Development of minor late-glacial ice domes east of Oppdal, Central Norway

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Glacial striations and ice-marginal forms such as lateral moraines and meltwater channels show that a major north-westerly-directed ice flow invaded the Oppdal area prior to the Younger Dryas (YD) Chronozone. Through the main valley from Oppdal to Fagerhaug and Berkåk, a northerly ice flow followed the major northwesterly-directed flow and is correlated with the early YD marginal deposits in the Storås area. A marked, younger, westerly-directed ice flow from a late-glacial dome east of the Oppdal area is thought to correspond with the Hoklingen ice-marginal deposits dated to the late YD Chronozone in the Trondheimsfjord district. In the main Oppdal-Fagerhaug-Berkåk valley, this younger ice flow turned to the southwest and can be traced southwards to the Oppdal area where it joined the remnants of a glacier in the Drivdalen valley. Along the western side of the mountain Allmannberget, a prominent set of lateral, glacial meltwater channels indicates a drainage which turned westward as it met and coalesced with the N-S orientated glacier in Drivdalen. The mountain ridge linking Allmannberget (1342 m a.s.l.) and Sissihøa (1621 m a.s.l.) was a nunatak standing up above these two merging valley glaciers.
The surface of the inland ice represented by the Knutshø moraine systems at c. 1300 m a.s.l. in the Hjerkinn area did not cover the Stororkelsjøen lake (1058 m a.s.l.), as it terminated in the run-off pass between the Folldalen and Einnundalen valleys, southeast of the Hjerkinn area. It is therefore concluded that the Knutshø event, which is thought to belong to the Preboreal Chronozone, is younger than this easterly-situated glacial dome and thus supports a late YD age for the glacial dome east of Oppdal. The lower-lying, lateral, glacial meltwater channels indicate the presence of rather passively melting valley glaciers in the Oppdal area. Thus, it is thought that the deglaciation of the main Oppdal-Fagerhaug-Berkåk valley area was more or less completed before the Knutshø event occurred in the Hjerkinn area. The glaciofluvial drainage patterns demonstrated in this study by the marginal flushed areas and meltwater channels have provided important data for a detailed model of the deglaciation and the distribution of glacial domes in this part of Norway.

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Introduction

The Oppdal area (Fig. 1) has a key position in connecting the western, northern and eastern parts of central South Norway during the Weichselian glaciation. However, only a few authors, e.g., Løkås (1955), Sollid (1964, 1968), Sollid et al. (1980), Reite (1990, 1994) and Sveian et al. (2001) have discussed the deglacialtion history of the area. The most detailed description is that of Løkås (1955) for the valley of Jernbanedalen, which is the valley between Oppdal and Berkåk. Revisions of the existing maps at scales of 1:100,000 (Sollid et al. 1980) and 1:250,000 (Reite 1990) were carried out during the years 2000-2002. In this paper the new results are combined with the existing map data and used for the establishment of a deglaciation model for the Oppdal area. The following issues will be considered in this contribution:

(1) the extension and ice-surface gradient of the inland ice sheet during different stages of deglaciation, discussed on the basis of the distribution of lateral moraines and lateral-/sublateral glacial meltwater forms and glaciofluvial deposits found at different altitudes;

(2) attempts to relate these glacial surfaces to the generally accepted deglaciation model in Sør-Trøndelag and Møre & Romsdal counties, as described e.g., by Follestad (1994), Reite (1994) and Sveian et al. (2001).

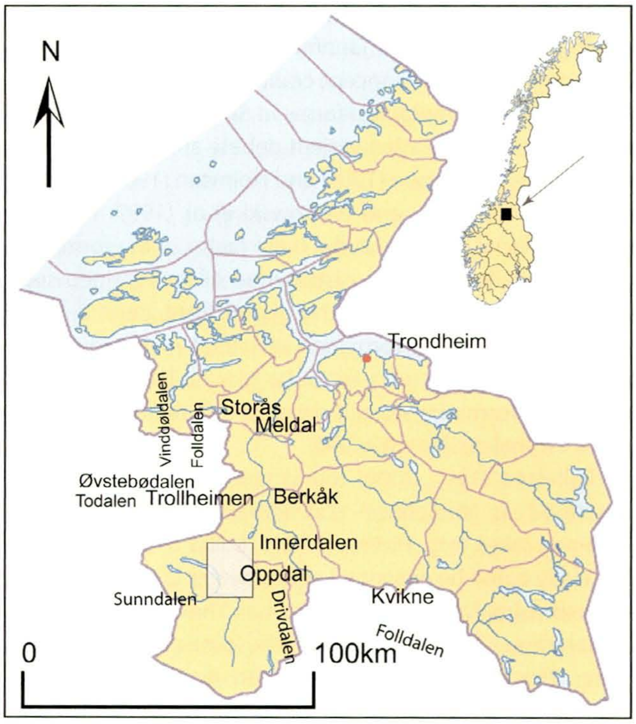

Fig. 1. Outline map of Sør-Trøndelag county showing the location (box) of the Oppdal area.

Deglaciation models based on ice-marginal moraines and systems of glaciofluvial meltwater channels

Ice-marginal moraines, such as lateral moraines and end moraines, have been used for the reconstruction of the ice recession in Norway, since Andersen (1954) made the first reconstruction of the surface of the glacier in Lysefjorden in Southwest Norway based on lateral moraines. Later investigations have used this method and shown its value for modelling the extension of the glaciers and the expected positions of the ice margins in southern, western and northern Norway; e.g., Andersen (1960, 1968, 1975), Sollid (1964), Anundsen & Simonsen (1968), Follestad (1972), Fareth (1987), Reite (1990, 1994), and Sveian et al. (2001).

Patterns of marginal systems of meltwater channels are, together with glacial striations the major sources of information for reconstruction of ice divides and run-off models in the Swedish parts of the Scandinavian mountain chain (e.g., Kleman & Borgstrøm 1995).

