C years BP). These rock avalanches constitute 522 million m^3 of a total of 587 million m^3, or 89 % of the total volume. Five of these slides contribute 79% of the total avalanche volume. Twenty one slides are equal to or larger than the 1934 Tafjord Slide, but only six of them occurred during the Holocene.

The avalanche activity was especially high shortly after the final deglaciation c. 10 000-9000 ^{14}C years BP. Since then, the number of events per 1000 years has been relatively constant, with five to eight events for the fjord system as a whole.

The rock-avalanche activity differs from fjord to fjord within the system, with the highest activity in Geirangerfjorden. Here we see a frequency of one slide every 350 years. The average size of the slides, however, is smaller than in other fjords. In Tafjorden the frequency is one slide every 650 years, in Synnylvsfjorden one slide every 1300 years and in Storfjorden from Stordal to the mouth of Sunnylvsfjorden, the observed frequency is one slide every 3000 years.

The data clearly shows that Storfjorden in Møre og Romsdal has a relatively high frequency of large rock-avalanches. This demonstrates also the need for investigations to document unstable and active rock slopes in the fjord areas.

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APPENDIX 1

Slide inventory. Database over registered rock-avalanches on the fjord bottoms in the inner part of the Storfjorden and tributary fjords, Møre og Romsdal County.

Fjord	Slide no.	Source area	X utm32	Y utm32	NGU seismic lines	Area 1000 m^2	Thick-ness max	Thick-ness average	Volume mill m^3	Age ^{14}C-ka	Interpretation quality 1- 7(best)	Comments
Tafjord	1	Heggurdaksla	414250	6906800	8609001,9908001,003,006,007,009,026	1350	50 m	15	20	11-10	2	Huge rock avalanche. Some glaciomarine deposits in the fjord prior to event. Huge blocks, most likely toppling.
Tafjord	2	Kallskaret	417700	6899900	8609001,019,020,021,9908001,002,007,008				100	11-10	2	Megaslide from Kallskaret. Most of slide deposits on land. Distal parts in inner fjord arm. Not able to map debris flow continuously further to the west. Limitation partly on morphology.
Tafjord	3	Heggurda	415900	6905250	9908026	450	20	7	3,2	11-10	2	Interpreted from seismic. Volume estimates uncertain.
Tafjord	4	Uncertain	416900	6903900	8609001,009,010,016,9908007,024	790	10	4	3,2	11-10	2	Irregular seismic reflector indicating slide surface. Can be distal part of slide from Kallskaret and thus part of slide Tafjord2. Another possible explanation collapse of seafloor sediments similar to what we see in Nordalsfjord. Possible slide scarp more than 20 m high. Volume estimates uncertain.
Tafjord	5	Heggurda	416100	6905100	8609001,006,007,008,009,010,011,012,013,014,015,9908026	310	15	5	1,6	10-9	3	Extent uncertain, overlain by younger slides and seismic unclear. First large slide from this location to be identified.
Tafjord	6	Middagshornet	412000	6907000		10		2?	0,02	5-1	6	Rock fall. Deformations of seafloor sediments.
Tafjord	7	Olsvikneset	413350	6907400	9908009	10		3?	0,03	5-1	6	Rock fall.
Tafjord	8	Heggurdaksla	414550	6907050	8609001,006,9908001,003,006,007,009,026	1000	10	5	5	9-8	4	May represent two episodes.
Tafjord	9	Stigflåna	413950	6907600	9908003	50	2	1	0,05	5-1	6	
Tafjord	10	Heggurdak/ytste Furuneset	414800	6906600		140		1	0,1	8-5	5	
Tafjord	11	Kasthøgfjellet	414400	6905800	8609006,9908003,006	50	2	1	0,05	5-1	6	Rock fall. Deformations of seafloor sediments.
Tafjord	12	Heggurda	415950	6905200	8609001,006,007,008,009,010,011,012,013,014,015,9908026	710	15	7	5	5-1	6	Repeated event. Not able to separate single events in an areal context on seismic records. Slidecone development - extending westwards. Volume probably underestimated.
Tafjord	13	Grunnvikkolvet	416500	6904550	8609001,016,9908001,003,004,006,007,009,026	160	15	3	0,5	8-5	5	Rock fall. Deformations of seafloor sediments.
Tafjord	14	Alvikhornet	416100	6904050	990802	65	2	1	0,07	5-1	6	Rock fall. Deformations of seafloor sediments.

