Dating rockfall-avalanche deposits from degree of rock-surface weathering by Schmidt-hammer tests: a study from Norangsdalen, Sunnmøre, Norway

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In order to obtain age estimates for the formation of two rockfall-avalanche deposits in Norangsdalen, degree of rock-surface weathering was measured using a type 'N' Schmidt hammer at six sites in Norangsdalen/Nibbedalen, Sunnmøre, Norway. By assuming a linear weathering rate, the mean Schmidt hammer rebound (R-) values obtained on the rockfall-avalanche deposits compared to mean R-values obtained on sites of 'known' age indicate that the rockfall at Skylstad may have occurred 6000 ± 700 BP, while the rockfall avalanche at Uraseter may have been deposited 4200 ± 800 BP. The indication that these rockfall events occurred in the mid-Holocene may suggest that they were initiated in connection with the deteriorating and changing climate conditions characterizing the period after the Holocene climatic optimum. This study demonstrates the potential for using the Schmidt hammer to obtain age estimates for rockfall-avalanche deposits in Norway.

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There is a general problem in dating prehistoric rockfall-avalanche deposits, mainly due to difficulties in obtaining dateable organic material directly related to the avalanche events. A few studies of rockfall avalanches in Norway including stratigraphic investigations of the Skorgeura avalanche in Ørsta, Møre, western Norway, demonstrate that the avalanche took place some time between 12,000 BP and the Younger Dryas Chronozone (Blikra 1991). Dawson et al. (1986) concluded that a rockfall avalanche in Verkilsdalen, Rondane, eastern Norway, occurred some time between 9000 and 1000 BP. Improved methods for more accurate dating of such avalanche events are particularly interesting, since they may give indications as to whether these rockfall avalanches were triggered during periods of changing climate or tectonic activity.

Based on the assumption that surfaces of boulders become more weathered with time, several methods have been developed (e.g. Brookes 1982). In this study, a Schmidt hammer type 'N' was used to give a relative measure of surface weathering as indicator of age on boulders of similar lithology in Norangsdalen/Nibbedalen, Sunnmøre.

Study area

The Norangsdalen/Nibbedalen valley (Fig. 1) was chosen for this pilot study because it is there, within a fairly limited area, that several rockfall-avalanche deposits exist. In addition, there are deposits of 'known' age and rock surfaces exposed to subaerial weathering since the deglaciation of the continental ice sheet. The steep-sided and narrow Norangsdalen stretches about 12 km from the head of Norangsfjord to about 320 m altitude at the watershed toward the 5 km long Nibbedalen in the southeast. The Norangsdalen/Nibbedalen valley, surrounded by 1400 to 1700 m high alpine peaks, is characterized by accumulations of several types of avalanche deposits. Snow-avalanche deposits dominate the valley slopes; especially prominent are a wide specter of avalanche-impact features (e.g. Hole 1981). However, some deposits are clearly deposited by large rockfall avalanches. Two distinct boulder accumulations at Uraseter and Skylstad are interpreted to have been formed by rockfall avalanches due to their long run-out distance and their morphological features. A rockfall avalanche at Lyngstølsvatn is historically reported to have occurred in 1908 (Ahlmann 1919). Here, a rockfall avalanche from the Keipen mountain dammed the river through Norangsdalen and led to the formation of the 640 m long lake Lyngstølsvatn, putting some summer farm houses and a part of the road under water.

The Schmidt hammer

The Schmidt hammer is a light (1 kg), portable and robust instrument that records the distance of rebound of a spring-loaded mass impacting a surface. The distance of rebound (R) is related to the elastic properties of the surface and therefore its compressive strength. A

