Ice-front Variations of Different Parts of the Scandinavian Ice Sheet, 13,000-10,000 Years BP

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ABSTRACT

Ice-front variations of the Scandinavian Ice Sheet from 13,000 to 10,000 years BP are summarised with the main emphasis on the Allerød and Younger Dryas chronozones. In Finland, Sweden and eastern Norway there was a great net retreat, in SW Norway the ice-front oscillated back and forth, and in the NW part of southern Norway the ice-front retreated during the Allerød and halted during the Younger Dryas. The differences are interpreted in terms of different topography and therefore different glacial responses to climatic changes.

In the present paper ice-front variations of the Scandinavian ice sheet from 13,000 to 10,000 BP are discussed by means of time-distance diagrams. First the basis and the accuracy of each curve are discussed. Thereafter the curves from different parts of the ice-front are compared. The positions of the profiles are indicated in Fig. 1, and all curves are shown in Fig. 2.

Estonia - Western Finland

The curve for this area is constructed from data given in Donner (1978). For the Luga-Haanja moraine an age of 13,200 - 13,000 BP was accepted, and for the Neva-Pandivere moraine 12,200 - 12,000 BP. The average distance between the two moraine systems is about 140 km.

The ice margin probably withdrew to the south coast of Finland at 11,800 or 11,600 BP. The latter date has been adopted for the relevant curve. However, Donner points out that this age implies that northern Estonia was deglaciated earlier than the commonly accepted age of 11,200. Thus the age suggested for the Neva-Pandivere moraine may also be too young.

On the basis of correlations of C14-dated pollen-zone boundaries, Donner concluded that the Salpausselkä III moraine was deposited immediately before 10,100 BP. The duration and relative age of each of the three Salpausselkä moraines is based on the varve chronology of Niemelä (1971). Possible errors for the Younger Dryas part of the curve are thought to be minor.