In Norway, Hansen (1886) described the distribution of 'shorelines' in ice-dammed lakes and established the first model of 'glacial lakes' formed south of the present-day water divide. Later geoscientists have used this concept (e.g., Holmsen 1915). The value of meltwater channels (Swedish: skvalrennor) was first recognised and added to the deglaciation model by Mannerfelt (1940). He found that lateral channels and 'nunatak lines' proved that the peaks in the Rondane Mountains were real nunataks and stood up above a climatologically passive inland ice. Later, Gjessing (1960) introduced the concept of subglacial drainage and a corresponding water table in the ice/ice-tunnel systems, and concluded that subglacial run-off passes have a geomorphological effect on the landforms in a proximal direction. He thought that this concept could be used to explain the marked geomorphological forms in Southeast Norway. This idea precipitated a rather violent debate and his model was rejected by, e.g., Hoppe (1960) and Holmsen (1967).

Piotrowski (1997) and Piotrowski et al. (1999) reported that subglacial drainage is the main factor in the formation of tunnel valleys and the distribution of fine-grained sediments in areas proximal to the glacier front. Benn & Evans (1998) discussed the formation of lateral meltwater channels at the margins of a subpolar glacier. They concluded that these formations could develop in a marginal or even sub-marginal position (Fig. 2A).

Follestad (1997, 2000) found that meltwater channels described as 'shorelines' and formed in open glacially dammed lakes (e.g., Holmsen 1915, Sollid & Carlson 1980), generally could be explained as meltwater channels formed in the proximal areas to run-off passes. These 'shorelines' are, in many areas, found to represent the lowest limit for flushed zones along the valley as described by Follestad (2000). These flushed zones reach up to 10-50 m above the 'shoreline' and can only be explained by violent glaciofluvial drainage between the hillside and a passive remaining glacier or inland ice in the lower parts of the terrain. Follestad (1997) described marked erosion gullies and glaciofluvial accumulations on the distal side of run-off passes, and concluded that only a subglacial drainage through the run-off passes could explain these formations. In some of the run-off passes he described glaciofluvial accumulations at different altitudes downhill. As the altitude of these deposits in a distal position from a run-off pass will be determined by the subglacial water table in the distal areas, a falling water table will create a new, lower lying, accumulation base (Fig. 2B).

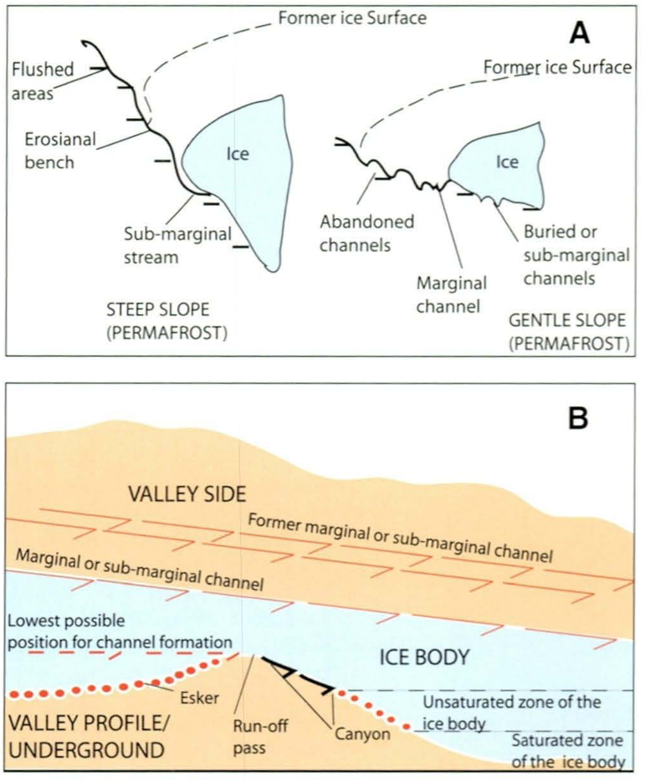

Fig. 2. A: The formation of meltwater channels at the margins of a subpolar glacier according to Embleton & King 1975 in Benn & Evans (2002), slightly modified by the author. As the marginal stream undercuts the ice edge, the ice margin collapses and sub-marginal drainage will take place. B: Marked drainage features formed in the area of a run-off pass during the deglaciation of an area where nunataks stand up in a climatologically passive inland ice. The features are modified slightly from the first version, presented in Follestad & Thoresen (1999). Eskers are formed against the terrain in the proximal areas of the run-off pass. Slukåser are formed and deposited on the distal side of the run-off pass. Here, accumulation will take place in the unsaturated subglacial water zone of the passive inland ice as the drainage velocity gradually decreases and approaches zero in the saturated parts of the glacier. Flushed zones and marginal channels will be formed above and into the run-off pass. The lowest possible marginal channel will be determined by the altitude of the run-off pass and will look like a shoreline. However, sorted material ascribed to wave washing in an open ice-dammed lake is missing.

Glacial striations and erratic blocks have been used for the location of ice divides since Hansen (1895) introduced the term. In combination with reconstructions based on the marginal moraines, glacial striations have been used for establishing the positions of ice divides and migration of younger glacial domes and ice divides during the deglaciation in Norway, e.g., Rye & Follestad (1972), Vorren (1973), Bergersen & Garnes (1981), Olsen (1983,1985) and Nesje et al. (1988).

Topography of the Oppdal area

Barrett (1900) and Reusch (1905) recognised tributary valleys of the 'fish hook type' and noticeable ledges in the valley sides in an older preglacial relief. Holtedahl (1949) measured and described these ledges west of Oppdal up to c. 530 m a.s.l.; and he considered they were of a fluvial origin from before the beginning of the Ice Age. During the glacial cycle of the Ice Age a younger valley system, known as the Driva-Sunndalen valley, was eroded into the old preglacial valley. This valley became an important topographical feature for drainage of the inland ice in a westward direction (Holtedahl 1953, 1960).

From this description of the terrain it might be concluded that the old terrain, consisting of the high plateau 1100-1300 m a.s.l. and outstanding peaks such as, e.g., Stororkelhøa 1524 m a.s.l. and Snøhetta 2286 m a.s.l., cut through by an old major valley system of fluvial origin before the beginning of the Ice Age (Holtedahl 1949), was an important factor in the development of ice surfaces during the different phases of glaciation. Thus, this old landscape and the younger Driva-Sunndalen valley, together with the remaining surface of the inland ice at the end of the Weichselian glaciation, and the main routes of the atmospheric cyclones with their associated heat flow and precipitation, would have had to have acted together to determine the development of deglaciation in the Oppdal area.