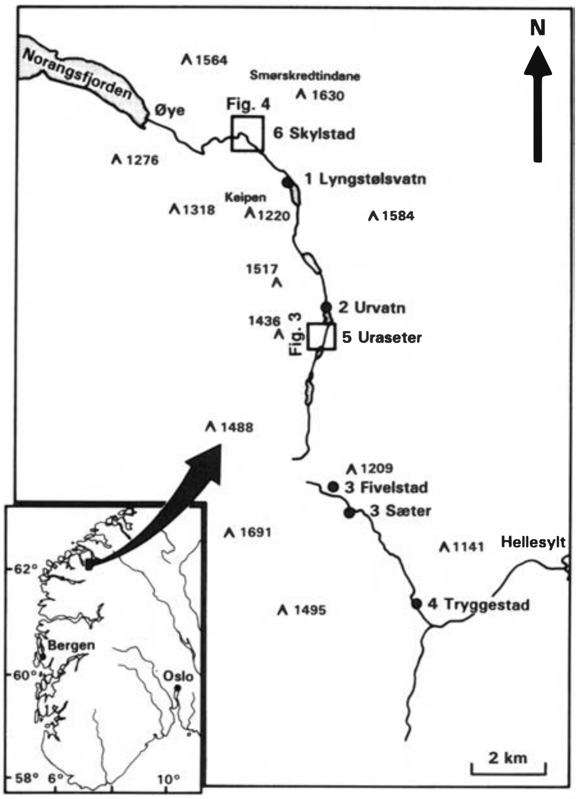

Fig. 1. Index map showing the study sites (numbered 1–6) in Norangsdalen/Nibbedalen. The study sites are: (1) Lyngstølsvatn; (2) Sæter and Fivelstad; (4) Tryggestad; (5) Uraseter; and (6) Skylstad.

large number of readings can be made in a short period. Commonly, the accuracy of the Schmidt hammer is good and no significant operator variance has been detected (Day & Goudie 1977; Matthews & Shakesby 1984).

The Schmidt hammer has previously been used to compare the surface hardness of different rock types (Barton & Choubey 1977; Day & Goudie 1977), and as a measure of degree of rock-surface weathering (Day 1980; Whitlow & Shakesby 1988; Ballantyne et al. 1989; McCarroll 1990; Sjöberg 1990, 1991; Sjöberg & Broadbent 1991), and as degree of weathering as an indicator of surface age (Ballantyne 1986; Dawson et al. 1986; Matthews & Shakesby 1984; McCarroll 1989a, b, 1991; Cook-Talbot 1991; McCarroll & Nesje 1993).

The degree of rock-surface weathering was measured using a Schmidt hammer on boulders of similar lithology (banded gneiss) in the rock-avalanche deposits. In order to obtain age estimates of the formation of the rockfall-avalanche deposits, the degree of weathering was measured on rock surfaces of 'known' age: on a rockfall-avalanche deposit at Lyngstølsvatn from AD 1908 (site 1); on fracture surfaces on 'fresh' snow-avalanche deposits at Urvatn (site 2); on surface boulders forming a Younger Dryas (about 10,500 BP) marginal moraine at Sæter and Fivelstad (site 3); and on a bedrock surface at Tryggestad (site 4) exposed to subaerial weathering since the Allerød Chronozone.

In the present study three or more series of 50 R-values were obtained from nearly horizontal, lichen-/moss-free bedrock surfaces of uniform lithology (banded gneiss) at six sites in Norangsdalen (Fig. 1). Commonly, a banded gneiss is anisotropic. Therefore, the Schmidt-hammer readings were made randomly across the banding in the gneiss. The average error limits are the arithmetic mean of ±2 standard errors (95% confidence interval) of the R-values obtained from the individual boulders.

Study sites of 'known' age

Site 1 Lyngstølsvatn

In the spring 1908 a rockfall avalanche from the Keipen mountain (1220 m a.s.l.) in the western valley side of Norangsdalen (Fig. 1) dammed the river through the valley and formed a lake called Lyngstølsvatn (Ahlmann 1919). In the lake it is still possible to see the foundation walls of summer-farm houses ('seter') that existed before the rockfall avalanche. The rockfall-avalanche deposit is characterized by a cover of large boulders up to 6 m in diameter, locally by an irregular and hummocky surface. Schmidt hammer R-values were obtained from three rockfall avalanche boulders, giving a mean R-value of 60.23 ± 1.93 (la–c in Table 1). A composite histogram of the three Schmidt hammer series is shown in Fig. 2.

