Deglaciation chronology in the mountain area between Suldal and Setesdal, southwestern Norway

PER BLYSTAD & LOTTE SELSING

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Lithostratigraphic studies, ^{14}C dating and pollen analysis were performed on sediments from six basins in the mountain area between Suldal and Setesdal in order to establish the deglaciation chronology for the area. The deglaciation of the Younger Dryas ice sheet occurred by 10 100 ± 280 years B.P. at 720 m a.s.l. The Skute thermomer occurred at 10 100-9800 years B.P., the Fidja cryomer at 9800-9700 years B.P., the Sandsaos thermomer at 9700-9300 years B.P. and the Sandsa cryomer at 9300-9100 years B.P. The high mountain area east and north of the terminal moraines of presumed Preboreal age was deglaciated by 8800 years B.P. and probably the high mountain areas of southern Norway were deglaciated at this time or 100-200 years later. The inland valley of Setesdalen seems to have been deglaciated at about the same time as the high mountain area. This indicates that the whole of southern Norway was deglaciated at some 8800-8600 years B.P., most probably 8800 years B.P.

Per Blystad, Norwegian Petroleum Directorate, P.O.Box 600, N-4001 Stavanger, Norway
Lotte Selsing, Arkeologisk museum i Stavanger, P.O.Box 478, N-4001 Stavanger, Norway.

Introduction

In this paper we try to establish the deglaciation chronology for a mountain area in southwestern Norway (Fig. 1).

The bedrock in the area (Fig. 2) is characterized by Precambrian metamorphic rocks, mainly gneiss, granite, metabasalt and meta-arkose, the Ryfylke Schists, phyllite and mica schist, and the Caledonian allochtonous gneisses of Precambrian age (Sigmond 1975, 1978). The rocks of Precambrian age contain old carbon in local secondary deposited fissure fillings, and the Ryfylke Schists contain old carbon in graphite.

Quaternary sediments were investigated in the eastern part of the area (Blystad 1978). In Setesdal ice-contact sediments dominate and are usually covered by a rather coarse melt-out till in the lower part of the valley. Further up the valley sides, basal till dominates. In the central part of the mountain plateau, on the watershed area, the bedrock is almost bare. Generally, there are more sediments in the Ryfylke Schists area than in the Precambrian basement area.

The vegetation is monotonous and poor in species. The distribution of Ryfylke Schists in bedrock and sediments gives richer and more varying plant communities in restricted areas of the northern and western regions. The area lies in the low alpine vegetation zone characterized by heather- and grassmoor including part of the subalpine birch zone characterized by mountain birch forest *Betula pubescens* of nordic type. In the east it also lies partly in the mountain coniferous forest zone dominated by dense pine forest *(Pinus sylvestris)* mixed with some spruce *(Picea abies).* The forest limit comprises birch and rises eastwards from the westernmost areas at 750 m a.s.l., reaching 1050 m a.s.l. east of the watershed in the Setesdal area. It has been lowered due to human influence. The pine forest limit, too, rises eastwards from 630 m a.s.l. in the westernmost areas and reaches 930 m a.s.l. east of the watershed in the Setesdal area (Selsing & Wishman 1984). The pine forest limit has presumably not been lowered to any notable extent (Selsing 1983).

The investigated area is situated inside the terminal moraines of presumed Younger Dryas age (Anundsen 1972). Prominent end moraines of the so-called Lysefjord stage, demonstrated to be of Younger Dryas age, have been described from the southern part of the area by Andersen (1954), who also described end moraines of the Trollgaren stage situated east of the Lysefjord stage end moraines. Sørensen (1983) suggested a correlation between

