The surface of the inland ice in the Atndalen valley, South-central Norway

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On the basis of different field observations, several authors have discussed the form of the surface of the inland ice in southern Norway. In this work, lateral features indicating the upper limit of zones of meltwater drainage marked by meltwater channels are used for the reconstruction of two distinct ice surfaces during the deglaciation of the valley Atndalen. Through the mapping of these features a detailed image of the deglaciation can be obtained and also be used for regional correlation of the ice surface.

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Introduction

The shape and distribution of the inland ice in South-central Norway have been the topic of a long-standing discussion (Hansen 1886, Holmsen 1915, Mannerfelt 1940, Strøm 1956, Gjessing 1960, Sollid & Carlson 1980, Andersen et al. 1995, Andersen 2000). During the deglaciation of the area, the ice divide of the inland ice moved to the south and allowed the formation of ice-dammed lakes at successively lower elevations (e.g., Holmsen 1915, 1960). This view was based on the study of glacial striations and the formation of shorelines. Since Mannerfelt (1940) found no evidence for terminal moraines in the cirque valleys of the Rondane Mountains, he concluded that the limit of glaciation had been far above these mountains and that the area was deglaciated through a vertical downwasting of the inland ice. Gjessing (1960) questioned the proposed extension of ice-dammed lakes, as he found that a shoreline could be formed in a sublateral and/or semi-sublateral position in relation to the edge of the inland ice. This view was supported by Follestad (1997) and Follestad & Thoresen (1999) who concluded that sublateral and/or semi-sublateral erosion and accumulations can explain the presence of shorelines related to the Upper and Lower Glomsjø in the Alvdal area.

In this paper the distribution of sublateral and/or semi-sublateral meltwater channels are used to reconstruct the surface of the inland ice during the deglaciation in the surroundings of the valley Atndalen. The map data of Gjessing (1960) and Sollid & Carlson (1980) are combined with a large data-set, mainly of meltwater channels, collected by the author during the last few years.

The Atndalen valley

The topography of the area around Atndalen (Fig. 1A) can be characterised as a landblock, into which the Atndalen valley and its tributary valleys, e.g. the Langglupdalen valley and the Rånåbekken valley (for locations; see Fig. 2), have been eroded. The elevation of the Atndalen valley is 710 m a.s.l. in southern areas (at Stor-Elvdal, Fig. 1B) and 800 m a.s.l. in the northern parts. As the general surface of the surrounding landblock is 1100 – 1200 m a.s.l, this gives a relief amplitude of 400 to 500 metres for the Atndalen valley in the northern and southern areas, respectively. Prominent peaks, such as e.g. Høgronden (2115 m a.s.l.) and Eiriksrudhøi (1535 m a.s.l.), occur, respectively to the west and east of the Atndalen valley. As the increasing relief amplitude is to the south in Atndalen and to the east in the valley Folldalen, a

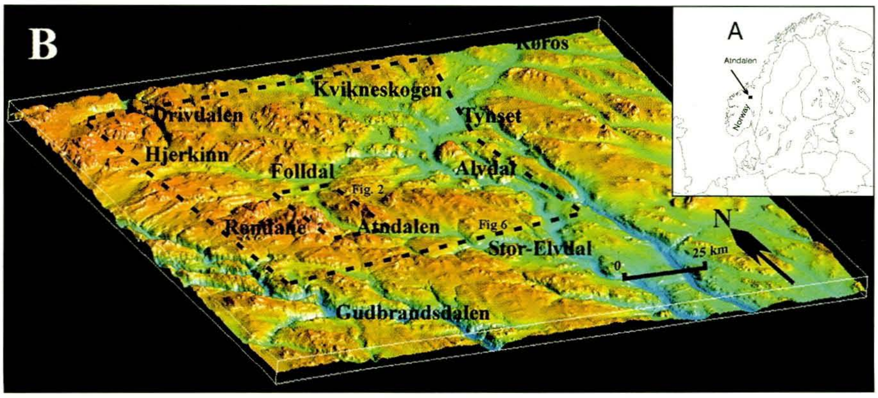

Fig.1 (A) Location map of the area. (B) Relief map of the land surface between the valleys of Gudbrandsdalen and Glåmdalen (Østerdalen). The terrain model shows that the valleys are tiny fingers penetrating into a land block with a surface at c.1100 m a.s.l. Some adjacent mountain areas, such as Rondane, rise above this general level, and reach up to c. 2100 m a.s.l.