Site 2 Urvatn

North of Urvatn a tail of 'fresh' material has been deposited by recent snow avalanches plunging into the lake outlet from the western valley side. Schmidt hammer R-values were measured at three fracture surface boulders (2a–c), giving a mean of 57.33 ± 1.64 (2a–c in Table 1). A composite histogram of the three Schmidt hammer series is shown in Fig. 2.

Site 3 Sæter and Fivelstad

At Sæter and Fivelstad in Nibbedalen (Fig. 1), prominent marginal moraines were deposited by cirque glaciers from the western valley side during the Younger Dryas Chronozone. Schmidt hammer R-values were measured on four surface boulders (3a–d in Table 1) on top of the marginal moraines at Sæter and Fivelstad. The mean R-value is 34.82 ± 2.04 (Table 1). A composite histogram of the four Schmidt hammer series is shown in Fig. 2.

Site 4 Tryggestad

Three Schmidt hammer R-series (4a–c in Table 1) were obtained from a bedrock exposure at Tryggestad in Nibbedalen (Fig. 1). The site is located outside the Younger Dryas cirque moraines (Fareth 1987) and the site has therefore been exposed to subaerial weathering since deglaciation of the valley glacier prior to the

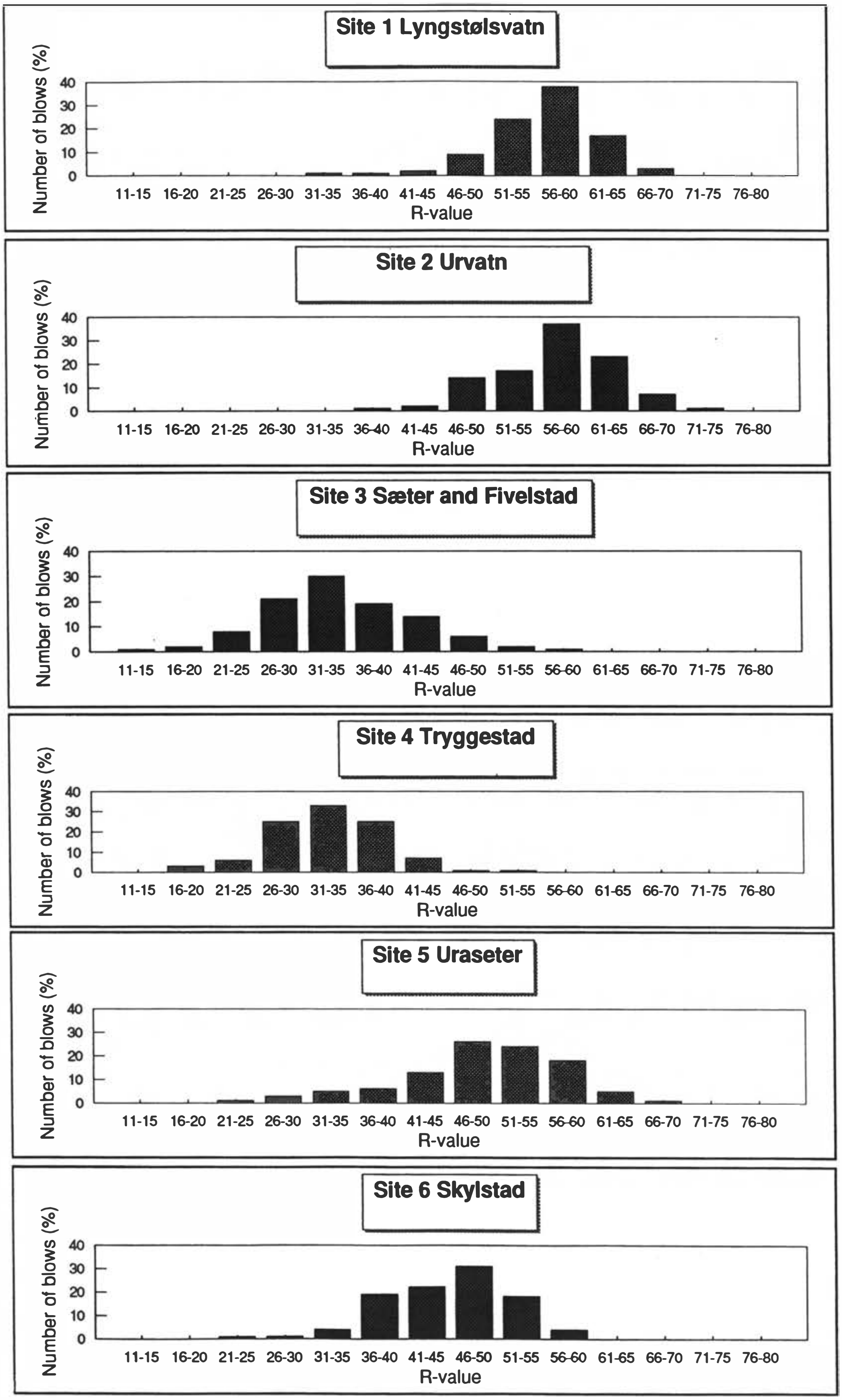

Fig. 2. Composite R-value histograms of the study sites in Norangsdalen/Nibbedalen.

Table 1. Schmidt hammer rebound (R-) measurements in Norangsdalen/Nibbedalen. The error limits are given as ± standard errors.