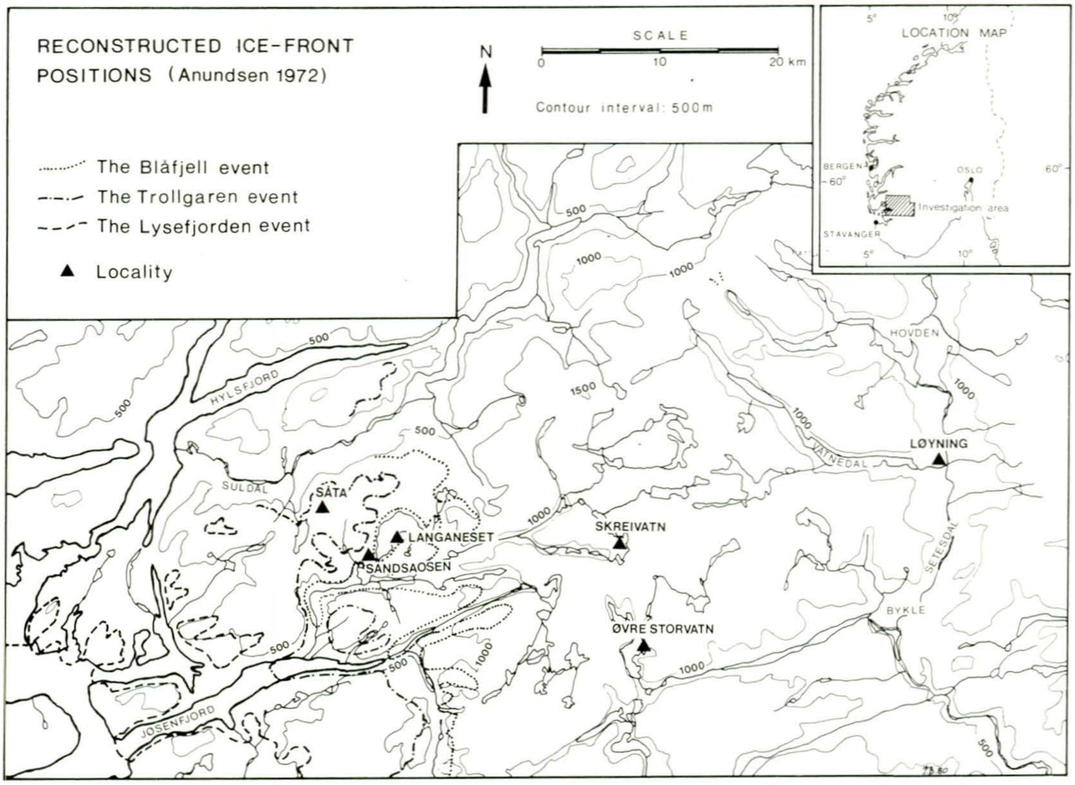


Fig. 1. Map showing the location of reconstructed ice-front positions (Anundsen 1972). The terminal moraines of presumed Preboreal age are located south of the map in the Setesdalen area. The three localities in the western part were chosen as close as possible to the ice front deposits. Two localities are from the high mountain area and one locality from the inland valley Setesdalen.

the Trollgaren stage and the Aker moraine, i.e. an early Preboreal age (Nydal 1960, p. 86). Anundsen (1972) reconstructed the glacier front variations in the western part of the investigated area, describing the Younger Dryas end moraines, the Trollgaren end moraines assumed to be of Preboreal age, and the Blåfjell end moraines assumed to be of either Preboreal or early Boreal age. No terminal moraines younger than the Blåfjell moraines are reported from the area of investigation. Geological mapping of the glacial deposits in this area (Blystad 1978) shows that the last phase of deglaciation was characterized by downwasting glaciers in the Upper Setesdalen valley and in the high mountain area.

Only a few radiocarbon dates related to ice front positions are available from this area. Anundsen (1977) interpreted organic matter in clay, deposited close to the ice front between Sandeid and Ølen with ^{14}C-ages of 10 720 ± 180 and 10 540 ± 170 years B.P. as dating the maximum extent of the Younger Dryas ice sheet. At Hjelmeland just to the south of the mouth of Jøsenfjorden, the glacier front remained for several hundreds of years at the fjord mouth after 10 800 years B.P. (Blystad & Anundsen 1983). Neither the Trollgaren moraines nor the Blåfjell moraines were radiocarbon-dated in this area. The Trollgaren moraines are correlated with the Odda - Eidfjord - Osa substage at the southern part of Hardangervidda (Anundsen & Simonsen 1967). The early Odda - Eidfjord - Osa substage has been radiocarbon-dated to younger than 9 680 ± 90 years B.P. (Rye 1970) and to 9 720 ± 330 years B.P. on a basal gyttja from Busnes, in the innermost Hardangerfjord (Anundsen & Simonsen op.cit.).

Various authors have described end moraines of Preboreal age from the coastal and fjord areas of Western Norway (e.g. Vorren

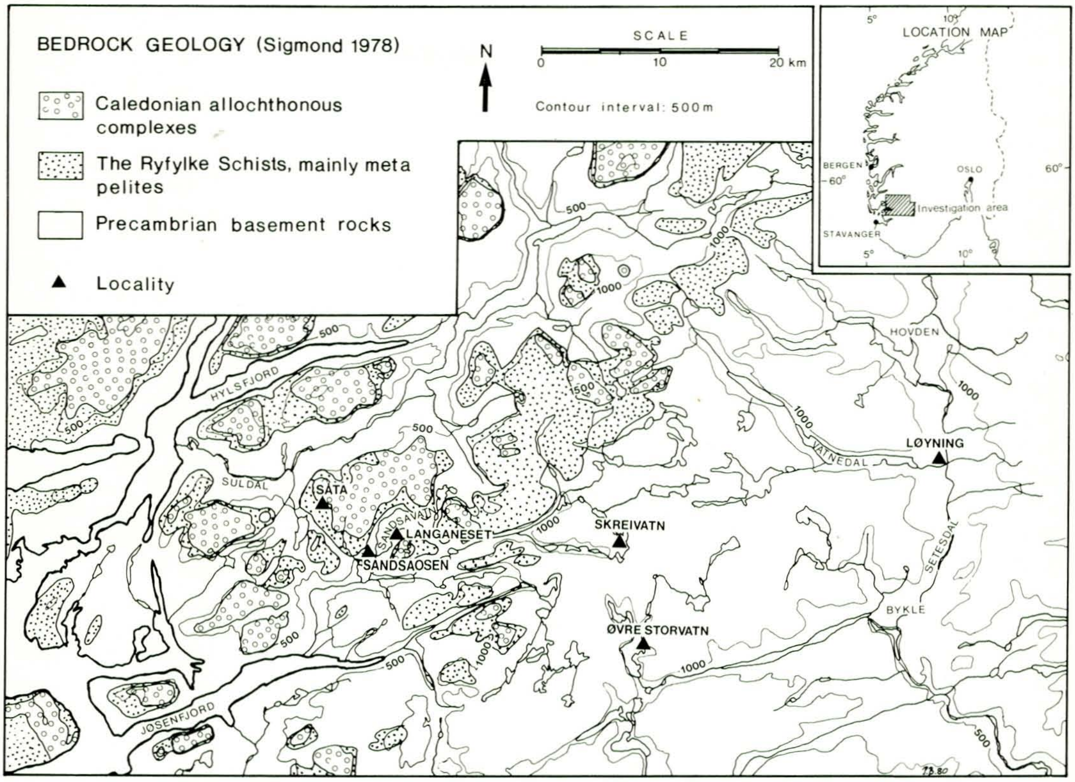


Fig. 2. The bedrock in the investigation area (Sigmond 1978).