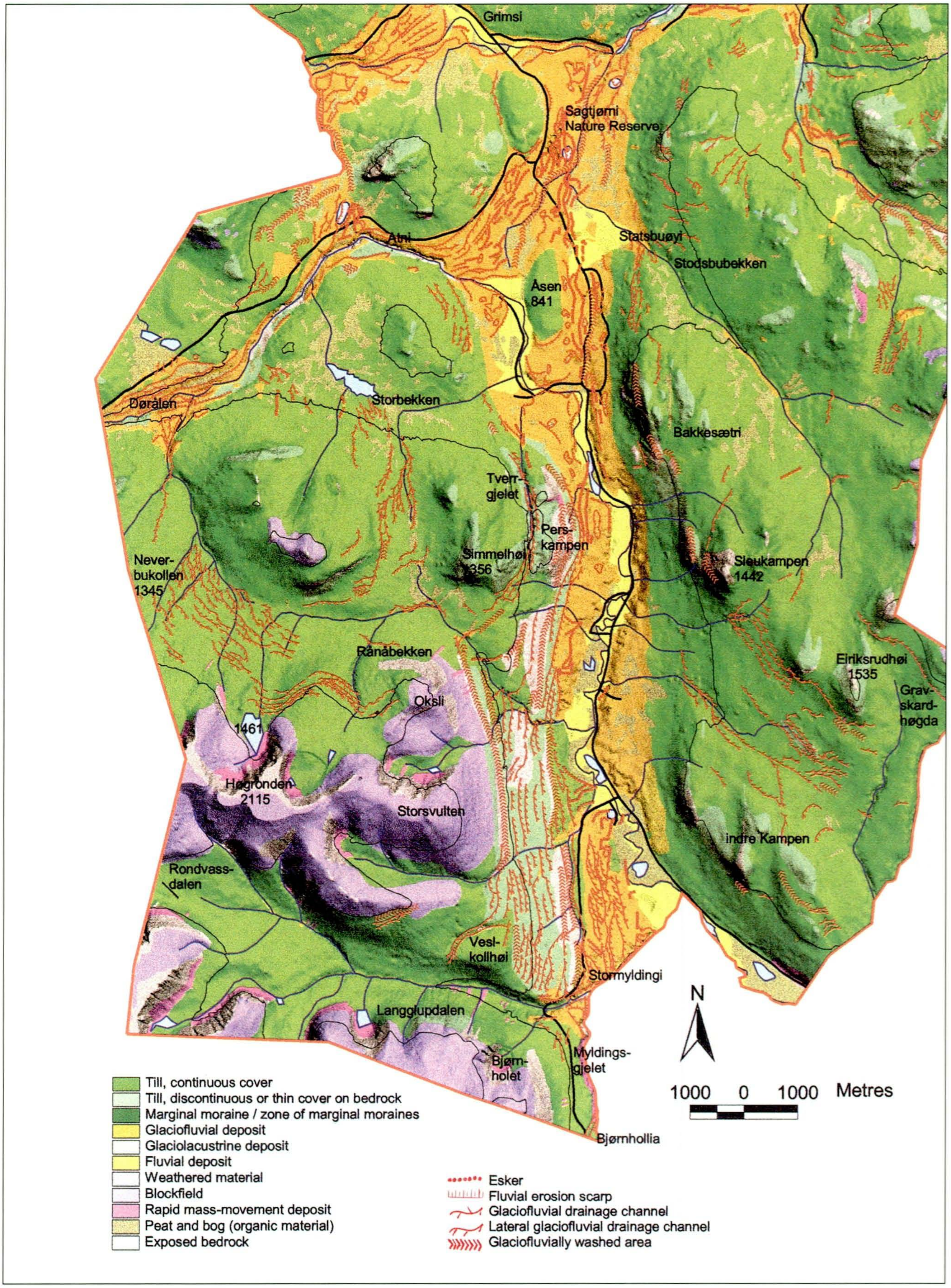

Fig 2. Simplified Quaternary map of the surroundings of the Atndalen valley, taken from the NGU digital database.

