A record of late Holocene avalanche activity in Frudalen, Sogndalsdalen, western Norway

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A 3.2 m deep section 495 m.a.s.l. in Frudalen, a western tributary to Sogndalsdalen, inner Sogn, shows alternating layers of debris and peat. Except for the basal diamicton, interpreted as a till deposited during the early Holocene deglaciation of the continental ice sheet, the minerogenic horizons are interpreted as having been deposited during periods of enhanced avalanche activity. One radiocarbon date from a broken birch (*Betula* sp.) log and six peat dates show that four periods of pronounced avalanche activity occurred between 580 ± 60 BP (AD 1310–1420) and 3920 ± 70 BP (2340–2490 BC). The stratigraphic record is well correlated with avalanche activity in the Sunnmøre area and with the record of glacier fluctuations in western Norway.

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Introduction

Steep valley sides in western Norway are exposed annually to avalanche activity, and avalanche material tends to be the dominating superficial material along the west Norwegian valleys and fjords (Thoresen 1990). Despite this, only a few attempts have been made to date periods of enhanced avalanche activity in western Norway. Grove (1972, 1988) and Grove & Battagel (1983) used tax records from western Norway to document damage in historical time caused by several types of avalanche activity. Their results show that this activity peaked during the 'Little Ice Age' from about AD 1650 to 1760.

Stratigraphical studies around Jostedalsbreen show that avalanche activity there was initiated after 2500 to 3000 BP (Nesje et al. 1991). Blikra & Nemec (1993), who investigated a series of depositional facies successions of postglacial avalanches in selected areas in the Møre region, western Norway, have convincingly demonstrated that the earliest record of Holocene snow-avalanche activity dates to ca. 4600 BP, while radiocarbon evidence indicates that snow-avalanche activity peaked between ca. 3800 and ca. 3000 BP. Renewed snow-avalanche activity occurred around ca. 2600 and ca. 1800 BP. Their record shows increased debris-flow activity subsequent to 3000 yr BP.

McCarroll (1993) used lichenometry on boulders in scree slopes to date periods of enhanced avalanche activity from the 'Little Ice Age' up to the present in western Norway.

The term 'avalanche' is in the present paper used as a synonym of rapid mass movements on steep slopes, including both debris flows and snow avalanches.

The purpose of this study was to date periods of enhanced avalanche activity at one site in Sogndalsdalen along the new road through Sogndalsdalen to Fjærland (Fig. 1).

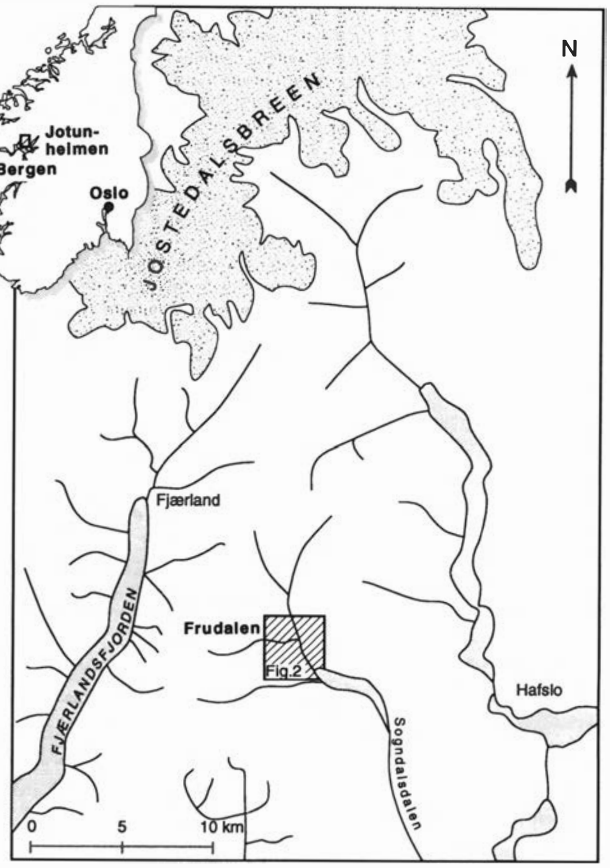

Fig. 1. Location map of the study region.

