

# Block fields, ice-flow directions and the Pleistocene ice sheet in Nordmøre and Romsdal, West Norway

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On the basis of till fabric analyses, glacial striations, the distribution of tills and block fields in this region the vertical and horizontal extension of the continental ice sheet is discussed. The glaciation model indicates that the Late Weichselian ice sheet covered the entire area. The ice flow was to the north-northwest and only to a minor extent influenced by the local topography. The ice sheet extended to the continental edge west of the Nordmøre region. During the retreat of this Late Weichselian ice sheet a re-advance probably occurred. Nunataks were formed and the marked boundary for the block fields was developed as an erosional limit along the surface of the ice sheet. The block fields themselves, however, were probably formed before the last glaciers covered the area and have thus survived beneath the ice sheet

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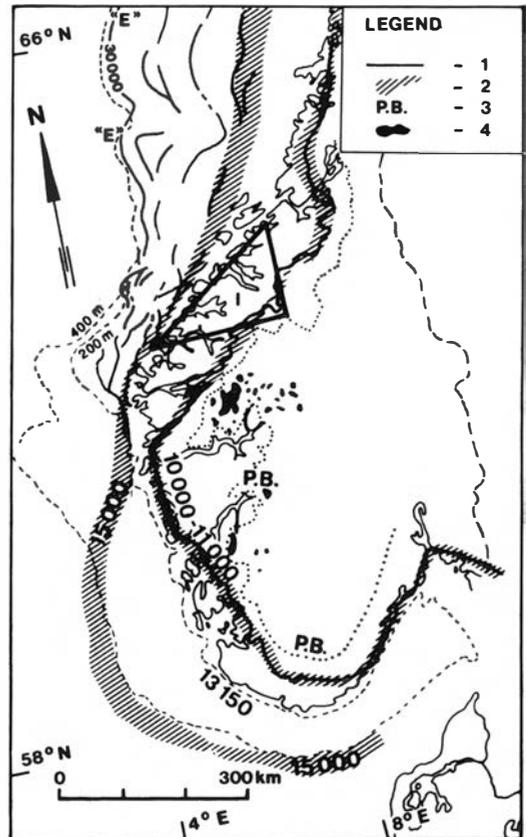
The apparently well defined lower limit of autochthonous weathering material (e.g. Sollid & Sørbel 1979) in the mountains of southern Norway is considered by Nesje et al. (1987, 1988) to represent the highest surface of the Late Weichselian ice sheet. In this paper this limit is discussed in relation to ice-flow directions deduced from till fabric in some localities of terrestrial till. The interpretation suggests that till fabric analyses might be an approach by which to correlate the shelf deposits with terrestrial glacial deposits.

## The Nordmøre region

The Nordmøre region (Fig. 1) consists of three different types of landscape: a submerged shelf in the west, a low-lying coast or strandflat and an area of high mountains in the east and southeast. The topography has affected the accumulation of the Quaternary sediments.

The shelf extends 100 km west of the Nordmøre coast and increases in width to the north (Fig. 1).

*Fig. 1.* Marginal moraines modified from Andersen (1987). (1) Marginal moraines, 'E' (the Egga moraines). (2) Younger Dryas ice-margin position (10000–11000 years BP) and suggested ice-front position 15000 years BP. (3) Preboreal moraines. (4) Existing glacier. The Nordmøre region is indicated (I).



Glacial deposits and moraine ridges are widespread in this area (e.g. Andersen 1987; Lewis et al. 1987).

The strandflat, which was formed during the Pleistocene ice age (Larsen & Holtedahl 1985), is a lowland area surrounding more elevated mountains. These well marked landforms reaching up to 100 m above present-day sea level are mostly barren. Surficial deposits of any notable extent are here mostly found below sea level.