vertical downwasting of the inland ice will have resulted in deglaciated areas in the northwestern district (Hjerkinn, Fig. 1.B) which is situated at up to 1026 m a.s.l. By comparison, the inland ice was still some 300 metres thick in the southern parts of the Atndalen valley and in the Alvdal area.

Meltwater forms in the Atndalen valley

Surficial deposits with meltwater forms are extensively developed along the sides of the Atndalen valley (Gjessing 1960, Sollid & Carlson 1980, Follestad 2000), in several areas (see Fig. 2 for location).

In the area of Gravskardhøgda, a marked upper zone of meltwater channels can be seen east of the mountain Eiriksrudhøi (1535 m a.s.l). The upper limit of these channels, which start in the run-off pass of Gravskardet and run northwest, is at 1482 m a.s.l. They terminate after c. 2.5 km in an area with a marked run-off pass, at c. 1396 m a.s.l. Another set of lateral channels is seen along the southwestern side of the mountain Eiriksrudhøi (1535 m a.s.l.). This meltwater system starts at c.1330 m a.s.l., and can be followed to the north for c. 3 km. Farther to the north, flushed surfaces along the western side of Sleukampen mountain and lateral channels in the mountainous terrain south of Statsbuøyi show the continuation of this lateral drainage to the north. These meltwater channels are commonly more than 10 m wide and 2-6 m deep, and in places they expose flushed rock surfaces. Some of these lateral channels are hanging along the valley side (Fig. 3), which indicate a formation contemporaneous with the presence of an ice body in the main valley.

Another zone of lateral meltwater channels is seen at c. 1140 m a.s.l. in the lowest parts of the depression between the mountains Eiriksrudhøi (1535 m a.s.l.) and Indre Kampen. These channels are directed towards a marked run-off pass farther north, lying at 1130 m a.s.l. The southward continuations of these drainage systems indicate that the meltwater drainage mainly came from the catchment areas west of Gravskardhøgda (1735 m a.s.l.) and from a glacier in the Atndalen valley.

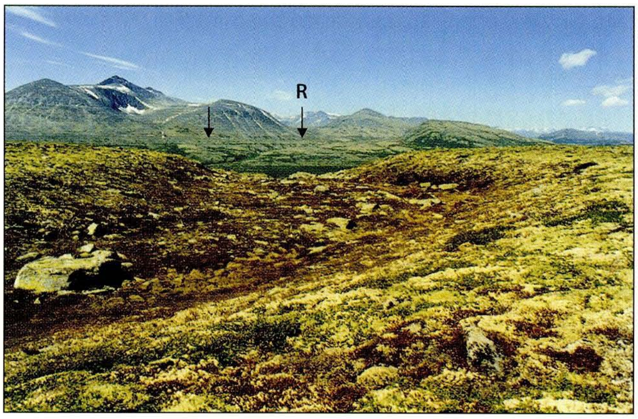

Fig. 3. View from the western side of the mountain Eiriksrudhøi to the western side of Atndalen. Marked meltwater channels are present in this area. In the background, the Rånåbekken (R) valley. Arrows indicate the marked upper limit for the flushed areas along the western side of Atndalen. Photo: B.A.Follestad, 1999.

In the tributary valleys of Langglupdalen and Rånåbekken, prominent one- and two-sided meltwater channels are seen in an area dominated by a thick and continuous cover of till. In Langglupdalen, the uppermost channel starts at c. 1480 m a.s.l. and runs in a westerly direction towards the run-off pass between the valleys of Langglupdalen and Rondvassdalen situated at c. 1418 m a.s.l.. The channel is up to c.10 m wide and, in most places, shows a marked inner brink. The outer brink of the channel is less distinct and generally missing. Exposed bedrock can be seen in the channel.