1973, Andersen 1975, Bergstrøm 1975). Two or three distinct zones of end moraines have been found, and the radiocarbon dates from many of these cluster around ca 9 900±100 years B.P., 9 600±100 years B.P., and 9 300±100 years B.P. (Andersen 1980).

Methods

Site selection

Different criteria were used for selection of localities for chronology studies:

a) The locality should be close to the ice front deposits to ensure the most reliable radiocarbon datings of the deglaciation.

b) Localities should preferentially be outside the Ryfylke Schists areas, where one might encounter radiocarbon dating problems.

c) In the high mountain area, characterized by exposed bedrock and a thin sediment cover, localities were favoured in areas with sediment cover. The sedimentation of organic matter could also thereby include debris from the vegetation surrounding the basin and not only algae and aquatic plants from the basin itself. The sedimentation rate of organic matter would therefore theoretically be greater than in areas with exposed bedrock which would give a better resolution for pollen analysis and radiocarbon dating.

These circumstances reduced the range of possible sites for locations likely to reflect possible climatically induced vegetational alterations.

Approximately seventy basins were examined by means of a Hiller sampler, a 'Russian' peat corer (Tolonen 1967) or by an exploring stick. Basins with sediments presumed to have been deposited just after deglaciation were selected for preliminary palynological analyses. Based on pollen analytical dating of the basal organic sediments, studies were concentrated on ten localities. Six of these localities were chosen because the preliminary analysis of the pollen in the basal organic sediments indicated pioneer vegetation. Only the results from these sites will be presented here.

Sampling

A modified 11 cm piston corer (K. Krzywinski, pers. comm. 1978) was used in combination with digging of ditches for collecting the samples.

Lithostratigraphy

In the pollen diagrams the sediment and peat signatures proposed by Fægri & Gams (1937) are used. Loss-on-ignition was carried out on the sediments to measure the variations in organic content. Loss-on-ignition was done at 550°C (Sønstegaard & Mangerud 1977:315), and the results are shown on the pollen diagrams as weight percent loss-on-ignition.

Biostratigraphy

Preparation of the palynological samples mainly followed the acetolysis method. A few basal minerogenic samples at each locality were treated with hydrofluoric acid (Fægri & Iversen 1975). Pollen analysis was carried out by means of a Zeiss microscope with phase contrast objectives with analysis magnification 504x. Grains which were difficult to identify were examined at 1008x. Pollen identifications are based mainly on Fægri & Iversen (op.cit.). Ericales pollen were determined to genus (Beug 1961). The Ericales curve in the pollen diagrams includes unidentified tetrads. The determinations of the trilete spores were based on Moe (1974).

The pollen diagrams are percentage diagrams. Aquatic pollen grains, spores and algae are not included in the basic sum (ΣP). The Polypodiaceae curve includes fern spores from all genera. The sediments have been subdivided into local and regional pollen zones. The procedures suggested by Hedberg (1976), Mangerud et al. (1974) and Kaland (1984) are followed. The local pollen zones are pollen assemblages and the zone boundaries are drawn between two spectra which indicate marked changes in the pollen composition. The regional pollen zones are used for biostratigraphic dating and correlation. The boundaries of the chronozones are identified on the basis of radiocarbon dated pollen levels.

Chronostratigraphy

Twenty-two radiocarbon dates were performed by the Radiological Dating Laboratory in Trondheim, Norway (Table 1). Results are reported in conventional ^{14}C years before present (1950). The radiocarbon dates are discussed in a separate paper (Blystad & Selsing in manus) with emphasize on the dating errors.

Ages of the Corylus and the Alnus rises

The ages of the *Corylus* and the *Alnus* rises are important in chronostratigraphic subdivision of the early Holocene because they are the principal palaeobotanical events.

The age of the *Corylus* rise, 8800 years B.P., is based on the dates (Table 1) giving 8940 ± 200 years B.P. (T-3486 on macroscopic twigs) from the locality Langaneset just below the *Corylus* rise and 9280 ± 80 years B.P. (T-3489A, soluble fraction) from locality Sandsaosen 5 cm below the *Corylus* rise. These dates give a maximum age on the rise of *Corylus*. From locality Skreivatn the date of 8600 ± 250 years B.P. (T-3487A, soluble fraction) provides a minimum age for the *Corylus* rise. These dates indicate a contemporary rise of *Corylus* in the eastern and western parts of the investigated area and are in accordance with the dating of the *Corylus* rise in central Telemark (Høeg 1982) and the inner fjords of the Bergen district (Skår 1975).

The age of the initial *Alnus* rise, 8400 and 8000 years B.P., in the western and the eastern parts of the investigated area, respectively, are based on 3 dates from the investigated localities Såta, Skreivatn and Løyning (Table 1). The age in the western part is about the same as the age at Eigerøy at the southwesternmost coast of southwestern Norway (Simonsen pers. comm.). The *Alnus* rise in the eastern part of the investigated area is in accordance with Høeg (1982) for central Telemark.