The mountains with peaks and plateaux (for example, the mountain area between the valleys of Eide and Batnfjord reaching 1000 m above sea level, Fig. 2) are generally orientated southwest-northeast, parallel to Caledonian structures. Valleys striking southwest-northeast are intersected by fracture-controlled valleys with a northwest-southeast direction. The direction of the dominant ice flow towards the northwest/north-northwest (as indicated by glacial striae, see Fig. 2)

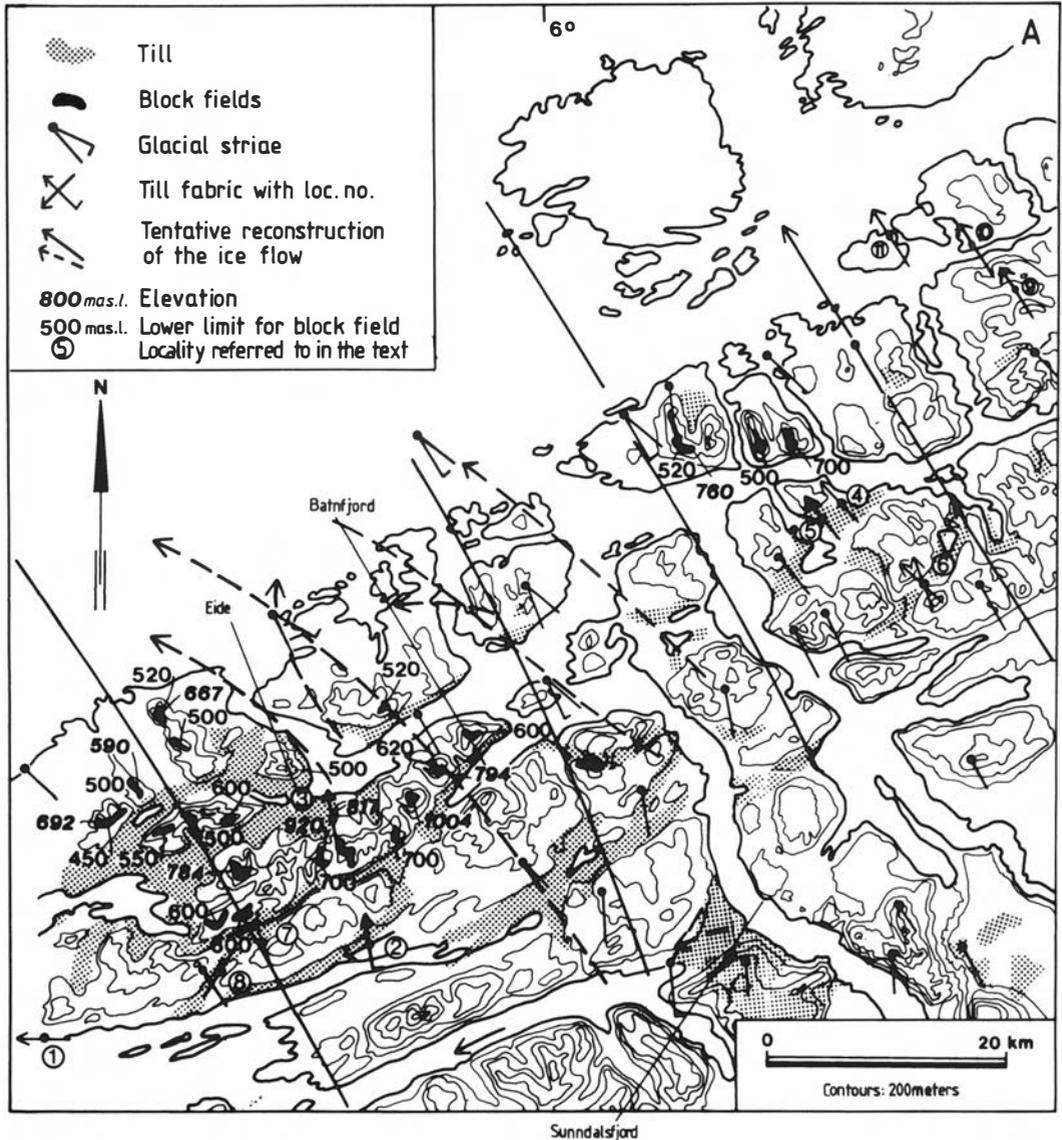


Fig. 2. The Nordmøre and Romsdal region. The distribution of till and block fields and the main ice movements (indicated by glacial striation and till fabric analyses).

indicates that the strike valleys were nearly at right angles to the flow, and thus had the potential to become sediment traps. The glaciers over-deepened the fracture orientated valleys to fjords, e.g. Sunndalsfjord, which is more than 500 m deep.