In the Rånåbekken valley, several systems of lateral channels can be seen (Fig 2). The uppermost channel in this area has an upper limit in the area of Oksli Mountain, at c. 1500 m a.s.l. It can be followed nearly continuously in a westerly direction for c. 2.5 km where it ends at c. 1480 m a.s.l. east of the small lake at 1461 m a.s.l (Fig. 4). This gives a gradient of c. 1% for the channel. These channels are eroded in a cover of block-rich till which shows well developed solifluction lobes above the upper channel. The system of lateral melt-

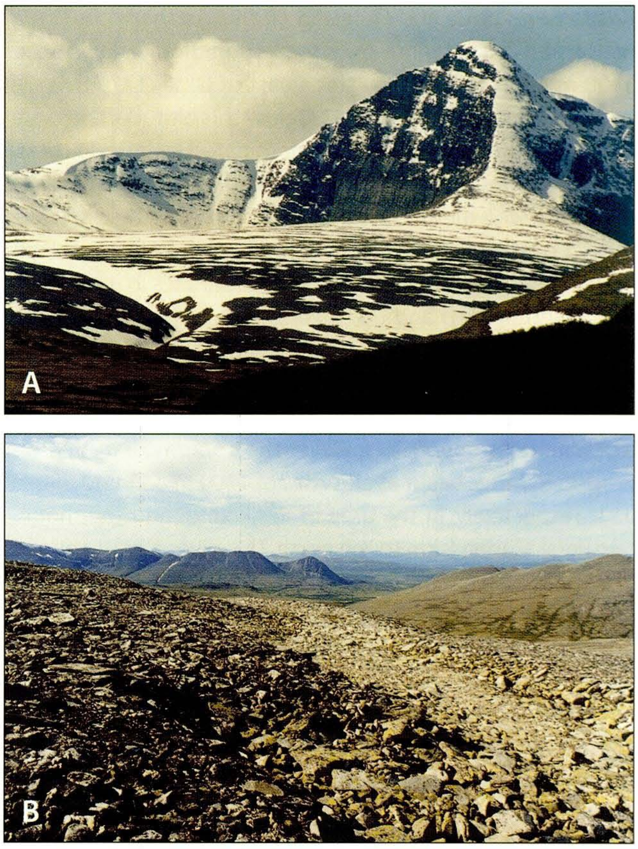

Fig. 4. (A) Marked lateral channels along the northern valley side of the mountain Høgronden.
(B) A summer picture of the uppermost meltwater channel, at c. 1520 m a.s.l. The meltwater channels are generally more than 5 m wide and, in some parts, have a marked outer edge. The photo shows lateral and marginal features. Photo: B.A.Follestad, 1999.

water channels terminates at c. 1300 m a.s.l., c. 500 m south of Neverbukollen (1345 m a.s.l.).

In the cirque valley north of Høgronden, a set of terminal moraines can be observed. The distal ridge (Fig. 5), lying at c.1650 m a.s.l. along the eastern side of the cirque, turns north and may be followed more or less continuously through a small lake (1584 m a.s.l.) to the western side of the cirque valley. Less distinct ridges are present proximally to the distal moraine ridge.

The uppermost channels in the valleys of Langglupdalen and Rånåbekken are dipping in a westward direction and show a meltwater drainage through marked run-off passes at, respectively, c. 1410 m a.s.l. and 1230 m a.s.l. Thus, it can be concluded that the hydrological meltwater gradient was towards the valleys of Rondvassdalen and Døràlen, when the surface of the inlandice was at c.1550 m a.s.l. in the Atndalen valley. As the terminal moraine in the nearby cirque valley is situated above and outside the areas which were covered by the inlandice during the formation of the lateral channels, information from the cirque glaciation cannot be related to the described features left by the ice sheet.