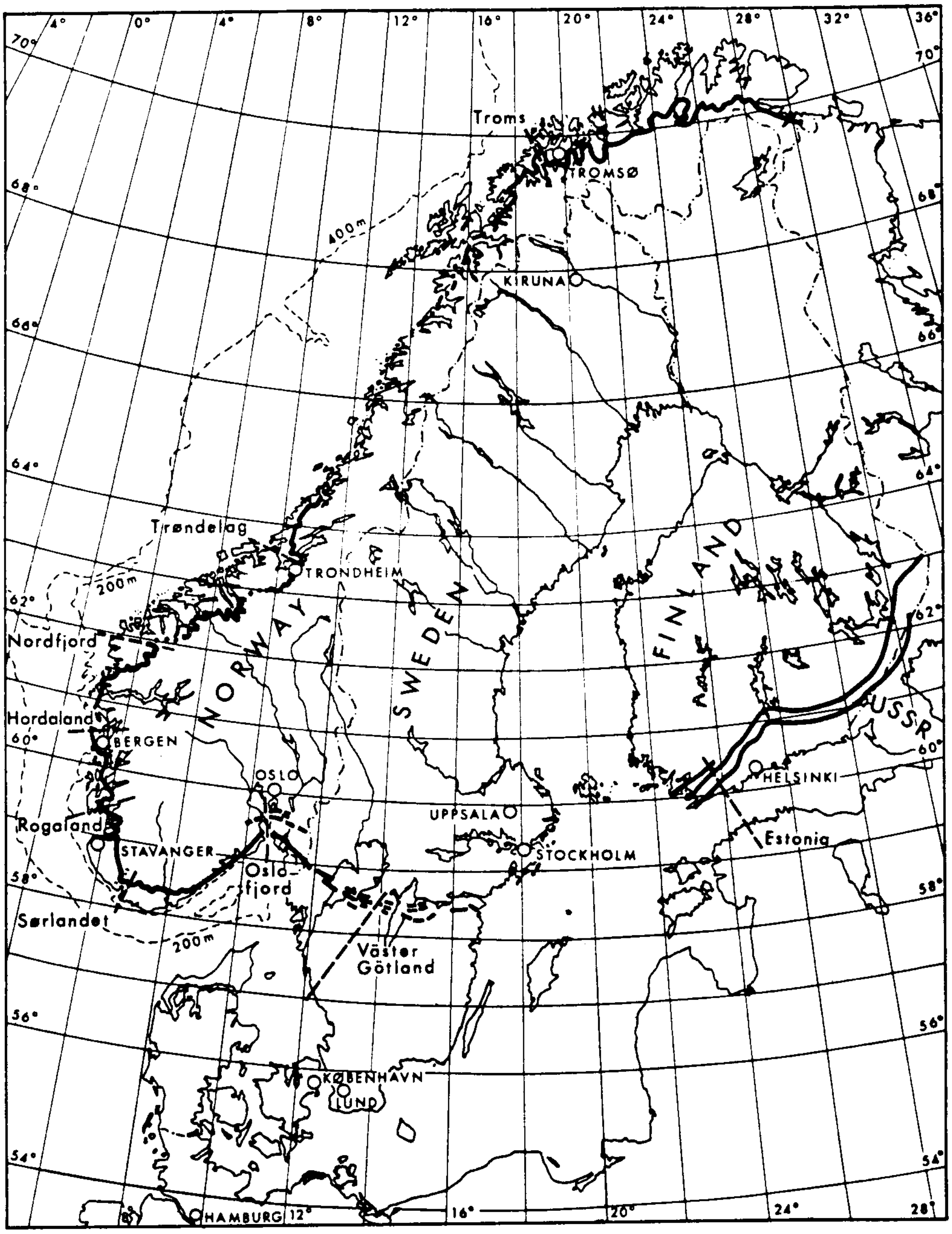

Fig. 1 End-moraines of Younger Dryas age around the Scandinavian Ice Sheet. The positions of the profiles given in Fig. 2 are indicated.

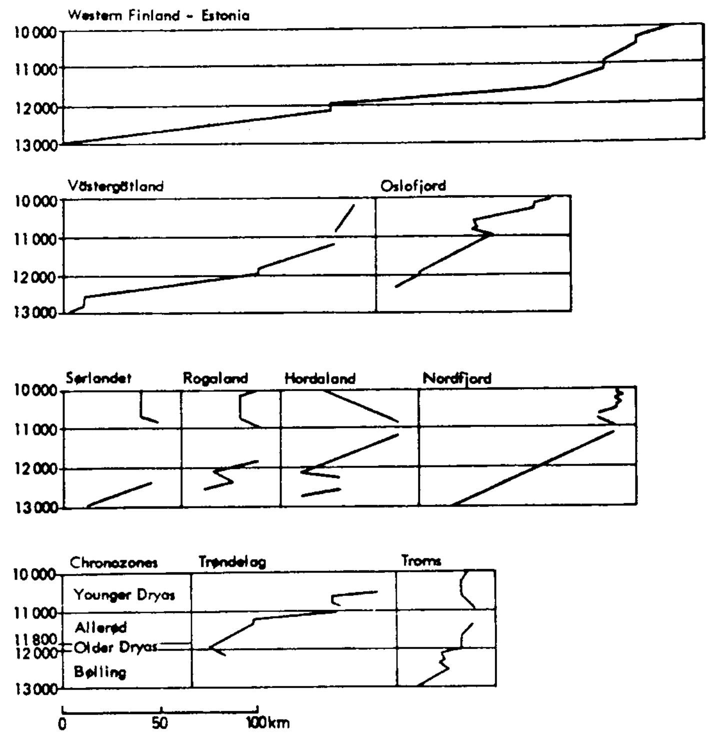

Fig. 2   Time-distance diagrams for the position of the inland ice front.

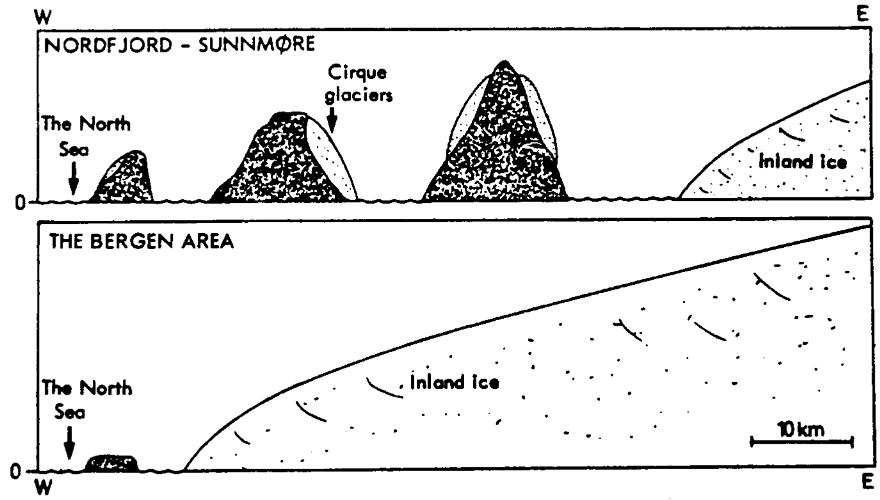

Fig. 3   A simple model showing the difference in glaciation types between Nordfjord-Sunnmøre and the Bergen area (Hordaland) during the Younger Dryas.