Site	M a.s.l.	Setting	R-value	Mean R-value
1a Lyngstølvatn	150	Rockfall avalanche 1908	62.80 ± 1.93	60.23 ± 1.93
lb Lyngstølvatn	150	Rockfall avalanche 1908	60.12 ± 1.70	
lc Lyngstølvatn	150	Rockfall avalanche 1908	57.76 ± 2.58	
2a Urvatn	250	'Fresh' snow avalanche	60.02 ± 1.63	57.33 ± 1.64
2b Urvatn	250	'Fresh' snow avalanche	56.36 ± 1.52	
2c Urvatn	250	'Fresh' snow avalanche	55.62 ± 1.75	
3a Sæter	350	Younger Dryas moraine	38.16 ± 2.40	34.82 ± 2.04
3b Sæter	340	Younger Dryas moraine	32.12 ± 1.85	
3c Sæter	310	Younger Dryas moraine	31.82 ± 2.26	
3d Fivelstad	330	Younger Dryas moraine	37.16 ± 1.52	
4a Tryggestad	270	Lateglacial rock surface	36.40 ± 1.57	32.76 ± 1.53
4b Tryggestad	270	Lateglacial rock surface	32.18 ± 1.51	
4c Tryggestad	270	Lateglacial rock surface	29.70 ± 1.50	
5a Uraseter	290	Rockfall avalanche	52.28 ± 1.57	49.08 ± 2.03
5b Uraseter	300	Rockfall avalanche	52.00 ± 2.36	
5c Uraseter	295	Rockfall avalanche	51.80 ± 1.77	
5d Uraseter	290	Rockfall avalanche	49.44 ± 1.33	
5e Uraseter	290	Rockfall avalanche	45.96 ± 2.22	
5f Uraseter	290	Rockfall avalanche	42.98 ± 2.61	
6a Skylstad	100	Rockfall avalanche	48.12 ± 1.56	45.29 ± 1.75
6b Skylstad	100	Rockfall avalanche	44.96 ± 1.82	
6c Skylstad	100	Rockfall avalanche	42.80 ± 1.86	

Younger Dryas Chronozone. The mean R-value is 32.76 ± 1.53 (Table 1). A composite histogram of the three Schmidt-hammer series is shown in Fig. 2.