Study site

In the southern valley side of Frudalen, a western tributary of Sogndalsdalen, a section 495 m above sea level (a.s.l.) revealed alternating layers of minerogenic layers and peat. The site lies at the base of the 120 m high

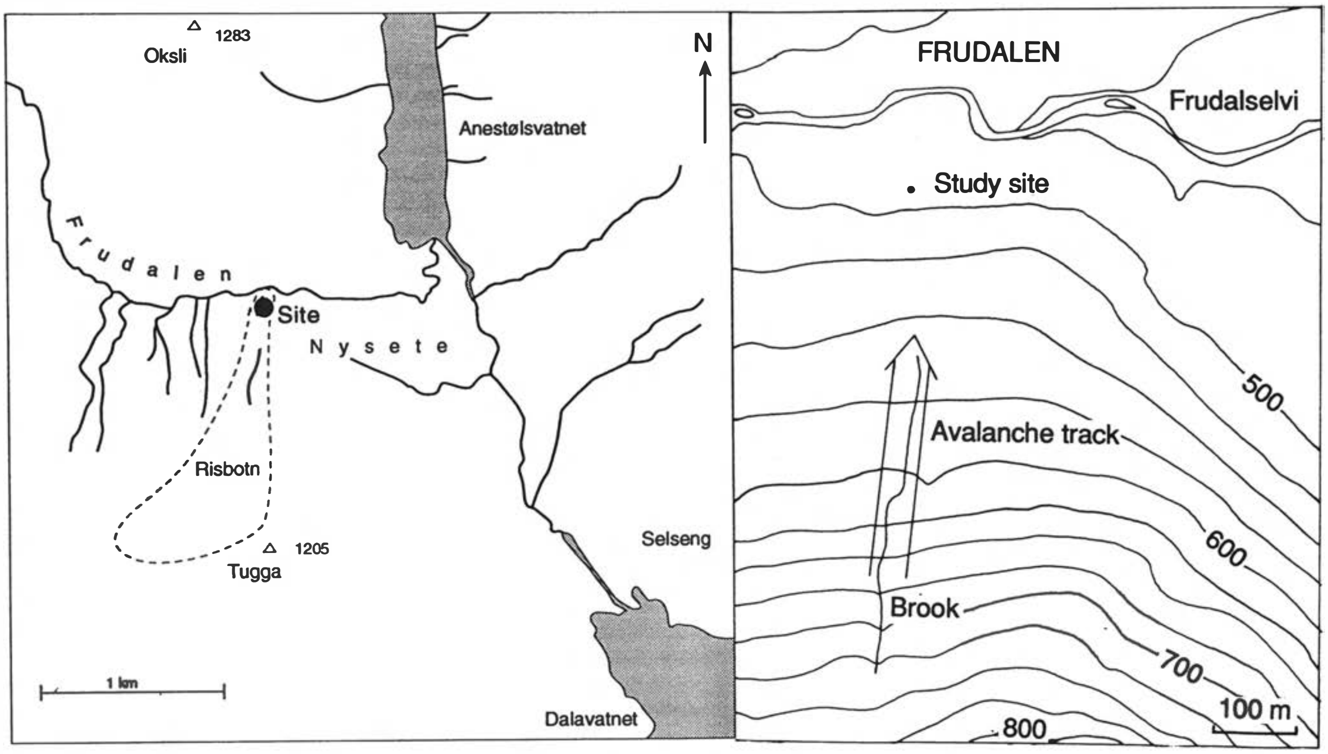

Fig. 2. Location map and topographical features at the study site in Frudalen. The contour interval on the map to the right is 25 metres.

mountain Tugga (Fig. 2.). The catchment area of the site is 0.5 km^2, of which the upper part forms a shallow cirque called Risbotn. The altitudinal difference from the top of the mountain to the site is 820 m and the mean gradient is 503 m km^{-1} (28°). The described section is situated at the base of the lower slope with a mean gradient of 338 m km^{-1} (19°) just below an avalanche track (Fig. 2). The avalanche track does not show evidence of lateral migration. The site may therefore give a more or less complete record of late Holocene avalanche activity.