Västergötland

This curve is reproduced from Berglund (1979). The older part is based on numerous C14 dates, and although most of them only give a minimum age of deglaciation at each site, this part of the curve is considered to be reliable. For the younger part of the Alleröd and especially for the Younger Dryas the curve is mainly based on floating varve chronologies. Whether or not major readvances took place in this area during the Younger Dryas remains essentially unsolved. Fredén (1978) and Sørensen (1979) have suggested slightly different ages for the Younger Dryas end moraines.

Oslofjord

The Oslofjord curve is from Sørensen (1979). The part older than 11,000 BP is based mainly on correlations of end moraines in the Oslofjord area with moraines in Västergötland (Berglund, 1979). These morphostratigraphical correlations seem convincing. However, each end moraine may be metachronous laterally, and may thus be of different ages in Oslofjord and Västergötland.

The younger part of the curve is based on numerous C14 dates. Sørensen's major new contribution is the dating of the deposition of the Ra moraine to between 10,800 and 10,600 BP, instead of to the entire Younger Dryas as was previously assumed. The maximum age is based on several C14 dates of shells from till, or sub-till sediments, and appears to be well established. The minimum age, which in this case is a crucial point, is based on two C14 dates of shells from the next younger moraine (Mona) and the interpretation of a well dated shore displacement curve. This age needs to be checked further, even though Sørensen's interpretations seem likely.

Sørlandet

This curve is constructed from Andersen's data (1960, 1979). He assumes an age of 13,500 BP for the Lista moraine, on the basis of a C14 date of 13,150 ± 300 BP (T-149 B) from gyttja deposits on the proximal side of the moraine. Andersen (1960) obtained a date of 12,550 ± 200 BP (T-168) from shells located only 9 km outside the Ra moraine and later (pers. comm) 12,250 ± 150 BP (T-2467) from *Mytilus edulis* shells in clay located at Lysefjorden just outside the Ra moraine. The Younger Dryas part of the curve remains undated in this area.

This curve is obviously preliminary, as it is based on few C14 dates. However, one very interesting feature seems well documented: the ice-front had retreated to the position of the Ra moraine, or probably even further inland, as early as 12,000 BP. If the recession continued during the Alleröd, a major readvance to the Ra moraine must have occurred during the Younger Dryas.

Rogaland

Anundsen (pers. comm.) has constructed the diagram for Rogaland, based on previously published results (Anundsen, 1977, 1978). A readvance after 12,380±150 BP (T-1621)) is documented by a dating of whale bones that are overlain by till. A minimum age of 11,970 ± 100 BP (T-1883) for the readvance is obtained from another whale bone date that is confirmed by pollen stratigraphy. Shells beneath till, giving an age of 11,630 ± 100 BP (T-1620) have been recorded from a locality 3 - 4 km outside the major Younger Dryas end moraines (Anundsen, 1977). The most likely interpretation is that the Younger Dryas Readvance extended to several kilometres beyond the position where the major end moraines were deposited.

For the Younger Dryas, Anundsen concludes that the ice-front reached its outermost position prior to 10,720 ± 180 BP (T-995). This is based on a date of organic matter in clay which he assumes was deposited close to the ice-front.

Hordaland

This curve is from Mangerud (1977), and is based on approximately forty C14 dates. A readvance at about 12,000 - 12,400 BP (probably 12,200 - 12,300 BP) is documented by several C14 dates of shells, whale bones, and wood below till. The retreat inland which followed during the Alleröd is demonstrated by many dates of shells in till or below till. During the major Younger Dryas readvance the glacier overrode the Alleröd deposits, and therefore minor halts or readvances during the Alleröd and early Younger Dryas would have been obscured. It appears that the ice did not reach the outermost Younger Dryas position simultaneously along the entire end moraine (Aarseth and Mangerud, 1974). However, even along the younger part of the moraine, the readvance may have culminated closer to 10,500 BP than to 10,000 BP as previously concluded by Mangerud (1977), since the latter age is based on only two C14 dates.