Tafjord	15	Bjørnalaupet	416400	6903800	9908004	330	5?	2	0,7	10-9	3	Not well defined by seismic, may represent more than one event. Probably more than 50 m thick shelf of sediments at the southern side of the fjord. May mainly be till with a veneer of avalanche deposits, or mainly avalanche deposits. Volume of slide uncertain.
Tafjord	16	Seineskupå	416700	6903500	9908002	140	8	2	0,3	8-5	5	
Tafjord	17	Årødalen	417400	6903700	9908007	308	10	4	1,2	5-1	6	May be two episodes.
Tafjord	18	Muldal	417900	6903150	9908007, 9908026	330	8	2	0,7	5-1	6	
Tafjord	19	Geitvika	417200	6902500	9908008	65	5	2	0,1	8-5	5	Can be part of the Kallskardet avalanche, but probably not.
Tafjord	20	Heggurda	416000	6905300	9908007,991	750	12	4	3	1-0	7	April 20 1934. 44 people killed by tsunami waves.
Nordalsfjord	21	Ospahjell	403150	6906950		40	15	4	0,2	10-9	3	
Nordalsfjord	22	Skrednakken1	400206	6907308	9908015, 9908025	520	30	10	5,3	10-9	3	Rock avalanche. May originate from cliff well above sealevel or even from subsea slope.
Nordalsfjord	23	Skrednakken2	399650	6907250	9908015	160	20	5	0,8	10-9	3	Rock avalanche. May originate from cliff well above sealevel or even from subsea slope. No seismic grip on age, but from morphology most likely same age as the nearest slide to the east.
Nordalsfjord	24	Skrednakken3	399200	6907200		80	10	4	0,3	10-9	3	Rock debris cone. May consist of several avalanches or rockfalls.
Storfjord	25	Grovavika	396050	6909900		165	50	15	2,5	10-9	3	Rock avalanche. Age uncertain, but no visible deformation of seafloor sediments and therefore estimated to be "old".
Storfjord	26	Skafjellet	395000	6910900	9908010	307	40	12	3,7	1-0	7	Historical event, with tsunami and loss of lives. Probably debris from avalanche 8. of February 1731 which took at least 9 lives.
Storfjord	27	Skafjellet1	395100	6910400	9908010, 9908023	350	15	5	1,8	11-10	2	Vague elevation from slide debris on the seafloor. The debris lobe is interpreted from seismic to be a rock avalanche and to come from Skafjellet and to be of Younger Dryas age. A proper debris cone is lacking or somehow buried by younger slides.
Storfjord	28	Roshamna	392750	6916750	9908011, 9908023	400	35	11	4,4	10-9	3	
Storfjord	29	Svartevassnakken	391850	6916500	8905003, 99008010, 9908011, 9908023, 9908024	840	20	8	6,7	11-10	2	Two slides at approximately same locality. Can be separated as at least two events on seismic, but more difficult from morphology. Volume estimates are hence approximate.