Rockfall-avalanche deposits of unknown age

Site 5 Uraseter

A 100 × 600 m boulder field at Uraseter is interpreted to have been deposited by a rockfall avalanche from the western valley side (Fig. 1). The morphological features are characterized by transverse ridges and depressions (Fig. 3), typical elements found in rockfall-avalanche deposits elsewhere (Cruden & Hungr 1986; Dawson et al. 1986; Johnson & Vaughan 1989; Bennet & Langridge 1990; Ryder et al. 1990). The boulder sizes are normally between 1 and 5 m, but locally boulders reach sizes up to 8 m in diameter. Snow avalanches from the western mountain side have formed a colluvial fan in the western valley side. There is thus a possibility that some younger avalanche boulders have been mixed into the older rockfall-avalanche deposit. The 'seter' on the surface of the rockfall-avalanche deposit (Fig. 3) was built during the Medieval, giving a minimum age for the rockfall-avalanche event. Schmidt hammer R-series were measured on six surface boulders (5a–f in Table 1), the mean R-value being 49.08 ± 2.03. A composite histogram of the six Schmidt hammer series is shown in Fig. 2.

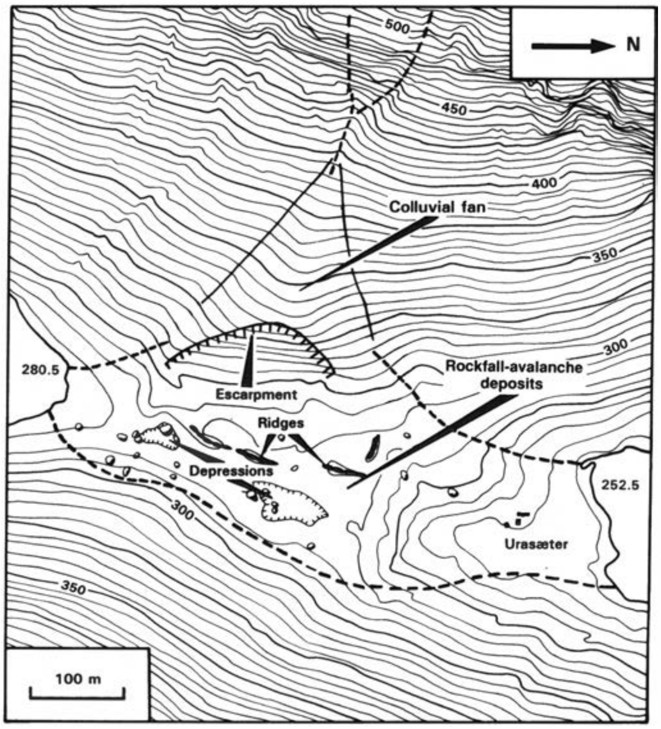

Fig. 3. The Uraseter rockfall-avalanche deposit. Note the escarpment in the colluvial fan dominated by snow avalanches.

Site 6 Skylstad

A boulder field across the valley bottom at Skylstad (Fig. 4) is interpreted to have been formed by a rockfall avalanche from Smørskredtindane in the NE (Fig. 1). Schmidt hammer rebound values were measured on three boulders (6a–c in Table 1), giving a mean of 45.29 ± 1.75. A composite histogram of the three Schmidt hammer series is shown in Fig. 2.

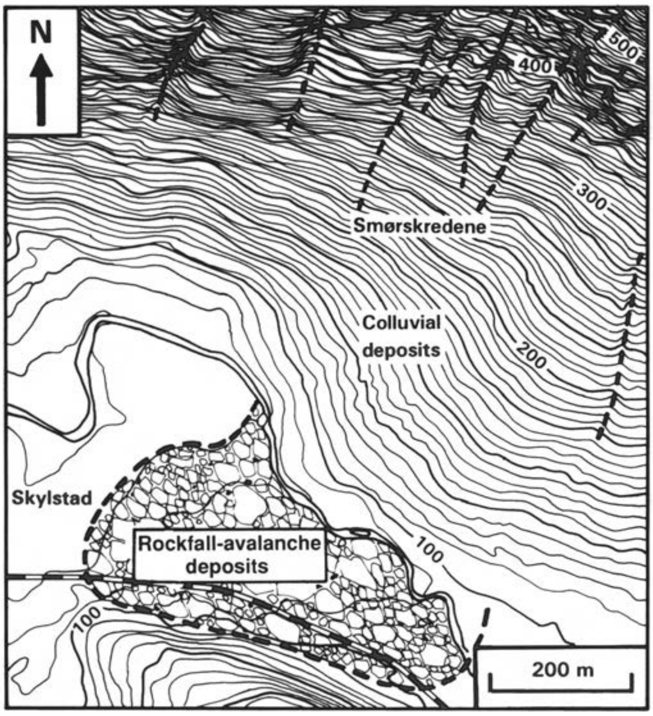

Fig. 4. The rockfall-avalanche deposit at Skylstad.