## Distribution of surficial deposits

The deposits have been mapped according to their mode of origin (genesis) as suggested by the Geological Survey of Norway. Detailed maps in scales of 1:20,000 and 1:50,000 with descriptions are given by Follestad (1983, 1984, 1985, 1986, 1987, 1989, 1990) and Follestad & Anda (1988) for most of the area. The results in these publications clearly demonstrate that tills and block fields are common surficial deposits in the area (Fig. 2).

## Tills, till fabrics and glacial striation

The tills consist of both basal till and ablation till, of which the former seems to have the widest occurrence. In most cases these tills show a rather smooth surface overlain by different types of bog. The stone size and stone frequencies change from place to place. The till may show deformation structures due to ice pressure. In the area of ablation tills layers of sorted material occur. The matrix of the tills less than 16 mm is dominated by the sand and silt fractions. The percentage of the clay fraction is generally below 10%. In those areas where the clay content is more than 10% the tills seem to be derived from former deposits of marine clay.

As the till deposits are described in the above listed map descriptions, only a brief description of some key localities will be given in the following sections of this paper.

On the site of the 'Fylkeshuset' in Molde (Fig. 2, loc. 1, see also Fig. 3) a silty sandy till of more than 3 m thickness is deposited on top of a marine clay. A transition zone with deformation structures occurs in the lowest 15–20 cm of the till sequence. A till fabric analysis of the pebble fraction (2 cm to 5 cm) shows an east-west orientation 10 cm above the deformation zone.

In the area of Oppdøl (Fig. 2, loc. 2) a landslide scar in a more than 10 m high erosion brink along the river Oppdøl shows 3 m of glaciofluvial

material on top of 1.5 m clay underlain by 2 m of fine sand, which is again underlain by a silty till of more than 3 m. Below the till there is evidence of a clay-rich marine deposit. Three till fabric analyses were carried out in the till. The upper fabric shows no preferred orientation, the second from the top gives a southwest orientation and even indications of a northwest orientation (Follestad 1990). The third fabric close to the bottom of the till shows a north-northwest/north orientation.

In the Eide area two till fabrics ca. 2 km apart (Fig. 2, loc. 3) in a basal till show north-northwest and northerly orientations (Follestad 1989). In the Halså area (Fig. 2 and Fig. 3, loc. 4 and loc. 5) till fabric in two ditches ca. 1.5 m deep in a silty till with no visible structures shows a northwest orientation (Follestad in press). In the valley of Settemsdalen at a depth of 1 m (Fig. 2, loc. 6), a till fabric shows a north-northwest orientation (Follestad in press).

Till fabric analyses from other parts of the area (Fig. 2, loc. 7 and loc. 8) show a north-northwest and a northeast orientation. Till fabric analyses from the northeastern parts of the area (loc. 9, loc. 10 and loc. 11) show a northwest orientation.

A representative selection of more than 200 glacial striations is given in Fig. 2. These indicate a main ice movement towards the north-northwest, followed by a movement more to the northwest. Both directions indicate ice movement independent of the terrain and thus that the ice surface was well above the mountain plateaux. The latest movements followed the fjords and valleys.

The ice-flow direction and thus the till fabric might be affected by the local topography (Paterson 1969). Local glaciers might also disturb a regional pattern. The till fabric in loc. 1 (Fig. 3) is affected by the east-west running fjord. This is also the case for the second till fabric from the surface in loc. 2 (Fig. 3), which closely corresponds with the direction of the southwest-northwest oriented valley. However, no topographical impact on the ice-flow direction is suggested by the third till fabric in loc. 2 (Figs. 2, 3, sample III); the north-northwest/north orientation is nearly perpendicular to the valley. In the Eide (loc. 3) and Halså areas (loc. 4/5) the fabrics indicate an ice flow that crosses the westerly valleys at an angle of about 30° and the south/northeast orientated valleys at a right angle. In the valley of Settemsdalen the ice flow was almost perpendicular to the southwest-northeast running