Marginal moraines and meltwater channels in the Oppdal area

As noted above, Løkås (1955) has given a detailed description of the surficial deposits in valley of Jernbanedalen, which in this paper is called the Oppdal-Fagerhaug-Berkåk valley. He found that a number of Quaternary ice deposits such as the marginal terraces along the southwestern side of the valley, the nearly horizontal terrace in the lower part of the valley, and the great esker in the bottom of the valley, are all formations which show evidence of a westerly-directed glaciofluvial drainage. These forms and deposits, as well as those on the high plateau and in the valley east of the Oppdal-Fagerhaug-Berkåk valley, seem to fit into a pattern which will be further documented here and used for a tentative reconstruction of the marked ice surfaces present in the area.

Marginal moraines in the Oppdal area

The area west of Oppdal-Berkåk can be characterised as a glacially sculptured landscape with the pronounced Oppdal-Fagerhaug-Berkåk valley cutting through an area surrounded by mountains, the highest reaching up to c. 1560 m a.s.l.

During the glacial cycles, cirques and cirques valleys were formed along the sides of the main Sunndalen-Oppdal-Drivdalen valley. In the Oppdal area, Holtedahl (1949) found no evidence for a younger cirque glaciation and he concluded that the glaciation limit was far above these cirques during the period of deglaciation. On the map compiled by Sollid et al. (1980), distinct younger cirque moraines are shown in the western parts of the Oppdal area. Such features have also been described by Follestad (1994) from the adjacent areas of Trollheimen (Fig. 1).

On the western side of the Oppdal-Fagerhaug-Berkåk valley, lateral moraines and lateral meltwater channels have been recorded by Sollid et al. (1980) and remapped by NGU in 2002. The highest and most westerly situated lateral moraine ridge (Figs. 3 and 4) is very distinct and reaches an altitude of c.1320 m a.s.l. in the southern part of the valley side west of the lake Stavsjøen (1114 m a.s.l). Here, marked lateral moraines occur as a belt of ridges, which can be followed northwards for c. 3 km. These forms terminate at c.1220 m a.s.l. in the lake Stavsjøen area where some of the moraine ridges are up to 5 m high. Farther downhill, marked flushed areas and lateral channels occur. They all slope in a northward direction towards a marked run-off pass at c. 1100 m a.s.l. west of the mountain Storhøa (1167 m a.s.l.). A small, but rather distinctive, terrace-shaped accumulation of

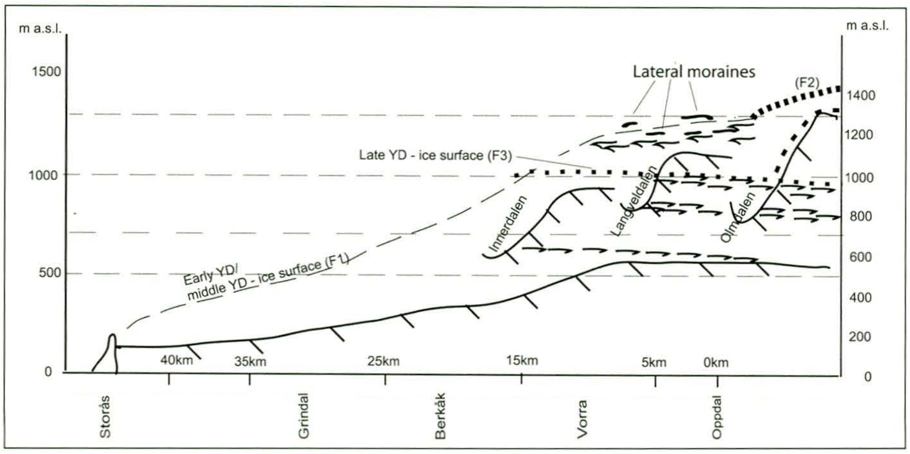

Fig. 3. A glacier profile is tentatively reconstructed through the main Oppdal-Fagerhaug-Berkåk valley and extrapolated to the Storås area in the northern part of the Meldalen v alley. On the basis of lateral moraines and lateral meltwater channels, the early/middle YD-ice surface (F1) and the correlated ice surface (F2) in the Olmdalen valley and the Late YD ice surface (F3) are indicated. It can be noted that the final drainage shown by 'arrows' from the bottom of Innerdalen was towards the Oppdal area. The altitude of this feature will have been determined by the bottom of the run-off pass in the main Oppdal- Fagerhaug valley (570 m a.s.l).