Lithostratigraphy and grain-size anlalysis

Description

The lithostratigraphy of the 3.2 m deep section 495 m a.s.l. in Frudalen is shown in Fig. 3. Five grain-size analyses were carried out from the section (Fig. 3). The sample from the lower part of unit D consisted of sandy gravel, while unit F contained gravelly sand. The sample from the upper part of unit G, on the other hand, consisted of 35% < 0.063 mm, while the grain-size analysis from the middle part of unit G showed a higher gravel content. The sample from the upper part of unit I consisted of sand and gravel.

Interpretation

Except for the basal diamicton (unit K), interpreted as a till deposited during the deglaciation of the continental ice sheet, the minerogenic horizons are interpreted to have been deposited during periods of enhanced debris-flow or snow-avalanche activity. The birch logs between 20 and 30 cm are evidently broken by snow avalanches.

The sand and gravel in units F and I are interpreted to be gravel sheets deposited in the outer part of a debris flow or a debris-rich snow avalanche. Unit G, consisting of coarse debris and lenses of organic material, is according to Blikra & Nemec (1993) typical of snow-avalanche deposits. The horizon is thus interpreted to have been deposited by several snow-avalanche events with intervening periods of reduced activity (peat/organic lenses). The 85 cm thick debris horizon in unit D, without significant amounts of organic material, indicates deposition by debris flows or debris-rich snow avalanches. The low organic content indicates a one-event avalanche or at least a very short period of deposition.

Pollen analysis

Eleven samples were prepared for pollen analysis (Fig. 4). Three samples were taken from the upper debris layer (unit D) and one from avalanche unit G, while the others were obtained from the peat horizons. The pollen percentages are calculated on the pollen sum, except for the *Polypodiaceae*, which are based on the sum of the pollen + spores.

The birch forest in Frudalen extends up to about 800 m. Locally, blanket bogs and areas influenced by avalanches form open areas of varying size within the forest.