Site descriptions and stratigraphy

The six investigated localities are all topogenous overgrown or partly overgrown bogs si-

Table 1. Radiocarbon dates from the 6 investigated basins.

Locality (m a.s.l.) Greenwich coor. morphostratigraphy	*Sample: sediment* (loss-on-ignition), and event dated	*Depth below* sediment surface, cm	*Weight of* sample dated, g	*Radiocarbon* date reference	*Age T½ 5570* years B.P.	$\sigma^{13}C$ ‰ PDB	suggested chronozone
SÅTA (710) 59°25'50"N 6°27'10"E between YD and	Sand with organic matter (3.6%), deglaciation	207.5-210.0	2.1 68.4	T—3488A T—3488B	10.100 ± 280 11.210 ± 150	-26.4 -26.4	late YD/early PB
Trollgaren ter.mor.	Detritus gyttja with sand (20%), Trollgaren stage	205.5-207.5	1.3 35.1	T—3846A T—3846B	9.610 ± 210 10.090 ± 100	-27.7 -24.5	PB
	Detritus gyttja with sand (10-20%), and 0.5 cm of sand with organic matter (6%), maximum age of Blåfell stage	203.5-205.0	3.8 18.4	T—3847A T—3847B	9.510 ± 150 9.700 ± 140	-26.6 -25.2	PB
	Detritus gyttja (58%), *Alnus* rise	189.5-191.5	14.02	T—5687A	8.370 ± 100	-26.4	late B
SANDSAOSEN (630) 59°23'30"N 6°31'50"E between	Detritus gyttja with sand (22-24%), deglaciation	220.5-222.0	6.4	T—3141A	9.650 ± 90		PB
Trollgaren and Blåfjell ter.mor.	Detritus gyttja with sand (24%), Blåfjell stage	219.0-221.0	8.7 12.9	T—3489A T—3489B	9.280 ± 80 9.340 ± 140	-29.5 -28.0	late PB
LANGANESET (610) 59°25'0"N 6°34'20"E	Algae gyttja (12%), deglaciation	371.0-372.0	12.7	T—3140A	10.210 ± 180		late PB/early B
just inside Blåfjell ter.mor.	Twigs from silt, deglaciation	372.0-384.0	0.9	T—3486	8.940 ± 200	-26.1	late PB
	Algae gyttja (45%), *Alnus* immigration on locality	321.0-323.0	5.42	T—5689B	7.170 ± 140	-28.1	late B/early A
ØVRE STORVT. (980) 59°20'10"N 6°57'20"E	Detritus gyttja (6%), deglaciation	139.5-141.0	3.5	T—3224A	8.640 ± 120		early B
inside Blåfjell ter.mor.	Detritus gyttja (38-42%), *Alnus* rise	128.0-130.0	30.17	T—5686	6.720 ± 90	-25.8	late B/early A
SKREIVT. (1030) 59°24'20"N 6°55'0"E inside Blåfjell ter.mor.	Silty detritus gyttja (4%), deglaciation	112.0-113.5	1.5 70.8	T—3487A T—3487B	8.600 ± 250 9.020 ± 210	-26.4 -24.3	early B
	Detritus gyttja (28%), *Alnus* rise	94.0- 96.0	27.45	T—5690A	8.280 ± 100	-27.1	late B
LØYNING (720) 59°2'30"N 7°23'50"E inside	Silty gyttja and algae gyttja (6-24%), deglaciation	476.0-478.5	3.7	T—3139A	9.270 ± 180		early B
Preboreal ter.mor.	Plant remains of *Pinus* from algae gyttja, and algae gyttja (24-32%)	470.0-476.0	0.5 30.7	T—4313 T—4314A	8.470 ± 210 9.000 ± 100	-29.8 -29.4	B
	Algae gyttja (38%), *Alnus* rise	461.5-463.5	8.15	T—5688B	7.900 ± 90	-29.4	late B/early A

A *NaOH soluble fraction*, B *insoluble fraction*, YD *Younger Dryas chronozone*, PB *Preboreal chronozone*, B *Boreal chronozone*, A *Atlantic chronozone*, *ter.mor. terminal moraines.*

Fig. 3. Såta 710 m a.s.l. is a partly overgrown tarn situated between the Younger Dryas and the Trollgaren end moraines in the subalpine open birch forest. The site is deforestated due to a thin and scattered sediment layer and to pasturing. The sample site is marked with an arrow.

tuated at altitudes between 610 and 1030 m a.s.l. (Fig. 1). The positions of the three westernmost localities are closely related to the former position of the ice fronts. The two localities in the high mountain area and the one in Setesdalen lay far east and north of the ice fronts of presumed Preboreal age. The localities are described from west to east.

Såta

The locality (Fig. 3) is a partly overgrown tarn situated in the Ryfylke Schist zone between the Younger Dryas and the Trollgaren end moraines at an altitude of 710 m a.s.l. (Figs. 1 & 3). The youngest ice movement here was towards SW. The bedrock is covered with a thin and scattered till layer. The present vegetation is subalpine open birch forest with an undervegetation dominated by bilberry. The recorded plant species at the mire, e.g. *Eriophorum angustifolium, Viola palustris* and *Menyanthes trifoliata,* indicate poor fen vegetation.