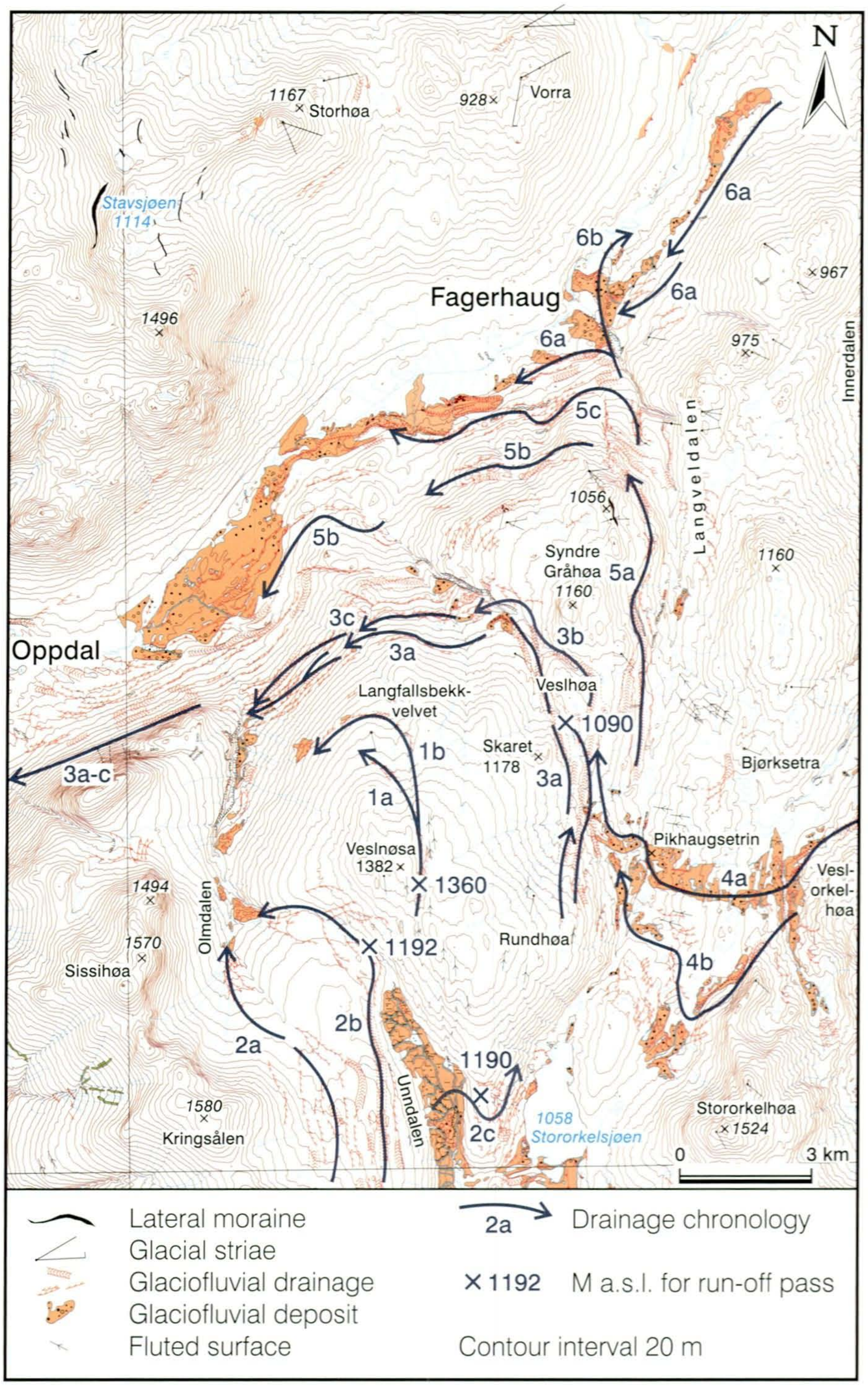

Fig. 4. Distribution of ice-marginal formations such as lateral moraines, lateral marginal/submarginal meltwater channels and flushed areas of bedrock in the Oppdal area.

glaciofluvial material is located on the northern side of this run-off pass (Fig. 4), proving that meltwater drainage was towards the north. These features, together with lateral moraines farther north, are plotted in a profile following the main Oppdal-Fagerhaug- Berkåk valley to the Storås area (Fig. 3).

As shown in Fig. 3, these high-lying moraine ridges may represent a corresponding surface for a glacier in the Oppdal-Fagerhaug area which may have reached as far northwest as Storås, as suggested by Reite (1990). As the distance to the Storås deposit is some 45 km from Oppdal village, this indicates a mean ice-surface gradient of 28 m/km. The terrain gradient over the same distance is c. 11 m/km, giving a relative gradient of c. 17 m/km. This is a steep, though acceptable, terrain-guided gradient for glacier surfaces of YD age (e.g., Fareth 1987, Follestad 1972).

The marked trim line (Fig. 5A-B) seen along the southwestern side of the Olmdalen valley rises from c. 1300 m a.s.l. along the northern valley side of the mountain Sissihøa (1570 m a.s.l) to c. 1400 m a.s.l. near Kringsålen (Fig. 4). This

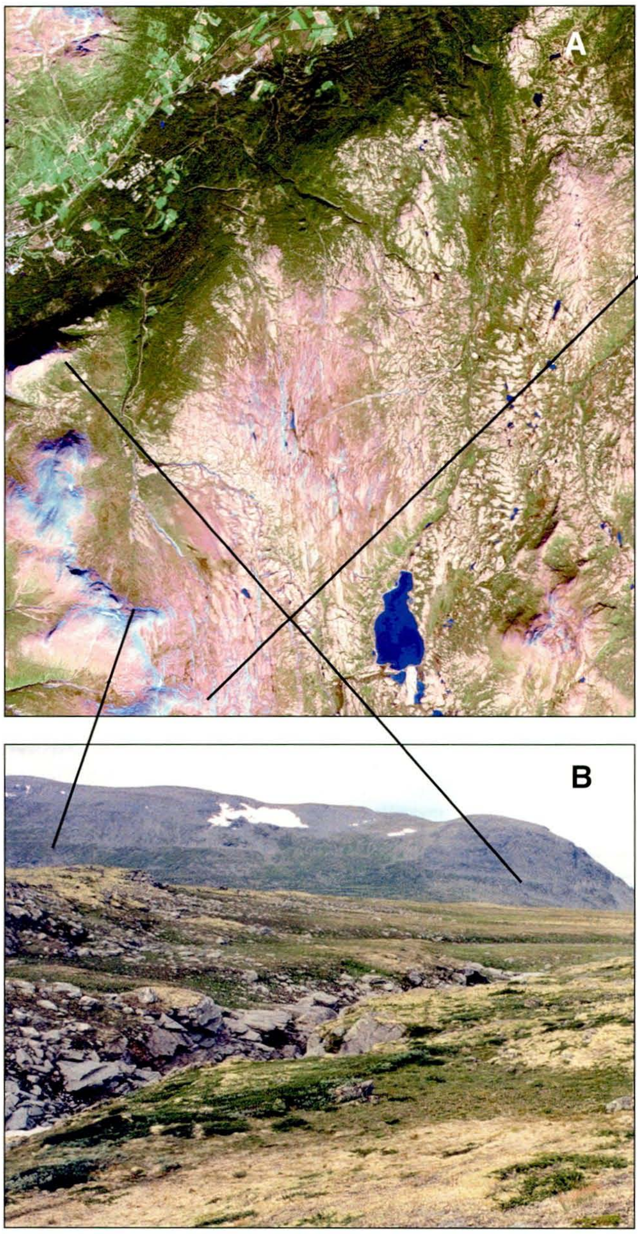

Fig. 5. **A**: A SPOT satellite image of the studied area in the Oppdal-Stororkelsjøen district. Marked northerly-directed drumlin features can be seen in the centre of the image. To the right there are younger and westerly-directed drumlin features. For names, see Fig. 4. The SPOT image is provided by Statens kartverk, Arendal, and has been colour-coded by John Dehls (NGU). **B**: A marked trim line is falling from c. 1400 m a.s.l. in the south (left Kringsålen, 1850 m a.s.l.) to c. 1300 m a.s.l. in the eastern valley slope of Sissihøa mountain (central parts of the photo). In the foreground a marked erosional canyon has cut through a glaciofluvial deposit. The upper limit for this deposit is at c. 1020 m a.s.l. Photo - B.A. Follestad, 2001. **C**: Marginal lateral meltwater channels along the western valley slope of Olmdalen indicate a vertical downmelting of the inland ice during a later phase of the deglaciation. The photo is taken from Stororkelhøa (1524 m a.s.l.). The Stororkelsjøen lake can be seen in the middle part of the photo. Photo - B.A. Follestad, 2001.