Age estimates and discussion

The R-values obtained from the sites of modern age are significantly higher than the values obtained from the surfaces exposed to subaerial weathering since the Late Glacial (Table 1). The different degree of rock-surface weathering is interpreted as an indicator of time exposed to subaerial weathering and therefore of surface age. By assuming a linear weathering rate over this period of time (Colman 1981) (regression line between the sites of 'known' age), it is possible to obtain age estimates of the rockfall-avalanche deposits of unknown age (Fig. 5). Accordingly, the rockfall avalanches may have occurred in the mid-Holocene [Skylstad at 6000 ± 700 BP (Atlantic Chronozone) and Uraseter at 4200 ± 800 BP (Subboreal Chronozone)].

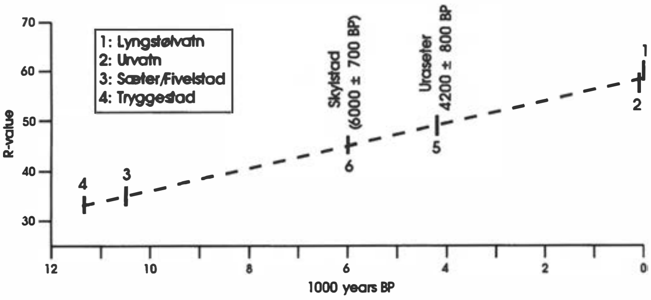

Fig. 5. Age estimates for the rockfall-avalanche deposits based on sites of 'known' age [rockfall avalanche at Lyngstølsvatn dated at AD 1908 (site 1), 'fresh' snow-avalanche deposits at Urvatn (site 2), boulders forming a Younger Dryas (about 10,500 BP) marginal moraine at Sæter/Fivelstad (site 3), and a bedrock surface at Tryggestad (site 4) exposed to subaerial weathering since the Allerød Chronozone]. The vertical bars indicate ±2 standard errors.

The results obtained indicate that the investigated rockfall-avalanche deposits in Norangsdalen were formed during a period characterized by falling temperatures in western Norway after the Holocene climatic optimum (Nesje et al. 1991; Nesje & Kvamme 1991; Matthews & Karlén 1992).

Stratigraphic studies of avalanche deposits in the county of Møre and Romsdal convincingly demonstrate that the most pronounced periods of avalanche activity occurred during the Younger Dryas Chronozone and during the second half of the Holocene (Blikra & Nemec 1993; Blikra & Nesje in press). The earliest record of snow-avalanche activity in Møre dates to 7200–5200 BP, with the highest frequency around 4700–4200 BP, 3800–3000 BP, 2500–1800 BP, subsequent to 1400 BP, and during the 'Little Ice Age'. There is also evidence of increased rockfall and debris-flow activity in the second half of the Holocene (Blikra & Nesje in press).

The fact that the two rockfall-avalanche deposits in Norangsdalen seem to have been formed during the mid-Holocene, after the Holocene climatic optimum, may indicate that these events were initiated by the deteriorating and changing climate at that time. Previous opinion that such events were particularly active shortly after the deglaciation, due to unstable valley slopes and/or tectonic activity due to differential glacio-isostatic uplift, seems not to be valid in the present case. It cannot, however, be totally excluded that some earthquake and neotectonic activity in the mid to late Holocene could have been the trigger for these rockfall-avalanche events. Further investigations of rockfall-avalanche deposits in this region may give further information about the timing and cause of the these events.

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