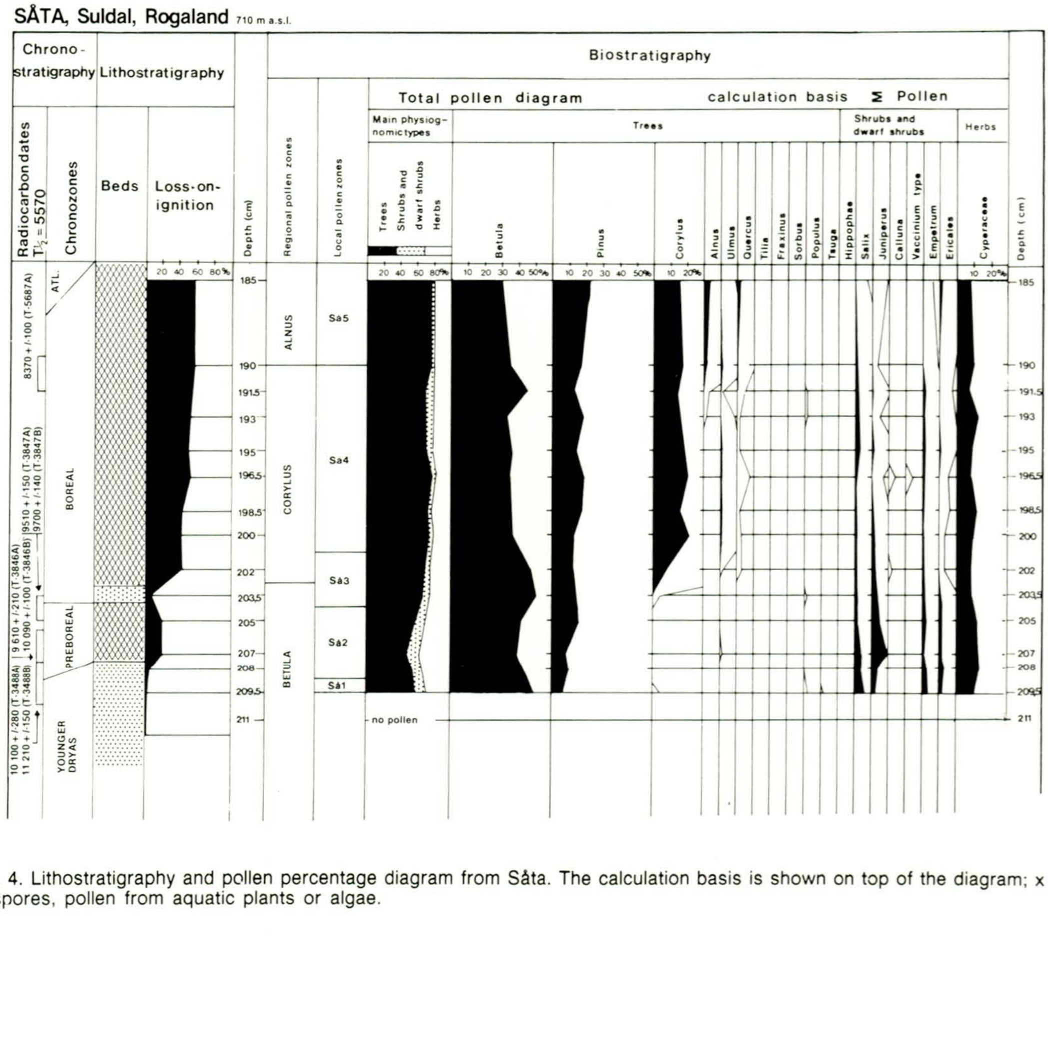


Fig. 4. Lithostratigraphy and pollen percentage diagram from Såta. The calculation basis is shown on top of the diagram; x is spores, pollen from aquatic plants or algae.

Lithostratigraphy: At the base there is a grey, silty sand (Fig. 4) with a transition to poorly sorted sand with organic matter covered by dark brown coarse detritus gyttja with a marked sandy gyttja layer in the lower part, and followed by *Sphagnum* peat at the top.

Pollen analysis: The lowest pollen zone *Så1 local zone* (Fig. 4) is defined by high *Betula* values (50%), *Salix* values more than 5% and *Rumex* values just below 5%. The relatively high herb, shrub and dwarf shrub values (40%), e.g. *Salix, Juniperus, Empetrum, Rumex, Artemisia* and *Urtica,* reflect an open pioneer vegetation (cf. Moe 1977, Simonsen 1980). The lower boundary of the *Så2 local zone* is defined by a depression of *Betula* dropping to 40% and by maxima in *Juniperus* and *Rumex* rising to 9% and 6%, respectively. Loss-on-ignition values stabilize at 16%. The lower part of this assemblage zone is characterized by a maximum in shrubs, dwarf shrubs and herbs. The lower boundary of the *Så3 local zone* is characterized by a rise in *Betula* to more than 50%. The AP-values rise, while shrubs- and dwarf shrubs-, and NAP-values decline. *Corylus* rises in the upper part of the zone. The lower part of this zone is characterized by a depression in loss-on-ignition values (9%) in a marked 1 cm-thick layer of sandy gyttja. The lower boundary of this sandy gyttja layer is interpreted to represent an unconformity representing a hiatus. Both the T-3847A radiocarbon date and the pollen record above the sandy gyttja layer indicate that sediments of late Preboreal age are missing. The lower boundary of the *Så4 local zone* is defined by the *Corylus* rise to 21%. *Betula* declines and stabilizes around 35%. The loss-on-ignition and the ratio between the main physiognomic types is stabilized at the lower boundary of this zone. The lower boundary of the *Så5 local zone* is defined by the initial *Alnus* rise to 2%. *Betula* declines and *Pinus* rises