The western side of the Atndalen valley, from the area of *Bjørnhollia to the valley Rånåbekken*, has been mapped and described by Gjessing (1960) and later by Sollid & Kristiansen (1983) and Follestad (1999). As shown in Fig. 2, meltwater channels are only seen sporadically, down to c. 1100 m a.s.l. on the valley slope east of Oksli (1779 m a.s.l.) and Storsvulten (1790 m a.s.l.). Below this altitude, there are lateral channels and large areas dominated by flushed rocks. As pointed out by Gjessing (1960), small canyons c. 4 metres deep and 2-3 metres wide are present. This belt, characterised by meltwater erosion, is dominating the valley slope down to 860 m a.s.l. There, the zone terminates in a canyon 5 to 15 metres deep and up to 20 metres wide which can be followed continuously for 2.5 km. Gjessing (1960) pointed out that lateral channels in this zone are dominated by meltwater erosion features that are sloping towards the north (at a gradient of some 2%). However, the uppermost distinctive erosion features occur at altitudes of 1100 m a.s.l. and 990 m a.s.l., respectively, in the area of Veslkollhøi and the mountain Perskampen 8 km to the north. This gives a gradient of c. 1% for the upper limit between the continuous cover of till and the zones dominated by meltwater erosion towards the north. These lateral forms terminate in the proximal part of the Tverrgjelet canyon, which is eroded along a N-S trending fracture between Perskampen (1050 m a.s.l.) and Simmelhøi (1356 m a.s.l.). This canyon is more than 100 m deep. As several meltwater channels at different levels merge in the proximal parts of the canyon, it can be concluded that this canyon has been a major lateral drainage channel. In the distal parts of the Tverrgjelet canyon and farther north, marked lateral meltwater channels occur along the valley side. These channels are commonly 5-10 m wide and 1-2 m deep and can be followed distally for c.1.5 km.

Along the opposite side of the Atndalen valley, marked

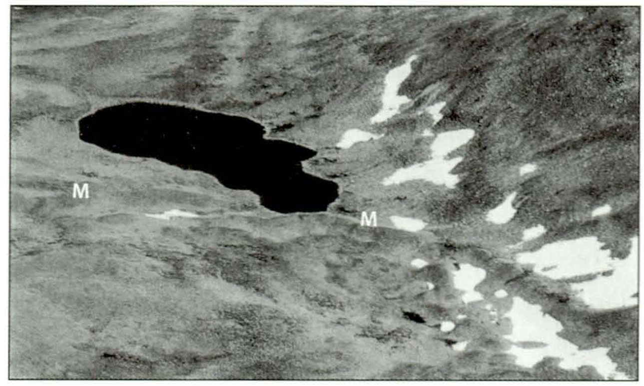

Fig. 5. A distinct end-moraine (M) occurs in the cirque valley north of Høgronden. Smaller terminal moraines can be observed in the proximal area of the cirque. Photo: B.A.Follestad, 2000.

lateral meltwater channels are seen in the area of the stream Storbekken. These features are sloping northwards from 870 m a.s.l. to 840 m a.s.l. At the mouth of the valley Døràlen, where the river Atni enters the Atndalen valley, a fan formed of glaciofluvial material is present. In its central parts, this deposit is eroded and three, large, lateral terraces occur on both sides of the Atni river from 860 m a.s.l to 800 m a.s.l. On the uppermost terraces, one- or two-sided meltwater channels and small kettle holes are seen, indicating a sublateral/subglacial formation in connection with the presence of inland ice in Atndalen. These lateral terraces can be followed northeastwards towards the Sagtjørni Nature Reserve, where they gradually disappear. East of the farms at Statsbuøyi, marked lateral meltwater channels are present at an altitude of c.900 m a.s.l. These channels, and the terraces north of the stream Stodsbubekken, are thought to have formed more or less simultaneously with the terraces at the mouth of the Døràlen valley, as pointed out by Sollid & Kristiansen (1983).

The meltwater deposits in the lower parts of Atndalen are of minor interest in assessing the validity of using the meltwater channels for reconstructing the inland ice surface. However, they are shown on the map (Fig. 2) in order to complete the overall picture of deglaciation features.