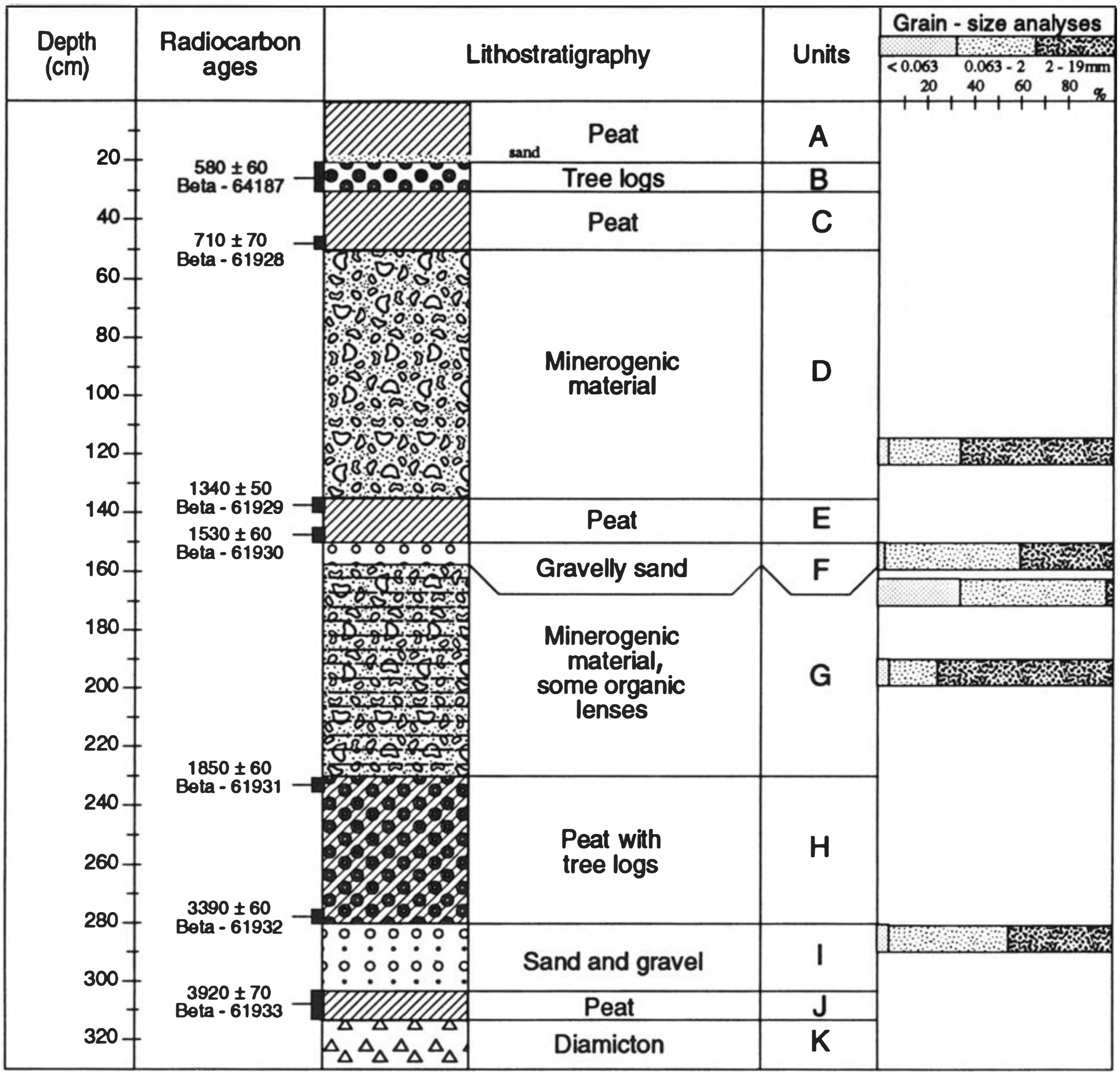

Fig. 3. Lithostratigraphy, radiocarbon dates and grain-size analyses at the Frudalen site.

Striking features in the pollen diagram are extremely high contents of *Polypodiaceae* spores (up to 93%) and *Asteraceae* sect. asteroid. (up to 25%) in the avalanche layers combined with low values, or complete absence, of *Cyperaceae*. This composition corroborates the interpretation that the minerogenic horizons represent periods with frequent and extensive avalanche activity and fern vegetation. Similarly, the disappearance of *Cyperaceae* could reflect the local effect of the development of well-draining minerogenic soil at the expense of peat. Lower *Betula* values, too, may reflect the damaging effect on parts of the birch forest of avalanche activity.

It is, however, a difficult task to interpret the vegetational implications of a diagram made from a section containing alternating beds of *in situ* peat and secondary avalanche deposits containing redeposited pollen and spores. In addition, the content of *Polypodiaceae* and *Cyperaceae*, respectively, is influenced by their highly different resistance to physical and chemical processes. Commonly, *Polypodiaceae* are strongly overrepresented in sandy flood layers in peat (Kvamme 1988). The high values of *Asteraceae* sect. asteroid. seem, however, to reflect a vegetation characterized by tall herbs during periods of frequent avalanche activity.

At this site the first appearance of spruce occurs around AD 1250. Native stands of spruce in western Norway are restricted to a few localities in inner Hardanger, Voss and inner Sogn. One of these sites, Luster Common (Fægri 1950a), lies some 30 km east of Frudalen. Sporadic finds of assumed long-distance *Picea* pollen in the Sogn region occur after about AD 1000, whereas a local spruce population might have been established from AD 1400 to 1500 (Fægri 1950a,b, 1970; Ve 1968; Hafsten 1985, 1992).