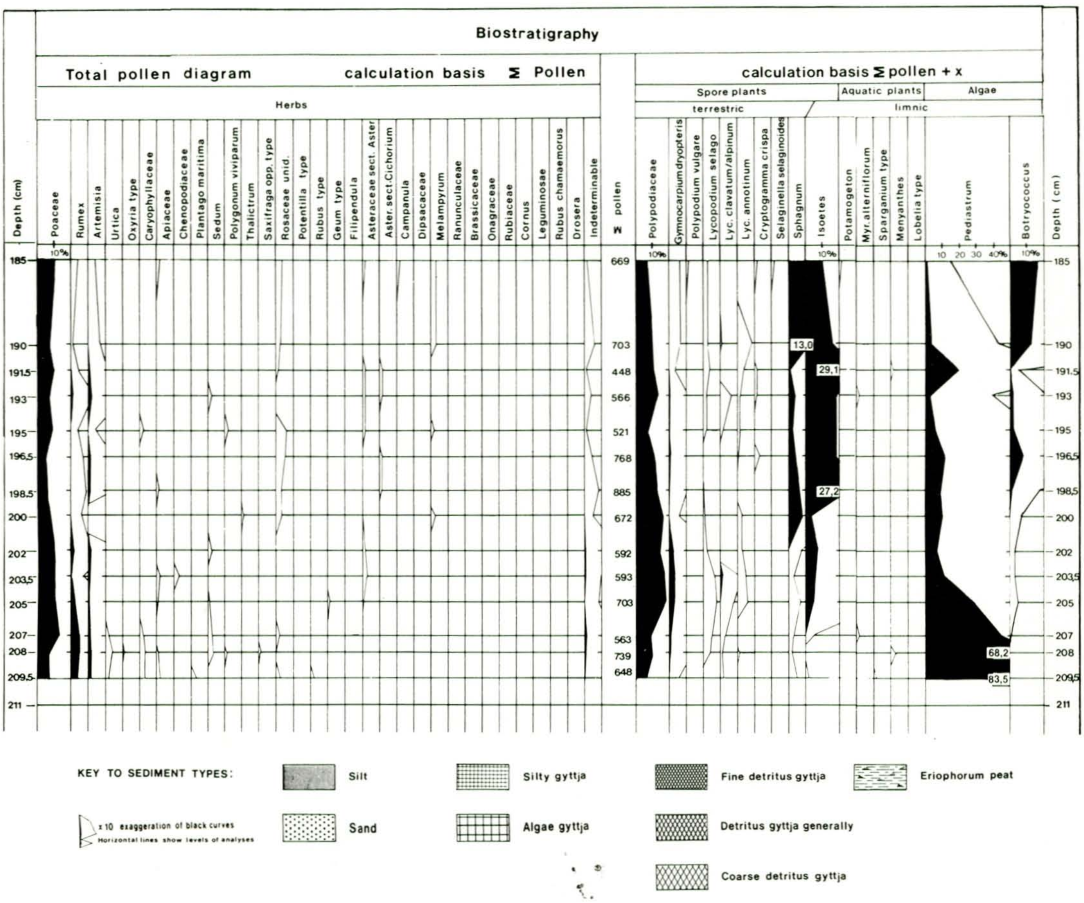


Fig. 5. Sandsaosen 630 m a.s.l. is a partly overgrown tarn situated between the Trollgaren and the Blåfjell moraines, just outside the Blåfjell moraines in the subalpine open birch forest. The site is deforestated due to a thin and scattered sediment layer and to pasturing. The person marks the sample site.