indicates that tributary glaciers entered the main Oppdal-Fagerhaug-Berkåk valley from the Olmdalen, Langveldalen and Innerdalen areas. As indicated by the above-mentioned trim line, the ice flowed in a northerly direction and originated from an inland ice sheet with a surface which reached up to c. 1400 m a.s.l in the eastern plateau areas above the Veslnøsa mountain (Fig. 4). The lateral moraine (c.1020 m a.s.l.) at the mouth of Langveldalen (Fig. 6, see Fig. 4 for location), and moraines and marginal meltwater channels along the western side of the main Oppdal-Fagerhaug-Berkåk valley (Figs. 3 and 4), indicate a northerly-sloping glacier in the main valley as long as the surface of the inland ice still reached above c. 1000 m a.s.l. Below an altitude of c.1000 m a.s.l., a marked change in the drainage direction of the meltwater channels can be observed, e.g., in the lake Stavsjøen area (Figs. 3 and 4). These southerly and southwesterly drainage features, seen along both the western and the eastern valley sides, will be described and discussed below.

Marginal channels in the Stororkelsjøen area

The Stororkelsjøen area (Fig. 4) east of the Oppdal-Fagerhaug-Berkåk valley is dominated by a high plateau some 1100 m a.s.l., with outstanding mountains such as Stororkelhøa (1524 m a.s.l.) and Kringsålen (1580 m a.s.l.). The basin between these mountains is occupied by the Stororkelsjøen lake. To the south, a marked valley runs into the lake Fundin area in the county of Hedmark. North of the lake Stororkelsjøen the terrain generally slopes towards the north.

This geomorphology exposes several, more or less distinct, run-off passes where marginal lateral channels and related features, such as flushed surfaces of bedrock, are

Fig. 6. A marked lateral moraine at 1020 m a.s.l. east of the Langveldalen valley. The lateral moraine shows a falling gradient into the valley of Langveldalen. Photo - B.A. Follestad, 2000.

quite common. An outline of these lateral systems is presented below. More comprehensive descriptions are given in an Appendix file which can be obtained from the author upon request.

In ***the Veslnøsa Mountain (1382 m a.s.l.) area,*** two sets of lateral meltwater drainage systems have been recorded (Fig. 4). These show a northerly-directed, marginal glaciofluvial drainage along the eastern side of Veslnøsa through a run-off pass situated at 1360 m a.s.l. (Fig. 9 and Appendix file). These drainage systems can be followed to the western side of Veslnøsa where marked glaciofluvial deposits occur at c. 1220 m a.s.l. In the text that follows, these formations are referred to as drainage systems (1a) and (1b) (Fig. 4).

In ***the Olmdalen area*** marked meltwater channels are present along the western side of the valley (Fig. 5A and C). These lateral channels reach up to c. 1300 m a.s.l. and can be followed more or less continuously into northwestern parts of the Olmdalen valley. The gradient of these channels is c.13 m/km. In the further text below, these marginal forms are referred to as (2a) (Fig. 4). More detailed descriptions of these drainage systems are given in the Appendix.

Along ***the western side of the Unndalen valley*** (Fig. 4), prominent marginal channels are seen which are pointing into the marked run-off pass situated at 1192 m a.s.l. (Fig. 7). The run-off pass, which is 3-400 m wide in its upper parts, has large areas of flushed rocks and well developed marginal channels. In the bottom of this run-off pass a marked 10-20 m-broad and 5-10 m-deep canyon can be followed downhill in a distal direction for some 4 km. Two distinct accumulations are seen along the edges of the canyon at altitudes of 1120 m a.s.l and 880 m a.s.l. The upper one can be followed continuously down to 1040 m a.s.l. where it terminates (Figs. 8 and 5A). Both deposits have rather irregular surfaces with several depressions, here interpreted as kettle holes. Minor sections expose poorly sorted gravelly sand. In the text that follows, these forms are referred to as drainage systems (2a) and (2b) (Fig. 4).

From the drainage systems (1a), (1b), (2a) and (2b) it can be concluded that the marginal channels and meltwater deposits, characterised by irregularities in the surface and poorly stratified glaciofluvial material, were formed in close contact with the remaining inland ice in the plateau area around Stororkelsjøen and in the main valley of Oppdal-Fagerhaug-Berkåk. This indicates that the corresponding surface of the inland ice on the plateau area had to be situated at least 1360 m a.s.l for meltwater to be able to enter the main valley through this run-off pass on the mountain Veslnøsa (1382 m a.s.l). The position and formation of the lateral or sub-lateral kame terraces (at c.1080 m a.s.l.) in the Oppdal-Fagerhaug-Berkåk area in a subglacial water table in the main valley glacier or in an ice-dammed lake gives the approximate altitude of the surface of the main valley glacier. From the irregularities in the surface and the poorly stratified glaciofluvial deposits at, respectively, 1120 m a.s.l. and 880 m a.s.l. (drainage systems (2a) and (2b)), it can be concluded that the associated marginal channels and the weakly stratified and poorly sorted glaciofluvial deposits accumulated in a subglacial water table in contact with the margin of a glacier. As the prominent upper deposit corresponding to the above-described features formed by drainage along the eastern side of Veslnøsa, this accumulation is thought to have been deposited in approximately the same water table. This indicates that the plateau glacier in the Stororkelsjøen basin had an outlet 'glacier' flowing through the valleys of Olmdalen and Langfallsbekkvelvet (Fig. 4). Where these outlet glaciers reached the valley glacier in the Oppdal-Fagerhaug-Berkåk valley and the general water table in this glacier, subglacial accumulations would have formed. The lowermost deposit in the Olmdalen valley shows, further, that the plateau glacier and the outlet glacier in Olmdalen existed even when the general water table in

Fig. 7. The marked run-off pass 1192 m a.s.l. between the valleys of Unndalen and Olmdalen. The photo is taken from the pass area, looking towards southeast. Photo - B.A. Follestad, 2000.

the main valley glacier of the Oppdal-Fagerhaug-Berkåk valley had been lowered to c. 800 m a.s.l.