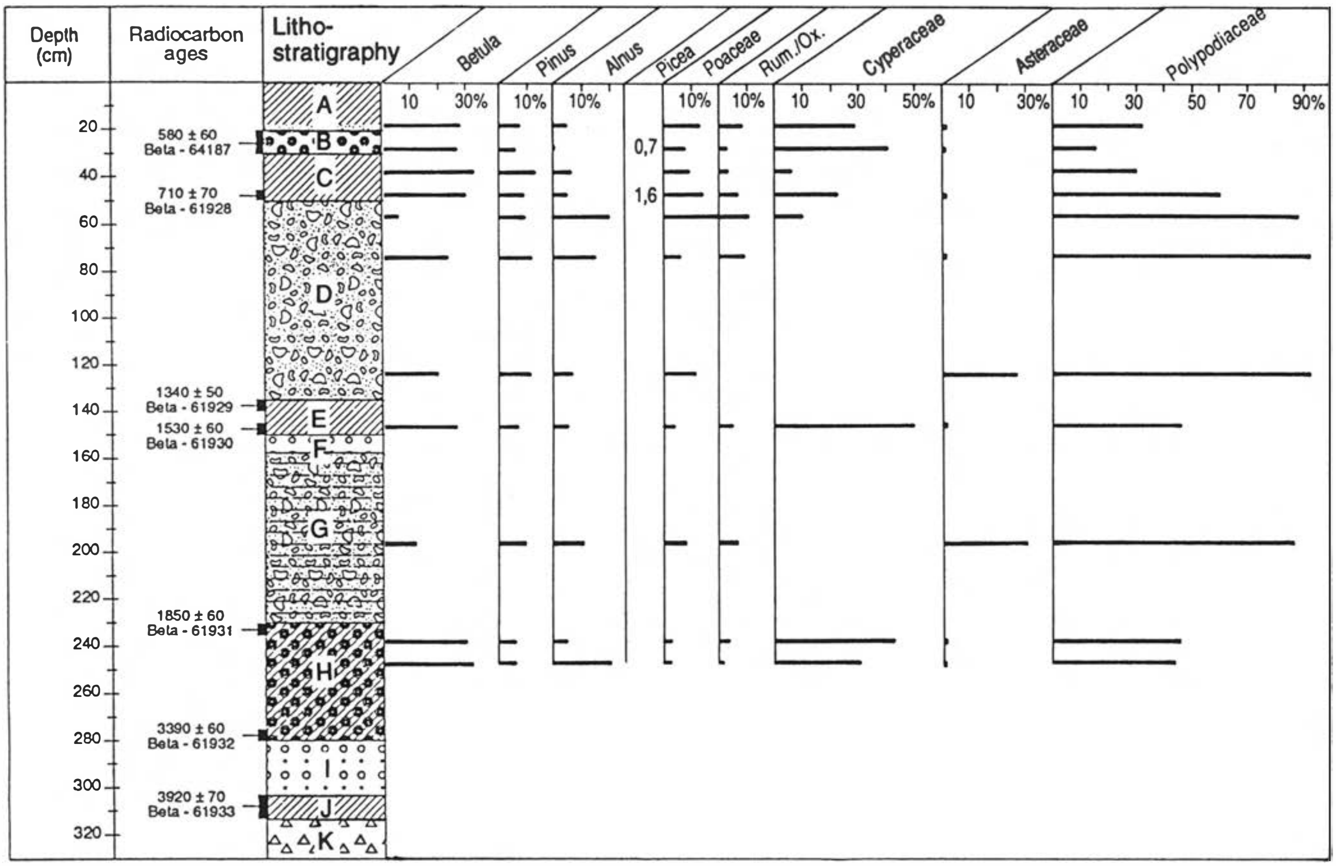

Fig. 4. Pollen diagram from the study section in Frudalen.

Radiocarbon datings

In order to bracket periods of enhanced avalanche activity at the study site, one birch log from unit B and six peat samples from units C, E, H and J were collected for radiocarbon dating. Peat slices 5 cm thick were collected immediately above and below the avalanche horizons.