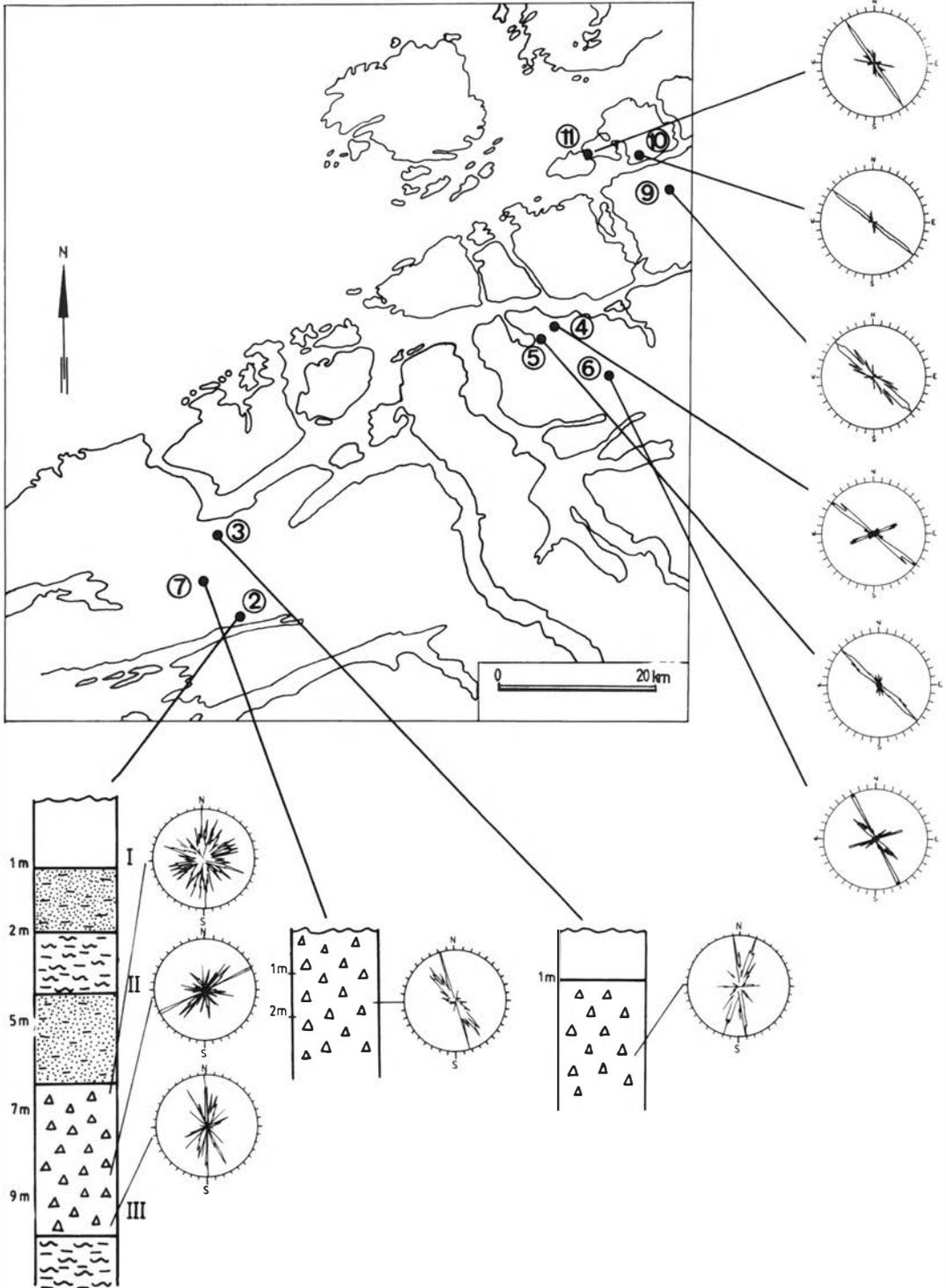


Fig. 3. Rose diagrams of some of the till fabric analyses carried out in the Nordmøre area.

valley, even though there is a high mountain plateau (over 1000 m) to the west. In none of these cases is there any evidence of a topographically controlled orientation of the pebbles.