Storfjord	30	Svartevassnakken 2	391550	6916350	8905003, 99008010, 9908011, 9908023, 9908024	350	10	4	1,4	5-1	6	Two slides at approx. same locality. Can be separated as at least two events on seismic, but more difficult from morphology. Volume estimates are hence approximate.
Storfjord	31	Fausa	391700	6915450	9908024	33	5	2	0,07	5-1	6	Small avalanche that has hit the seafloor and deformed the soft sediments. Morphologic details are vague, deep water. There was an avalanche in this area in 1918, but uncertain whether this is the one.
Storfjord	32	Bødaolsvika	393150	6914500	8905003, 9908010,	850	8	3	2,5	9-8	4	Interpreted from seismic. No clear morphologic signs of slide on seafloor. No obvious slide scar on shore. If rock avalanche, source from subsea cliff. Debris flow from sediment failure cannot be ruled out.
Storfjord	33	Skrenakken4	397400	6906200	9908017, 9908027,0004021	300	10	2	0,6	11-10	2	Age uncertain. One or several episodes.
Storfjord	34	Skrenakken5	397100	6905600	9908017, 9908027,0004021	490	40	10	4,9	12,5-11	1	Rock avalanche debris partly buried during deglaciation from deposits in front of end moraine at Gryddevikane (Fremste Blåhornet). Possible slide stratigraphically below this slide. In case, immediately after deglaciation
Storfjord	35	Skrenakken6	397100	6905600	4021	450	20	7	3,1	12,5-11	1	Interpreted from seismic.
Sunnylvsfjord	36	Raudebergsvika	397400	6904200	9908017, 9908027,0004021	180	30	7	1,3	10-9	2	Age uncertain. Perhaps several episodes and rockfall.
Sunnylvsfjord	37	Dukevika	396700	6902300	9908019, 9908022	160	10	4	0,6	10-9	2	Age uncertain. Perhaps several episodes and rockfall.
Sunnylvsfjord	38	Hildeborneset	396800	6901600		460	40	20	9,2	12,5-11	3	May be part of the Blåhornet1 event.
Sunnylvsfjord	39	Blåhornet1	397600	6900700	8905002, 0004021	3600	180	50	180	12,5-11	3	Huge blocks of rock in the central part of the fjord. Can be bedrock exposure, but valley geometry indicates that this are slide blocks. Deposit probably a terminal moraine built of huge rock avalanche from Blåhornet onto the glacier.
Sunnylvsfjord	40	Blåhornet2	397150	6899650	8905002, 0004021	2150	200	70	150	12,5-11	2	Gigantic avalanche, may consist of two episodes. Volume uncertain, may be as much as 400 mill. m³. Happens most likely during Younger Dryas, but there might be episodes both during deglaciation and YD.

Sunnylvsfjord	41	Gaddeflærne	396850	6898650	4021	60	40	20	1,2	5-1	6	Deformations of the soft seafloor sediments indicate that this is a rock avalanche cone. We cannot conclude that the entire cone is the result of one slide. The morphology of displaced sediments is partly levelled out and indicates a slightly older than modern age.
Sunnylvsfjord	42	Presthellaren	396950	6898000	9908017, 0004021	60	30	12	0,7	1-0	7	Freshly deformed sediments and historical records of avalanche in this area 1700 +.
Sunnylvsfjord	43	Kalvesanden	397650	6898150	4021	45	30	12	0,5	5-1	6	Deformed sediments, partly buried. May be combination of rock avalanche and rock fall.
Sunnylvsfjord	44	Vindsneset	397750	6896900	9908017	45	25	10	0,4	8-5	5	Deformed sediments, partly buried. May be combination of rock avalanche and rock fall. Age uncertain.
Sunnylvsfjord	45	Furneselva	396100	6893000		50	25	10	0,5	10-9	3	Probably several episodes. Age uncertain, but most likely before 5k.
Sunnylvsfjord	46	Furneset 1	395550	6892600		85	10	4	0,3	5-1	6	One in a series of avalanches at Furneset. Avalanche fans overlap in NE direction. In front of the fan the lobe is only partly buried and thus is estimated to be younger than 5000 ^{14}C BP. Each fan may involve several episodes. Ages most likely in early part of Holocene.
Sunnylvsfjord	47	Furneset 2	395350	6892400		60	12	6	0,3	8-5	5	
Sunnylvsfjord	48	Furneset 3	395150	6892300		50	15	7	0,3	9-8	4	
Sunnylvsfjord	49	Furneset 4	395000	6892150		50	15	7	0,3	10-9	3	
Sunnylvsfjord	50	Ljaen	393100	6889300	4021	830	30	8	6,5	12,5-11	1	Interpreted by I. Aarseth to be rock avalanche deposited on, and transported by a glacier.
Sunnylvsfjord	51	Herdalsnibba	394850	6893300	0004021, 0004003	1080	?	10	11	11-10	2	No avalanche morphology visible on seafloor, but seismic indicates a large slide or many events from the same source area. Rugged shape of seismic reflectors and blocking of acoustic penetration. Debris cone underneath Herdalsnibba probably covered from younger and smaller avalanches and rockfalls. Active slope, but difficult to distinguish between rock avalanches and "flomskred" on submarine debris fan.
Sunnylvsfjord	52	Jogardsstranda	390750	6887250	0004021, 0004003	36	?	5	0,2	10-9	3	Interpreted from seismic. No connection to slide debris fan, but probably source on the eastern side of the fjord. Early Holocene.