In the dating laboratory, the birch log was given a hot acid wash to eliminate carbonates. It was repeatedly rinsed to neutrality and subsequently given a hot alkali soaking to take out humic acids. After rinsing to neutrality, another acid wash followed and another rinsing to neutrality. The following benzene synthesis and counting proceeded normally.

The peats were pre-treated first by removing (hand picking) any apparent rootlets. The peats were then dispersed in hot acid to eliminate carbonates, repeatedly rinsed to neutrality, brought to dryness and combusted in an enclosed system. The following benzene syntheses and counting proceeded normally.

The radiocarbon datings show that a snow-avalanche event occurred close to 580 ± 60 yr BP (AD 1310–1420). Snow-avalanche activity peaked during the time interval 1530 ± 60 BP (AD 440–610) to 1850 ± 60 BP (AD 90–220). Debris-flow and debris-rich snow avalanches seem to have occurred sometime between 3390 ± 60 BP (1620–1760 BC) and 3920 ± 70 BP (2340–2490 BC), and between 710 ± 70 BP (AD 1260–1310) and 1340 ± 50 BP (AD 660–760) (Fig. 3, Table 1).

Table 1. Radiocarbon dates from the study section.

Depth (cm)	Radiocarbon date (BP)	Calibrated age*	Dated material	Lab. no.
20–30	580 ± 60	AD 1310–1420	Wood	Beta-64187
45–50	710 ± 70	AD 1260–1310	Peat	Beta-61928
135–140	1340 ± 50	AD 660–760	Peat	Beta-61929
145–150	1530 ± 50	AD 440–610	Peat	Beta-61930
230–235	1850 ± 60	AD 90–220	Peat	Beta-61931
275–280	3390 ± 60	1620–1760 BC	Peat	Beta-61932
308–313	3920 ± 70	2340–2490 BC	Peat	Beta-61933

* Calibration based on Stuiver & Becker (1986).

Discussion

The section described shows the depositional history of a limited part of the Frudalen valley. The possibilities of shifting sectors of avalanche deposition in such systems, well documented by Blikra & Nemec (1993), demonstrate that avalanche records may be incomplete. At the study site, however, there is no evidence for lateral migration of the avalanche track.

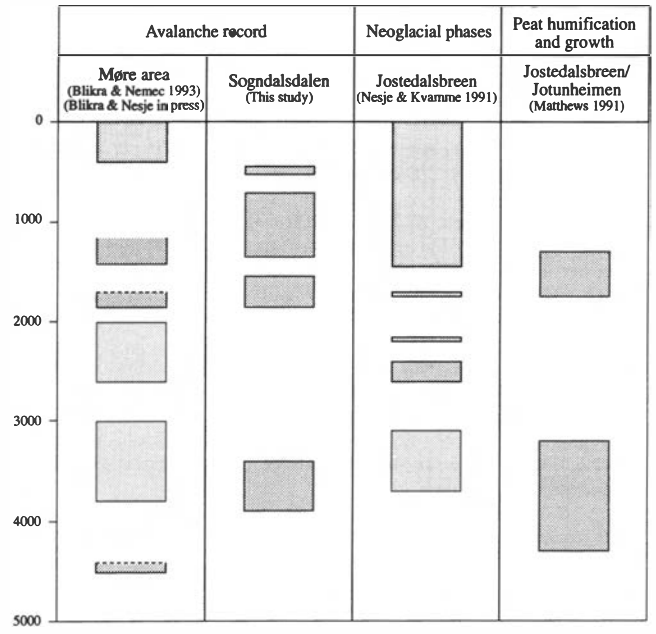

Fig. 5. Time distribution of late Holocene features related to this study.

The radiocarbon date of 3920 ± 70 BP (Beta-61933) from the basal peat layer (unit J) directly overlying a till deposited during the deglaciation of the continental ice sheet demonstrates a hiatus between units J and K. Similar hiatuses have been demonstrated in peat sections around Jostedalsbreen (e.g. Nesje et al. 1991).