A north-northwest/northwest direction is demonstrated in the reconstructions of the ice movement based both on the glacial striae and on the long-axis orientation assumed to be parallel to the ice movement direction (Ehlers & Stephan 1983). The location of some of the test sites demonstrates that the topographical conditions had little if any influence on the ice-flow direction suggested by the fabric.

## The block fields

These deposits are common throughout most of the area in Fig. 2 (Follestad 1985, 1986, 1987, 1989 and Follestad & Anda 1988). The block fields, at the surface, are mostly dominated by angular blocks and stones and thought to be formed through in situ mechanical and chemical weathering of the local bedrock (Holmsen 1951; Nesje et al. 1987). The thickness of these deposits could vary from 0.5 m to 3 m. However, erratic blocks and tills are mapped in the block fields in some areas, e.g. in the Eide area (Fig. 4) and in

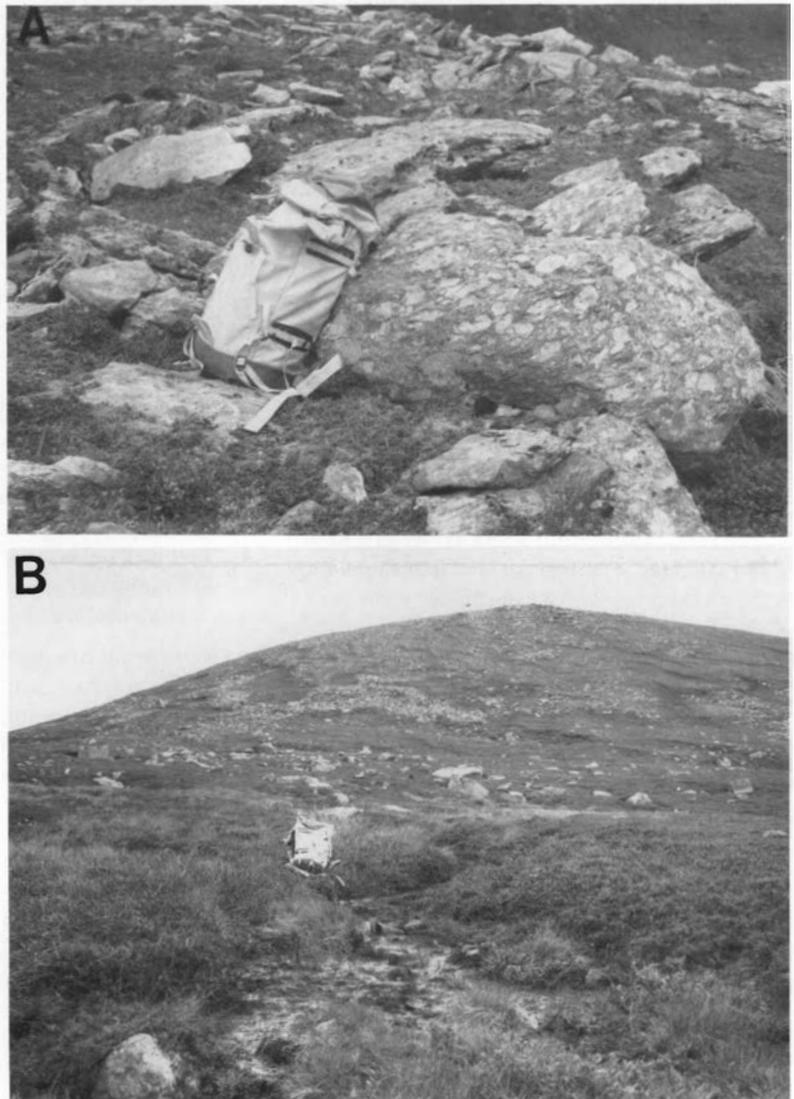


Fig. 4. Block fields in the Eide area. A. Erratic block in the block fields of the Eide area ca. 600 m above sea level. B. Block field affected by slope related processes.

the Tustna area at a level at least 600–700 m above sea level (Follestad 1986, 1990). These block fields have obviously at some time (before or after their formation) been overrun by glaciers. Weathering minerals such as kaolin and gibbsite have been described in connection with the block field material (Holtedahl 1956; Roaldset et al. 1982). Surface structures such as creep ridges and stone polygons are well developed forms throughout the area (Fig. 4B). These block fields often have a rather distinct lower border, though slope-related processes have locally transported the block field material below the actual limit.