Geirangerfjord	53	Nokkenibba	393300	6887800	0004005,008,009,020	240	10	5	1,2	9-8	4	Deforms soft sediments, but has a fossil surface. May overlie older slide deposits
Geirangerfjord	54	Nokkenibba/Sands vordalen	393600	6887600	4009	175	5?	2?	0,3	11-10	2	Uncertain. Registered from morphology, may underlie the other slides.
Geirangerfjord	55	Nokkenibba/Sand svordalen	394200	6887400	0004009,005,020	660	30	7	4,5	10-9	3	Volume may be underestimated. May consist of two major events.
Geirangerfjord	56	Korsen	395500	6887300		60	10	3	0,2	10-9	3	No seismic.
Geirangerfjord	57	Korsen	395500	6886800	0004005,009,010	200	5?	1	1	10-9	3	
Geirangerfjord	58	Stabben	395600	6886300	4009,01	140	?	?		11-10	2	Possibly several avalanches during deglaciation.
Geirangerfjord	59	Korsen	396200	6886300	4009,01	84	4?	2?	0,2	10-9	3	It is recognized from morphology and seismic, but seismic interpretation does not give exact thickness
Geirangerfjord	60	Korsen	396100	6886300	4010	70	4	2	0,1	1-0	6	Rockfall and deformation of mud.
Geirangerfjord	61	Korsen	396500	6886100	4008,01	180	5	2	0,4	11-10	2	
Geirangerfjord	62	Djevlegjølet	397900	6885800	0004006,011,020	560	25	10	5,6	11-10	2	Difficult to intrepret thickness of slide debris on the seismics. Conservative estimation of slide volume.
Geirangerfjord	63	Syltavika	398100	6885600	0004006,011,020	180	25	6	1	5-1	6	
Geirangerfjord	64	Megardsplassen	398700	6886100	4012	130	25	8	1	5-1	6	
Geirangerfjord	65	Megardsplassen	398600	6885900	0004007,011,012	25	3?	1?	0,03	10-9	3	Identified on seismic, but difficult to evaluate volumes.
Geirangerfjord	66	Megardsplassen	398800	6885900	0004006,007,012,013,020	140	10	5	0,7	11-10	2	Most likely source on the northern side of the fjord.
Geirangerfjord	67	Ljosura	399050	6885800		185	25	8	1,5	10-9	3	
Geirangerfjord	68	Ljosura2	399400	6885700		20	12	3	0,1	9-8	4	
Geirangerfjord	69	Ljosura3	399500	6885800	4012	70	10	3	0,2	8-5	5	
Geirangerfjord	70	Gjerkland1	399850	6886250	4006,000402	430	30	10	4,3	11-10	2	Collapse from southern side of the fjord. Cliff with repeated collapses. May include avalanche debris from the northern side at the toe of the debris lobe.
Geirangerfjord	71	Gjerkland2	399550	6886000	4020	110	20	10	1,1	1-9	3	Collapse from southern side of the fjord. Short outrun.
Geirangerfjord	72	Gjerkland3	399950	6886150	4020	110	10	3	0,3	10-9	3	Uncertain. Seismic and morphologic indications of a separate slide.
Geirangerfjord	73	Gjerkland4	400050	6886300	0004006, 0004020	25	5	2	0,05	5-1	6	This and Horvadrag1 may be part of the same slide, probably from the south-eastern side of the fjord
Geirangerfjord	74	Gjerkland5	400350	6886600	000406, 0004014 0004019, 0004020	92	7	3	0,3	5-1	6	
Geirangerfjord	75	Horvadrag1	400000	6886500	0004006, 0004020	40	10	2	0,08	5-1	6	
Geirangerfjord	76	Horvadrag2	399750	6886450	4014	40	8	2	0,08	9-8	4	
Geirangerfjord	77	Brudesløret	399000	6886200		33	6	3	0,1	5-1	5	Fresh looking slide. Volume estimates not exact.
Geirangerfjord	78	Almen	399300	6886300		17	5	2	0,04	5-1	5	Fresh looking slide. Volume estimates not exact.
Geirangerfjord	79	Horvadrag3	399550	6886300		30	10	3	0,09	5-1	6	