The avalanche record in Frudalen indicates that the initial avalanche activity after Hypsithermal climatic optimum in the Jostedalsbre region (Nesje & Kvamme 1991) occurred during the time interval 3920 ± 70 BP (2340–2490 BC) and 3390 ± 60 BP (1620–1760 BC) (Fig. 3, Table 1). The avalanche record from the Møre region (Blikra & Nemec 1993) shows that the initial activity after the Late-glacial period started a bit earlier, around 4600 BP (Fig. 5). Further increase in the snow-avalanche activity in Møre occurred between ca. 3800 and 3000 BP. This second phase is in close agreement with the Frudalen record (Fig. 5), which shows deposition of gravel sheets of debris-flow or snow-avalanche origin. In addition, this avalanche phase occurred at a time of neoglacial activity between 3700 and 3100 BP in the Jostedalsbre area (Nesje & Kvamme 1991; Nesje et al. 1991; Nesje 1992) (Fig. 5). Karlén & Matthews (1992) and Matthews & Karlén (1992) found similar evidence of neoglacial activity from glacial lake sediments in the Jostedalsbre/Jotunheimen region and in the Sunnmøre area. At Hardangerjøkulen, Dahl & Nesje (in press) found that the northern part of Hardangerjøkulen draining to Finsedalen has existed continuously from 3800 BP up to the present. Radiocarbon dating of buried soils formed during initial geli-/solifluction movement around Jostedalsbreen shows that this process started between 3200 and 2800 BP (Nesje et al. 1989). Two avalanche sites at Sprongdalen and Øyastrondi in the upper part of Jostedalen show that avalanche activity there started at 3300 and 2900 BP, respectively (Nesje et al. 1991). Finally, Matthews (1991) found evidence in the Jotunheimen/Jostedalsbreen region of pronounced climatic deterioration between 4300 and 3200 BP from radiometric data on the initiation of peat growth and changes in peat humification (Fig. 5).

The second phase of pronounced avalanche activity in Frudalen started around 1850 ± 60 BP (AD 90–220) and lasted until 1530 ± 60 BP (AD 440–610). In the Møre area, avalanches also occurred in a previous period, from about 2600 to 2000 BP. However, a phase of snow-avalanche activity in Møre seems to have commenced at 1850 BP (Blikra & Nemec 1993), in agreement with the Frudalen record. This phase seems to have occurred contemporaneously with a short-lived neoglacial phase in the Jostedalsbre region peaking around 1700 BP (Nesje & Dahl 1991; Nesje & Kvamme 1991; Nesje 1992). Karlén & Matthews (1992) and Matthews & Karlén (1992) found evidence of a glacier expansion around 2000 BP inferred from glacial lake sediments.

The penultimate phase of avalanche activity in Frudalen, starting around 1340 ± 50 BP (AD 660–760) and lasting until 710 ± 70 BP (AD 1260–1310), and the broken birch log 20–30 cm below the surface, indicating snow-avalanche activity at 580 ± 60 BP (AD 1310–1440), started around the initiation of the final neoglocial phase at Jostedalsbreen (Nesje & Dahl 1991) and at Hardangerjøkulen (Dahl & Nesje in press) leading up to the 'Little Ice Age' glacier maximum (e.g. Grove 1988; Bickerton & Matthews 1993). This stage of avalanche deposition is well correlated with the increase in the incidence of snow-avalanche activity in the Sunnmøre area (Blikra & Nesje in press), demonstrating deteriorating winter climatic conditions from ca. 1400 BP. Matthews (1991) found evidence of pronounced climatic deterioration between 1750 and 1300 BP from radiometric data on the initiation of peat growth and changes in peat humification in the Jostedalsbreen/Jotunheim region (Fig. 5). From the evidence, there seems to have been little avalanche activity at the site in Frudalen during the peak of the 'Little Ice Age', a period of historically reported enhanced avalanche activity in western Norway (Grove 1972, 1988; Grove & Battagel 1983).

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