## Stratigraphy

Stratigraphic investigations (Follestad 1985, 1986) have not clarified the age of the till and the block field material. In some cases the tills have a high content of clay, indicating that they were formed by erosion of marine sediments in the fjord areas. This indicates that the north-northwest/northwest orientated till in loc. 2 (Figs. 2 & 3, sample III) was deposited after an ice-free period, e.g. the Ålesund interstadial (Mangerud et al. 1979). Marine deposits are found in Nordmøre, as shown by  $^{14}\text{C}$  determination of ca. 40,000 years BP (T-8071 in Follestad, in press). The upper parts of this till sequence (Fig. 3, loc. 2, sample II), which are orientated by an ice movement determined by the topography, could easily be explained by later erosion and redeposition. As there is no evidence for an unconformity in the till between samples II and III (Fig. 3), it is suggested that this change in the till fabric took place during the same period of glaciation. In this connection it might also be suggested that the till in loc. 7 (Fig. 3) could be correlated with the lower part of the till in loc. 2 (given by sample III). One might also include the tills described in loc. 4, loc. 5 and locs. 9 to 11 in this correlation.

As mentioned above, ice transported boulders (Fig. 3) and tills in some of the block fields indicate that block fields were overrun by ice.

## Age relation between the tills and the block fields

Block fields have been described from the areas to the east and south by Holmsen (1951), Holtedahl (1956), Roaldset et al. (1982) and more recently

by Nesje et al. (1987) and Nesje et al. (1988). The lower limit of the block fields is an undulating surface descending from ca. 2000 m above sea level in the Jotunheimen mountains in Central Norway to 500 to 600 m above sea level in the Møre region. In the area described in Nordmøre, this limit descends from ca. 1000 m above sea level in the Sunndal area (Follestad 1983, 1985, 1987) to ca. 520 m above sea level in the Tustna and Eide area (Fig. 2). Even though an active block field formation is observed in the mountains of the Sunndalen area (Follestad 1984) and in other areas of southern Norway (Nesje et al. 1987), there is no connection between the post-glacial, high-altitude periglacial weathering and the marked lower limit of the block fields in Nordmøre (Figs. 2, 3). This leaves us with a slight modification of the alternatives for the formation of the block fields proposed by Nesje et al. (1988):

1. The block fields (with till in the Eide area) were developed on nunataks after the Late Weichselian glaciation maximum, which could have covered all the mountains.
2. The block fields were formed on nunataks during the Late Weichselian maximum. These nunataks must in this case have been glaciated at an earlier stage, e.g. during Early or Middle Weichselian.
3. The block fields are older than the Late Weichselian glaciation and were covered by a cold-based, non-erosive ice sheet during the Late Weichselian. The sharp boundary could have been formed by glacial erosion at a later stage.
4. The block fields are older than the Pleistocene glaciations and have never been overridden by a continental ice sheet.

As till deposits are included in the block fields of the Eide and the Tustna areas at high altitudes (Fig. 3) there is no doubt that the mountains in these areas have been overridden by an ice sheet. Thus I consider the last alternative to be disproved.

I have demonstrated above that the ice movement towards north-northwest/northwest was independent of the topography, and thus that the glacier surface must have been well above the block fields. I have also argued that the north-northwest/northwest movement dates from the last glaciation. The inescapable conclusion is that the block fields were overrun by the ice sheet during the Late Weichselian glacial maximum. Lagerbäck (1988) and Kleman & Borgstrøm

(1990) have demonstrated that a pre-glacial surface and block fields may survive beneath an inland ice. This conclusion is in strong disagreement with Nesje et al. (1988).

The borderline for the block fields as described by Nesje et al. (1988) is so well defined that it needs a regional explanation in a glaciological/climatological model. The most likely explanation conforming to my model is that the lower limit of the block fields was formed by a glacial readvance at some stage after the Last Weichselian maximum. Andersen (1987) indicates a phase of re-advance at ca. 15,000 years BP (see Fig. 1), which is marked by some distinct end moraines on the continental shelf.

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