The three run-off passes west of ***Stororkelsjøen (1058 m a.s.l.)*** have inlets situated at c. 1180 m a.s.l. along the ridge between the Unndalen valley and Stororkelsjøen (Fig. 4). This altitude is only a few metres lower than the run-off pass at 1192 m a.s.l. northward towards Olmdalen. Thus, we might conclude that glaciofluvial meltwater in the proximal areas of the run-off pass at 1192 m a.s.l. turned to the south and east before the run-off pass was deglaciated, and found its way along the eastern side of the Veslnøsa (1382 m a.s.l.). In the text below, these forms are referred to as drainage system (2c).

Along the valley side northeast of ***Rundhøa mountain (1374 m a.s.l.)***, marked flushed rock surfaces and marginal channels are present (Fig. 4). These systems can be followed continuously for 2-2.5 km to the north where a marked run-off pass (1090 m a.s.l.) is recorded between Skaret (1178 m a.s.l) and Veslhøa (1092 m a.s.l.). The marked canyon on the distal side of the run-off pass is 6-10 m deep and can be followed downhill over several kilometres. Broad zones of flushed bedrock surfaces occur along the sides of the canyon, indicating that there was a rather violent subglacial drainage in this area. An esker (slukås) up to 10 m high is seen at 980 m a.s.l. and can be followed 300 m downhill in a southwesterly direction, terminating at 940 m a.s.l. From this we can conclude that the accumulation of the slukås took place in the unsaturated zone of the ice body (cf. Fig 2B) in the main Oppdal-Fagerhaug-Berkåk valley.

Farther to the southwest, the marked and nearly horizontal marginal channel systems continue. The distinct flushed zone east of Veslhøa (1092 m a.s.l.) bends northwestwards and later southwestwards and than continues, together with the above-described marginal systems, to the southwest. As described by Løkås (1955), marked marginal meltwater forms, such as lateral channels and terraces, are

Fig. 8. In the distal parts of the run-off pass at 1192 m a.s.l. two marked terrace-shaped accumulations are seen. Small sections through the flanks of these deposits show poorly sorted sandy gravel. Pits and smaller depressions on the surfaces are interpreted as kettle holes. Photo - B.A. Follestad, 2001.

seen along the western side of the valley of the river Tinnia. These lateral channels and terraces occur from the upper parts of the valley side down to the bottom of the valley. It seems reasonable to relate the highest-lying forms to subglacial or subaerial meltwater drainage, which came through the run-off pass at 1090 m a.s.l. in the Skaret area. These drainage features can be followed more or less continuously in a southwesterly direction, as a set of marginal channels, to the area west of Olmdalen (Fig. 4). There, these channels disappear in the steep valley side at c. 800 m a.s.l. These forms are referred to below as drainage systems (3a) and (3b-c) (Fig. 4).

In the areas north of ***the Veslorkelhøa mountain,*** a distinct flushed zone more than 200 m wide occurs along the northern side of the mountain. This flushed zone continues into an area of ridges and terraces. Small sections through these deposits expose stratified and poorly sorted glaciofluvial material which, together with the irregularities in the surfaces, is considered to favour a subglacial origin.

Farther to the west, north of the road to the farm Pikhaugsetrin, a marked belt of ridges and terraces is seen. These features can be followed more or less continuously to Pikhaugsetrin where the continuation of the belt is shown as pronounced ridges along the slope down to the farm. Sections through some of the ridges show sorted glaciofluvial material. On the valley side west of Pikhaugsetrin, ridges more than 5 m high, interpreted as eskers, continue up the hill towards the west. These ridges are pointing directly into the run-off pass area west of Veslhøa (1092 m a.s.l). In the discussion below, these forms are referred to as drainage system (4a) (Fig. 4). The marked esker system along the northwestern side of Stororkelhøa can be followed over a distance of some 2 km to the southwest. There, marked lateral terraces with kettle holes are seen. The form of these terraces shows that they were deposited by meltwater entering the area along the southwestern side of Stororkelsjøen. Northwest of these terraces a set of lateral channels begins to take shape. These channels bend to the west and northwest towards the Pikhaugsetrin farm. In the text below, these forms are referred to as drainage system (4b) (Fig. 4).

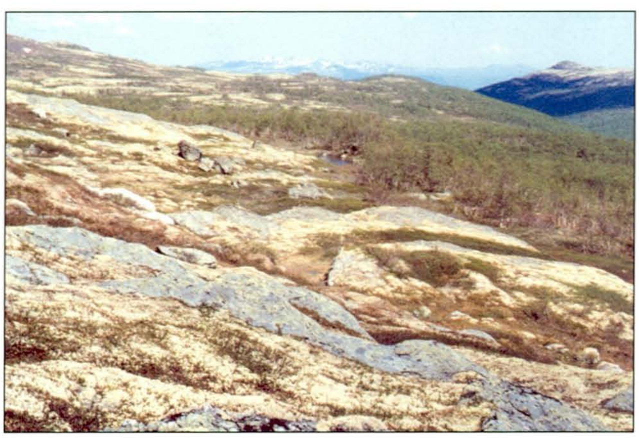

Fig. 9. Flushed zone (left) and a marked erosion ridge in an area with a continuous till cover, in the bottom of the Langveldalen valley. Photo - B.A. Follestad, 2001.

In the valley between Veslorkelhøa (1291 m a.s.l) and Stororkelhøa (1524 m a.s.l.), marked terraces are present. The elevation of the highest terrace is at c. 1030 m a.s.l. This altitude corresponds with the altitude of a marked run-off pass west of the Bjørksetra farms (Fig. 4), which drained the inland ice towards the Langveldalen valley. These deposits, and the marked ridges farther up the valley, were formed in a distal position to a marked run-off pass at 1095 m a.s.l, about 1.5 km northwest of Veslorkelsjøen (1010 m a.s.l.). The lower terraces in this valley towards Bjørksetra were formed when the Innerdalen valley started to drain the area. These forms are referred to as drainage system (5a) (Fig. 4).