Nordfjord

This curve is from Mangerud *et al.* (1979), and is extended 40 km offshore on the basis of a C14 date of 13,350 ± 340 BP (T-2708) of shells from glaciomarine clay that lies outside a submarine end moraine (Nordvik and Holtedahl, pers. comm.). However, the curve prior to 11,000 BP must be regarded as tentative, since it is based on only two C14 dates. The Younger Dryas part is also based on few dates, but data from key stratigraphical sites suggest this part to be more reliable. A readvance, which apparently did not deposit end moraines, is bracketed between 10,750 ± 140 BP (T-2304: a date based on shells in till) and 10,440 ± 170 BP (T-645). The huge Younger Dryas end moraines, named the Nor Moraines, were deposited after the latter date.

Trøndelag

This curve is based on dates from a large area and therefore there are problems with lateral correlations. The distances used in the diagram (Fig. 2) are partly measured south of the profile indicated on the map (Fig. 1).

From Kristiansund, Kraemer (in Gulliksen *et al.*, 1978) described shells in till yielding a date of 12,090 ± 100 BP (T-1805), thus indicating a younger readvance over this site.

Lasca (1969) dated an ice-front deposit to 11,300 BP by means of several C14 dates. He assumed the moraine to be a part of the Younger Dryas end moraine system, while Andersen (1979) has demonstrated it to be an older moraine.

Three C14 dates relate to a large ice-front delta at Heimdal, near Trondheim (Reite in Nydal *et al.*, 1972, p.528; Sollid and Sørbel, 1975). A whalebone was found in the lower part, or possibly below the delta deposits, and the C14 age is reported as 11,290 ± 190 BP (T-787). However, the δC13 was not measured and corrections for neither isotopic fractionation nor reservoir age were applied (Gulliksen, pers. comm.). Assuming a δC13 value of -16.5^{o}/oo PDB, and a reservoir age of 440 years (Mangerud and Gulliksen, 1975), these corrections would imply a younger age by about 300 years, that is 10,990 ± 190 BP. Two dates from shells in a clay above the delta deposits are 10,230 ± 130 BP (T-786) and 10,150 ± 100 BP (T-754). Sollid and Sørbel (1975, 1979) have shown that the Heimdal delta belongs to the prominent Younger Dryas end moraine system, which is now mapped as nearly continuous along the coast to the Ra moraine in Oslofjord (Fig. 1).

Kjemperud (1978) obtained six C14 dates from three localities about 25 km proximal to the Tautra moraine, which is correlated with the Heimdal delta. This indicates that the sites were deglaciated at about 10,300 - 10,500 BP.

Troms

This curve was constructed by T.O. Vorren (pers. comm.), based on data from Andersen (1968), K.D. Vorren (1978), T.O. Vorren *et al.*, (1978) and T.O. Vorren and Elvsborg (1979). Two parts of the curve are well established: the Skarpness end moraines were formed at about 12,000 - 12,400 BP, and the younger part of the Tromsø-Lyngen end moraine complex were formed during the Younger Dryas, probably at about 10,200 - 10,600 BP. Few dates are available for the rest of the curve.

The curve is not extended to offshore areas. Nevertheless, an early deglaciation of the continental shelf, as concluded by T.O. Vorren *et al.*, (1978) is assumed. Rokoengen *et al.*, (1977) assumed a considerably later deglaciation of the continental shelf, mainly on the basis of the interpretation of fossil-bearing overconsolidated clays being basal tills. The dates from deposits on land strongly indicate that the model of Vorren *et al.*, is correct, but the interesting problem of the overconsolidation remains unsolved.

DISCUSSION AND CONCLUSIONS

Though the total period considered above is comparatively short (*c*.3,000 years), a significant proportion of the deglaciation of the last Scandinavian Ice Sheet occurred within this time. For exact chronostratigraphical correlations within such a short period, detailed stratigraphy and precise datings are necessary. Our present state of knowledge does not allow any detailed comparisons of the curves. However, some major trends and regional differences seem well documented.

1. From 13,000 to 10,000 years ago there was a major retreat of the eastern flank of the Scandinavian Ice Sheet, and also in some areas in the west, while the ice-front oscillated back and forth on the coast of SW Norway where there are high and extensive mountain plateaux along the coast.

2. A halt or a readvance at 12,000 BP, or slightly earlier, is recorded in most areas. This was probably caused by a climatic event, the differences in time and extent being the result of different response mechanisms and response times in individual parts of the ice sheet.