Geirangerfjord	80	Horvadrag4	400550	6886900	0004006, 0004007, 0004014, 0004019, 0004020	85	10	4?	0,3	11-10	2	Volume estimates uncertain and might be larger. Possibly older slides from same source.
Geirangerfjord	81	Horvadrag5	400500	6886850	0004006, 0004007, 0004014, 0004019, 0004020	130	5	3?	0,4	10-9	3	Interpreted from seismic and morphology. Volume estimates uncertain. May involve more than one avalanche.
Geirangerfjord	82	Horvadrag6	400400	6886900	0004007,0004013, 0004014,	48	6	3	0,1	8-5	5	
Geirangerfjord	83	Horvadrag7	400600	6887200	0004013, 0004014, 0004019	67	6	3	0,2	5-1	6	Several slides?
Geirangerfjord	84	Skageflåfossen1	400750	6886850	0004014, 0004019	23	5	3	0,06	8-5	5	
Geirangerfjord	85	Skageflåfossen2	400850	6887050	0004007, 0004006, 0004020	60	10	4	0,2	5-1	6	
Geirangerfjord	86	Knivsflå1	400900	6887400	0004006, 0004007, 0004020	50	9	4	0,2	5-1	6	
Geirangerfjord	87	Knivsflå2	400900	6887550		25	2	1	0,05	1-0	7	
Geirangerfjord	88	Knivsflå3	401150	6887650	0004006, 0004007, 0004013, 0004020	30	3	1	0,03	8-5	5	
Geirangerfjord	89	Teinnosa1	401650	6888400	0004006, 0004015, 0004020	170	10	3	0,5	11-10	2	Older slides are indicated on the seismic, but not mapped.
Geirangerfjord	90	Teinnosa2	401700	6888550	0004006, 0004015, 0004017, 0004020	90	8	2	0,2	8-5	5	
Geirangerfjord	91	Skageflå1	401550	6888200		26	8	2	0,06	10-9	3	
Geirangerfjord	92	Skageflå2	401700	6888100		30	8	2	0,06	5-1	6	
Geirangerfjord	93	Skageflå3	401850	6888300		48	15	4	0,2	5-1	6	May represent more than one avalanche episode.
Geirangerfjord	94	Glomsdalen1	402350	6888950	0004006,0004007, 0004015, 0004017, 0004020	310	25	9	3	11-10	2	
Geirangerfjord	95	Glomsdalen2	402550	6889050	0004006,0004007, 0004015, 0004017, 0004020	322	12	4	1,3	8-5	5	
Geirangerfjord	96	Glomsdalen3	402450	6889150	0004007, 0004015	190	10	3	0,6	5-1	6	
Geirangerfjord	97	Nakkane	402350	6888600		69	8	2	0,1	5-1	6	
Geirangerfjord	98	Skagen	402900	6888750	0004006, 0004015	120	10	3	0,4	11-10	2	
Geirangerfjord	99	Preikestolen	403350	6888650	0004015, 0004020	134	8	3	0,4	10-9	3	
Geirangerfjord	100	Kvitura	403600	6888950	0004006, 0004007, 0004015, 0004020	480	50	10	4,8	11-10	2	Rock avalanche probably from Gjerdefossen area.
Geirangerfjord	101	Skagevika1	404250	6888400	0004006, 0004007, 0004020	246	15	3	0,8	10-9	3	
Geirangerfjord	102	Skagevika2	404050	6888300		67	7	2	0,1	5-1	5	
Geirangerfjord	103	Laushornet1	405400	6887700	0004006, 0004007, 0004020	247	15	5	1,2	11-10	2	Interpreted from seismic. Uncertain.
Geirangerfjord	104	Laushornet2	405400	6887900	0004006, 0004007, 0004020	215	10	3	0,6	5-1	6	
Geirangerfjord	105	Løstad	405800	6887300	4006	41	7	2	0,1	8-5	5	Interpreted mainly from morphology and volume estimates are uncertain.
Geirangerfjord	106	Homlung	405400	6887300	4020	55	4	1	0,05	8-5	5	Interpreted mainly from morphology and volume estimates are uncertain.
Geirangerfjord	107	Keipen1	405450	6887050		31	4	1	0,03	8-5	5	Interpreted mainly from morphology and volume estimates are uncertain.
Geirangerfjord	108	Keipen2	405750	6886850		97	4	1	0,1	8-5	5	Interpreted mainly from morphology and volume estimates are uncertain.