Reconstruction of the ice surface

As described above, the systems of meltwater channels have a wide occurrence in the Atndalen region. A reconstruction based on the upper limit for these meltwater systems (fig. 6) shows the occurrence of two, clearly separated, ice surfaces, some 400 metres apart. In the valleys of Rånåbekken and Langglupdalen, the upper system of channels corresponds to an inland ice thickness of c. 4-500 metres in these hanging valleys above the main Atndalen valley. In the Atndalen valley itself, the thickness of the inland ice was c. 800 metres. The lower system of lateral meltwater channels (along the valley sides of the Atndalen valley) indicates that the inland ice in the main valley was c. 400 metres thick in the area of Stormyldingi, and decreased northwards. Glaciers of this thickness in the tributary valleys and in the

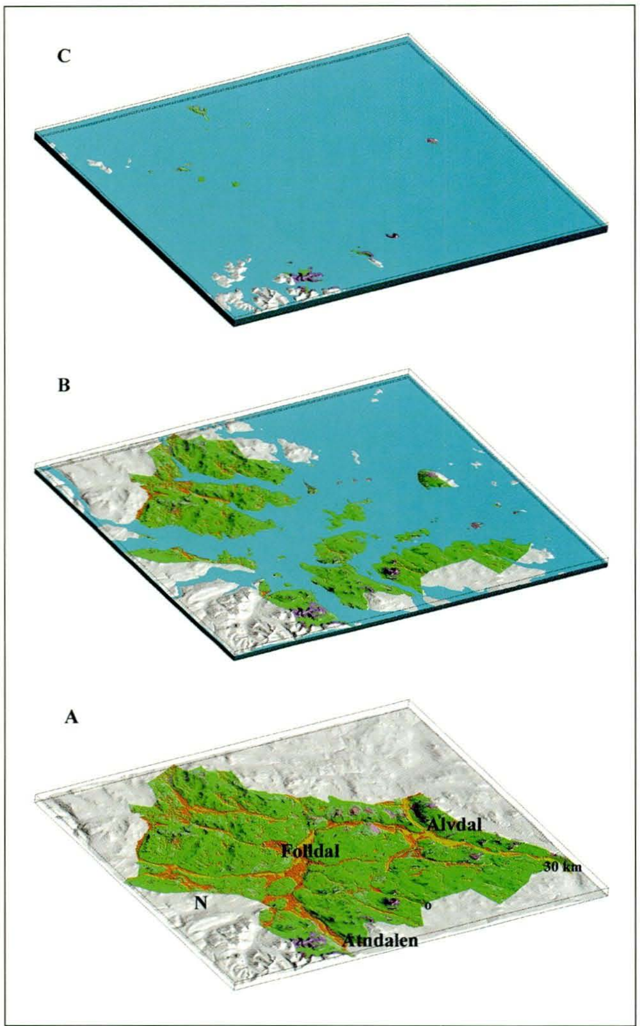

Fig. 6. A tentative reconstruction of the surface of the inland ice when the ice surface was situated at c. 20 m a.s.l in the northern parts of Atndalen valley. An altitude of 720 m a.s.l here, in the northern parts of the Atndalen valley, will give ice-free areas in the Folldalen area towards Hjerkinn. The reconstruction is based on a N dipping ice surface of c. 1%.

main valley can probably be characterised as temperate glaciers (Ben & Evans 1998) .

In a theoretical model for evaluating the meltwater runoff in the distal parts of a glacier, Piotrowski (1997) and Piotrowski & Talaczyk (1999) have shown that meltwater will have to drain subglacially if the substratum drainage capacity is exceeded. A similar view was invoked by Gjessing (1960) in his concept of sheet drainage, when the ice body started to float in a glacially dammed lake. In both models, additional meltwater coming into the subglacial drainage system will have to be drained laterally when the hydraulic transmissivity in the substratum and in the fractured ice body is exceeded. Thus, the lateral channels will have formed close to the surface of the inland ice and will give us the position of the corresponding ice surface when used in a regional model.

Conclusion

It is concluded that the regional pattern of meltwater channels can be used as a tool for reconstruction of the surface of the inland ice during the deglaciation.

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