According to the previously used climatostratigraphical subdivision, these halts and readvances could all be regarded as Older Dryas events, given different amplitudes and time-lags for the response of different biological and physical processes to climatic changes (Mangerud, 1970). However, several of these events did not occur within the Older Dryas Chronozone, as defined by Mangerud *et al.*, (1974).

3. For the Alleröd and Younger Dryas chronozones more details are available, and three different types of glacial response can be distinguished:

A. In the eastern area (the curves for Finland, Västergötland and Oslofjord) there was a major net retreat from 12,000 to 10,000 BP. There was also a net retreat during the Younger Dryas, though the glacier front oscillated somewhat. Trøndelag is also included in this group, as the relevant curve is very similar to that from Oslofjord. Similarity in response is probably related to the influence of topography, as there are extensive lowlands in Trøndelag and in the eastern areas.

B. The curves for SW Norway (including Sørlandet, Rogaland and Hordaland) together with Troms in northern Norway show that the ice-fronts retained nearly the same positions at 12,000 BP and 10,000 BP. For parts of Sørlandet the ice-front may have been even further inland at 12,000 BP than at 10,000 BP.

The retreat during the Alleröd in Hordaland was of the same order of magnitude as retreat in Oslofjord and Trøndelag. However, a major readvance occurred during the Younger Dryas in Hordaland but not in Oslofjord nor in Trøndelag. It is also assumed that a similar major readvance occurred in Sørlandet and Rogaland, even though this is not proven. In Troms the glacier reactions may have been slightly different.

C. The response of the ice sheet in the NW part of southern Norway, represented by the curve from Nordfjord, was similar to that of Group A, except that no retreat took place during the Younger Dryas. Outside the ice-sheet, however, a great number of cirque glaciers were formed (Fig. 3). This was a common occurrence in the Troms area (Andersen, 1968).

The variation in glacier response discussed above could be a result of climatic differences, especially differences in precipitation. That is, however, not necessarily the cause, or at least not the only cause. An earlier explanation (Mangerud, 1970), that the differences in ice-front variations between Hordaland and Västergötland result from glaciological differences, is strengthened by the additional information presented in this paper.

Southeastern Scandinavia, with response type A, is a lowland area. There were relatively long distances between the accumulation areas and the ice-front, and there was divergent ice-flow throughout this region, such that any net accumulation became spread out over an extensive ice-front. The result was that a considerable increase of accumulation was necessary to produce a major readvance, and the response time was long.

In SW Norway (type B) there are extensive mountain plateaux close to the coast, only dissected by narrow valleys and fjords. During the Younger Dryas these plateaux were accumulation areas, and there were convergent ice-flows through the valleys and fjords, resulting in a rapid and large readvance. Even during the Younger Dryas maximum there were but short distances between the accumulation areas and the ice-front. Similarly ice retreat during mild phases (in this case the Alleröd) was rapid in this area due to calving in the deep fjords. Therefore, in this area, topography caused the ice-sheet to respond rapidly and with large ice-front oscillations to short-lived climatic fluctuations. This interpretation is strongly supported by the similarities between the curves from Trøndelag and Oslofjord, as Trøndelag has climatic similarities with SW Norway and topographic similarities with the Oslofjord area. The difference between SW Norway (type B) and the area immediately further north (type C) can hardly be explained by climatic differences. There is, however, an important topographical difference (Mangerud *et al.*, 1979). As described above there are large mountain plateaux in the southern area, while the topography in the northern area is much more dissected. In the latter area many local glaciers were formed, but they did not coalesce into one ice sheet (Fig. 3).

4. Even though there is more than one end moraine of Younger Dryas age in some areas, in southern Norway there is only one major end moraine of that age, which is mapped nearly continuously from Oslofjord to Trøndelag. However, this one end moraine, often called the Ra moraine far outside the Oslofjord area where the name originated, is demonstrably metachronous. The Ra moraine in the Oslofjord was formed before 10,600 BP and the Herdla moraine in Hordaland after 10,500 BP (possibly as young as 10,000 BP). Thus there is no overlap at all in the time of formation. Even the Ra on Sørlandet is probably younger than the Ra in Oslofjord. In Nordfjord the Nor moraine is of the same age as the Herdla moraine, while the

moraine in Trøndelag is of the same age as the Ra in Oslofjord.

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For references, see pp 177-199 in the book.