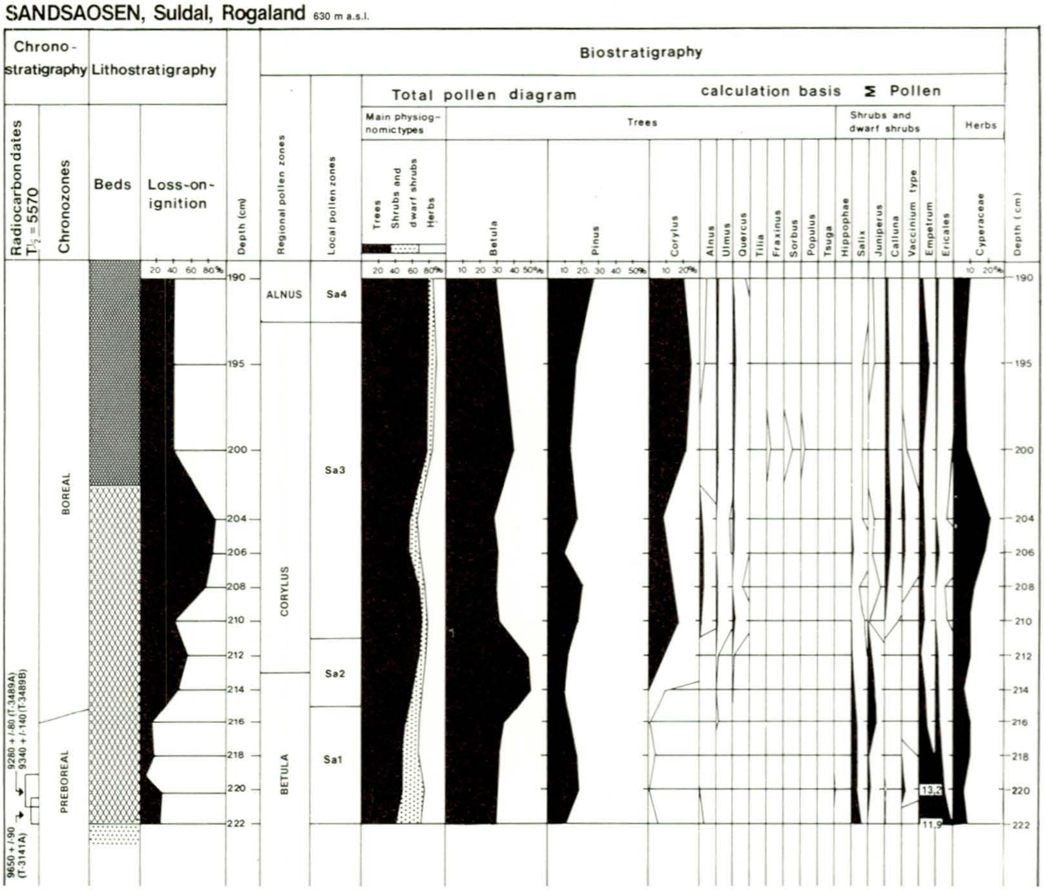
to more than 20%. Light demanding taxa are reduced except Cyperaceae and Poaceae.

Radiocarbon dating: Four levels of this core were ^{14}C-dated.

The two dates on the basal organic sediment are presumed to give the age of the first organic material deposited in the basin after deglaciation (T-3488A and B, NaOH soluble and insoluble fractions, respectively) (Fig. 4). The pollen record with high values of *Betula* indicates an early Preboreal age compared with the overlying pollen record, thus confirming the radiocarbon date of the NaOH soluble fraction. Paus (1988) reported rising *Betula* values at 10 100 years B.P.

The next two dates give the minimum age of a drop in *Betula*, combined with maxima in the *Juniperus* and *Rumex* curves. This pollen re-

SANDSAOSEN, Suldal, Rogaland 630 m a.s.l.



cord is interpreted to reflect a climatic deterioration caused by the ice advance during the Trollgaren substage. The pollen record indicates a Preboreal age and thus favours the date from the NaOH soluble fraction of 9610±210 years B.P. (Fig. 4).

The dates 9510±150 and 9700±140 years B.P. (NaOH soluble and insoluble fractions, respectively) give the maximum age of an expansion in the *Betula* values, and where sand dominates the sediment. These dates are presumed to give the maximum age of a bio- and lithostratigraphic record which is interpreted as being caused by the Blåfjell ice advancing and/or retreating in the area. These 2 radiocarbon dates thus give a maximum age of the Blåfjell substage. The pollen record indicates a Preboreal age. Both dates seem to be too old compared with *Corylus* immigration at some 8800 years B.P., thus supporting the previously discussed contention of a hiatus just below the *Corylus* rise.

The uppermost radiocarbon dated level comprising the initial *Alnus* rise was performed in order to establish the Boreal/Atlantic chronozone boundary. The age 8370±100 years B.P. (NaOH soluble fraction) is in accordance with the pollen record.

Sandsaosen

This locality (Fig. 5) is a partly overgrown tarn situated 630 m a.s.l. in the Precambrian basement gneiss, between the Trollgaren and Blåfjell moraines, just outside the Blåfjell moraines (Fig. 1). The sediment cover is scattered and thin, and the catchment area is entirely in the Precambrian zone. The youngest ice movement was towards the SW, draining out the Sandsa basin. The subalpine vegetation is characterized by heather and grassland