The meltwater forms in the valley of Langveldalen are represented mainly by the marked flushed areas (Fig. 9) in the southern parts of the valley and the prominent fan-shaped deposits of glaciofluvial material in the mouth of the valley. These forms indicate that the last drainage of the inland ice in the Stororkelsjøen basin took place through this valley before the ice became so thin that it broke up and was eventually drained out through the Kvikne area (Fig. 1). In the northern parts of the Langvella valley, the highest-lying terraces with channels and kettle holes spread out from some 570 m a.s.l. in a westerly direction. In the central parts the Langvella river has eroded this deposit, and several lower-lying terraces have been formed. A pit in the lower part of the deposit exposes more than 30 m of inclined layers of sand and gravel.

Two marked terrace-shaped deposits are seen farther to the northeast at c. 560 m a.s.l. These deposits have horizontal surfaces up to 50 m wide with small drainage channels pointing to the southwest, as described by Løkås (1955). Depressions of different size are present on these surfaces and these are interpreted as kettle holes. These formations, and the large areas of silt and fine sand in the valley bottom in the proximal areas of the run-off pass (560 m a.s.l.), demonstrate an ice damming and a late branch of a glacier flowing into this area from the Berkåk valley. In the text below, these forms on the eastern side of the main Oppdal-Fagerhaug-Berkåk valley are referred to as drainage systems (6a) and (6b) (Fig 4).

From the *drainage systems (3a-c), (4a-b) and (5a-b)*, it can be concluded that large amounts of glaciofluvial meltwater from areas to the southeast drained through the run-off passes in the Stororkelsjøen area. The westerly drainage can, in most cases, only be explained by a subglacial and/or submarginal drainage determined by a higher-lying ice surface to the north and northeast. The marked marginal channels and terraces along the eastern side of the Oppdal-Fagerhaug-Berkåk valley were formed during this period of glaciofluvial drainage, as already suggested by Løkås (1955). From these lateral forms it can further be concluded that the surface of the inland ice in the Oppdal-Fagerhaug-Berkåk area was at least at c. 800 m a.s.l. in the area east of Oppdal when this southwesterly drainage of the inland ice east of the main valley started. As illustrated in Fig 4, this marked drainage continued through the valley of Langveldalen even when the surface of the inland ice was lowered by c. 100 metres in the main Oppdal-Fagerhaug-Berkåk valley (cf. (6a), Fig. 4).

From the *drainage systems (6a) and (6b)*, it can be concluded that during a final phase meltwater drained in a westerly direction, and the altitude for this drainage was determined by the run-off pass at c. 560 m a.s.l. This is also the present watershed in the main valley today. Finally, the last remnant of the inland ice broke up in the Berkåk area and, as the ice dam was broken, the present-day drainage system was established (6b).

Discussion

Follestad (1994), Reite (1994), Andersen (2000) and Sveian & Rø (2001) have discussed the extension and distribution of the inland ice in the areas around Oppdal. Reite (1994) and Andersen (2000) indicated that the inland ice was rather extensive in the northeastern parts of Trollheimen (Fig. 1) and the Meldal valley, northwest of the main Oppdal-Fagerhaug-Berkåk valley, during the YD event, which was represented by the *Tautra-Tiller-Storås ice-marginal deposits* in Sør-Trøndelag. They concluded that the ice advance during this event reached as far north as the Storås deposits in the northern parts of the Meldal valley. These deposits, and a possible further westward extension of comparable deposits which were mentioned but not described for the northern valleys in the Trollheimen mountains, were related to the late Allerød /early YD chronozone. According to Reite (1994), the ice-marginal deposits in the Støren-Budalen-Berkåk area were related to the following event, the *Hoklingen Substage,* which has previously been dated to the late YD Chronozone, c. 10,300 – 10,400 ^{14}C years B.P. (Sollid & Reite 1983).

In the western parts of Trollheimen and in the Todalen valley (Fig. 1), lateral and terminal moraines related to valley and cirque glaciers have been described by Follestad (1994). These formations are not dated, but have been assigned a YD age. In the northeastern parts of Trollheimen, Follestad (1994) found no evidence for the presence of valley glaciers, e.g., in the Øvstebødalen, Vinddøldalen and Folldalen valleys (Fig. 1). In the upper, western parts of Øvstebødalen and Vinddøldalen, terminal moraines have been described and are interpreted to relate to an old cirque glaciation (Follestad 1994). As this took place most probably during YD, this is taken as evidence for a more or less complete deglaciation of the main Øvstebødalen and Vinddøldalen valleys.

No evidence for the presence of a huge valley glacier has so far been found either in Folldalen or east of the Meldal valley, as suggested for the continuation of the *Tautra-Tiller-Storås ice marginal deposits* (Reite 1994). Thus, it is concluded that the most probable continuation of the Tautra-Tiller-

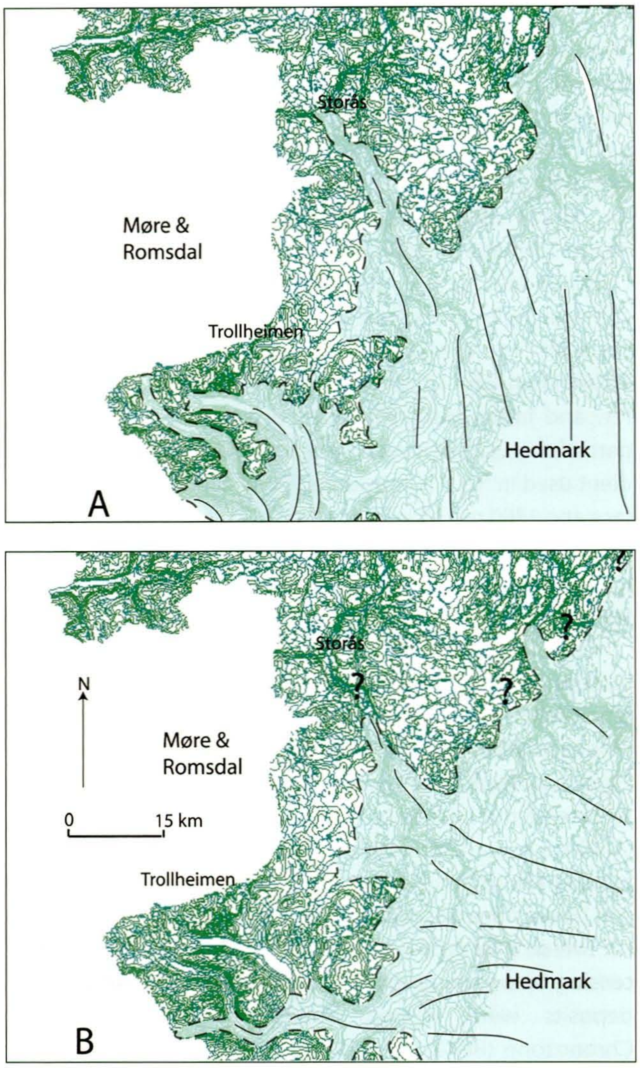

Fig. 10. A tentative reconstruction of the two main ice-stream phases during the deglaciation of the area: A: The early/middle YD ice surface (F1 and F2), which reached the Storås marginal deposits in the northern parts of the Meldalen valley. B: The late YD ice surface (F3) dominated by a westerly-moving ice-stream from an easterly-situated dome. This ice stream in the main Oppdal-Berkåk valley was divided into two major streams, which can be demonstrated in the Oppdal and Meldal areas, respectively.

Storås ice-marginal deposits has to be found in the areas east of the Trollheimen mountains (Fig. 10A). The gradient used to correlate the Storås deposits in the Meldal valley with the lateral moraines at c. 1200-1300 m a.s.l. in the Oppdal area is rather steep and, therefore, marginal deposits occurring farther north in the Orkdalen valley might be considered as alternative marginal positions for this valley glacier. Carbon datings recently carried out on shell fragments from glaciofluvial marginal deposits at Orkland (12 km north of Storås) and Kvale (17 km north of Storås) (Lars Olsen, pers. comm. 2003), dated respectively to 11,540 +/- 70 and 11,280+/- 60 14C years BP, indicate a late Allerød – early YD age for these deposits. In this case the gradient for the surface of the valley glacier would be c. 20 m/km or, reduced for the terrain gradient c. 10 m/km, which is considered acceptable for a YD valley glacier in this area. However, the magnitude of the Storås marginal deposit and the fact that possible correlative marginal deposits are not found either to the east or to the west of Storås for a westerly-directed branch of a glacier in the Meldal area, favour the interpretation that the Storås marginal deposits are representative of the *Tautra-Tiller-Storås ice-marginal event* in the Meldalen-Orkdalen area, as also suggested by Mangerud (2003). This will also help to explain the described lack of marginal deposits in the main northerly-directed valleys of Trollheimen (Fig. 10). Even though the lateral moraines are few and rather discontinuously distributed in the studied part of the Oppdal area, a reconstruction based on the gradient used in Fig. 3 is considered acceptable. Thus, an ice surface at c. 1300 m a.s.l. in the central parts of the main valley in the Fagerhaug area is thought to correlate with the Storås marginal deposits in the northern parts of the Meldalen valley.

The marked trim line (Fig. 5A-B) between a relatively continuous cover of till and the above-lying areas dominated by block fields in Olmdalen might, furthermore, be roughly synchronous with this c. 1300 m surface in the main Oppdal-Fagerhaug-Berkåk valley. This implies that the comparable surface of the inland ice in the Stororkelsjøen area was at c.1400 m a.s.l. and the peaks of the mountains Sissihøa (1570 m a.s.l.), Kringsålen (1580 m a.s.l) and Stororkelhøa (1524 m a.s.l.) were nunataks (Fig. 10A).

Sveian & Rø (2001) described marginal deposits characterising the younger Vuku event in the Ålen area. These deposits were formed during the early Preboreal Chronozone (Reite 1994), at a time when the ice surface reached more than 1000 m a.s.l. in the central eastern areas of Sør-Trøndelag county (Sveian & Rø 2001). In this connection it can be noted that the westerly oriented striations on the mountain at 1160 m a.s.l. and the drumlins in the areas west of Bjørksetra farm suggest that a younger westerly ice flow affected this mountain area in a later phase of the deglaciation (see Fig. 3). This ice movement is represented by younger westerly and southwesterly striations on the Vorra mountain (928 m a.s.l). This suggests that the ice movement through the main valley of Oppdal-Fagerhaug-Berkåk valley turned to the southwest, as shown by the southwesterly trending lateral moraines in the Stavsjøen lake area and the lateral, southwest-directed, marginal channels below c. 1000 m a.s.l. (Figs. 3-4). This gives an ice thickness in the main valley of c. 500 m when the ice flow turned to the southwest in the Fagerhaug area. Moreover, the altitude of the ice surface of the contemporary northwesterly-directed ice flow in the Berkåk area was close to c. 1000 m a.s.l. As the altitude for this ice surface at Berkåk is approximately the same as for the YD glacier surface, this younger ice flow might also have reached to Storås (Fig. 10B).

The surface of the inland ice represented by the Knutshø moraine system, which is falling in a northerly direction, is at c. 1300 m a.s.l. in the Hjerkinn area. This shows that the Stororkelsjøen (1058 m a.s.l.) was more or less deglaciated during the formation of this moraine system. It might therefore be concluded that the Knutshø event, which is thought to belong to the Preboreal Chronozone, is younger than the described, easterly-situated, glacial dome and thus supports a late YD age for the glacial dome east of Oppdal.

Conclusions

It can be shown that the northerly-directed ice flow through the main valley of Oppdal-Fagerhaug-Berkåk during the final phase of the Weichselian glaciation was followed by a younger, westerly ice flow from a glacial dome in the area east of Oppdal. When the surface of the inland ice was lowered to some 1000 m a.s.l. in the main Oppdal-Fagerhaug-Berkåk valley, this later ice flow had a complex flow pattern as it turned southwestwards in the southern and northwestwards in the northern part of the main valley. This flow pattern is here tentatively correlated with the Hoklingen Substage in Sør-Trøndelag county (Reite 1994), and is older than the Knutshø event (thought to belong to the Preboreal Chronozone). A younger dome in the areas east of Oppdal contradicts the common view of there having been a south- and southeasterly located ice-divide south of the present water divide that dominated the deglaciation during the entire YD in southeast Central Norway (Sollid et al. 1980). On the contrary, the glacial dome strongly supports the earlier view of, e.g., Løkås (1955) and Sollid (1964, 1968), which reported a subglacial drainage from east to west over the Kvikne run-off pass with a subsequent swinging of the meltwater drainage southwestwards towards the Oppdal area.

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