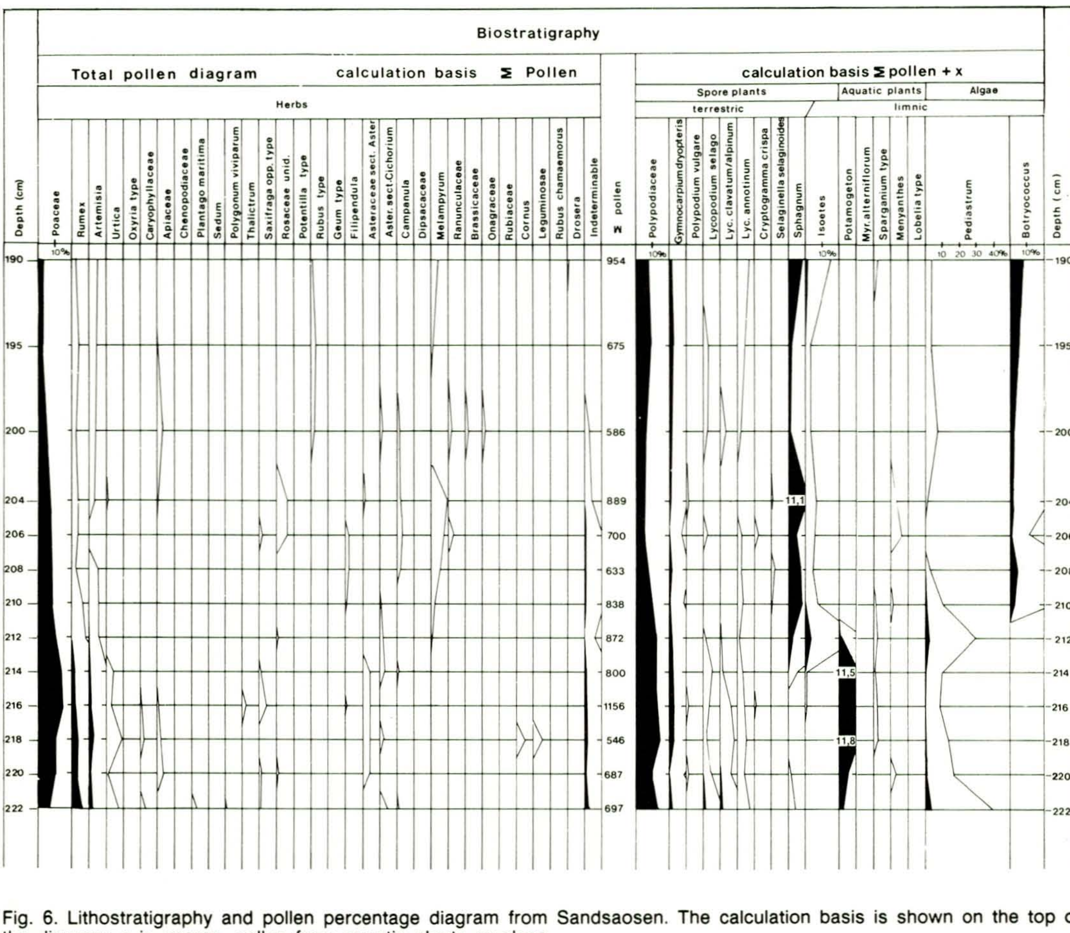


Fig. 6. Lithostratigraphy and pollen percentage diagram from Sandsaosen. The calculation basis is shown on the top of the diagram; x is spores, pollen from aquatic plants or algae.

pasture. The recorded plant species at the mire around the tarn indicate poor fen vegetation because of the absence of rich fen species and the presence of e.g. *Carex pauciflora* and *Rubus chamaemorus.*

Lithostratigraphy: At the base there is a poorly sorted sand (Fig. 6) in which a leaf of *Salix herbacea* was embedded, covered by brown, coarse and fine detritus gyttja with decreasing minerogenic content upwards and followed by peat at the top.

Pollen analysis: The *Sa1 local zone* is defined by tree values at about 50%, and *Empetrum, Salix* and *Rumex* values more than 5%, 3% and 2%, respectively. Loss-on-ignition is more than 20% in the two bottom samples, which is higher than in the bottom samples at the other localities. This may indicate either a slow sedimentation rate in the Sandsaosen basin in the time immediately following deglaciation, a climatic amelioration and/or a relatively high input of organic matter from an established vegetation close to the locality at the time of deglaciation. In the upper part of the assemblage zone loss-on-ignition drops to 11%, *Juniperus* increases to more than 5% and *Artemisia* increases to a maximum value of 3%. *Vaccinium* has a maximimn of 2,5% in this zone. *Hippophae* is present, and *Potamogeton* rises to values of more than 11%. The pollen flora reflects an open pioneer vegetation. The relatively low frequencies of tree pollen may indicate that the *Pinus* maximum in the middle of this zone is caused by a larger influx of long-distance pollen as a consequence of lower local pollen production. In this pine maximum loss-on-ignition drop to 12%. These changes are presumed to indicate a climatic deterioration. The *Sa2 local zone* is characterized by a maximum of *Betula* and the lower boundary is defined by a rise in *Betula* to 50%. The herbs, shrubs and dwarf shrubs decline, due to a decline of the pioneer taxa. *Corylus* rises in the upper part of the zone. Loss-on-ignition is increased to about 50%. The maximum for *Betula* is followed by a minimum in *Pinus.* The lower boundary of the *Sa3 local zone* is defined by a rise in *Corylus* to 18% and a depression to about 30% in *Betula* corresponding to higher values of *Pinus.* In the lower part of the zone there is a maximum in loss-on-ignition parallel to maxima in Cyperaceae and *Sphagnum.* Characteristic of this part of the zone is the early occurrence of a continuous curve of *Alnus.* In the upper part of the zone tree pollen rises to 80%. The lower boundary of the *Sa4 local zone* is defined by a rise in *Alnus* parallel to an increase in *Pinus* to more than 25% and a decline in *Corylus* to 20%. *Sphagnum* increases to 9%.

Radiocarbon dating: Two levels of this core were radiocarbon dated.

The ^{14}C-dating just above the basal poorly sorted sand without organic matter gave an age of 9650±90 years B.P. (NaOH soluble fraction) (Fig. 6) and is presumed to give the age of the first organic material deposited in the basin after deglaciation from the Trollgaren terminal moraines. The age is thus considered a minimum age of deglaciation from the Trollgaren moraines. This result agrees well with both the dating of the Trollgaren substage at Såta and with the estimated age based on the biostratigraphy indicating a pioneer vegetation and Preboreal Chronozone.

The next two dates are derived from a parallel core and overlap the underlying date. The two cores were correlated by pollen. The dates gives the age of a maximum in *Pinus,* the maximum age of a minimum in loss-on-ignition and a maximum in *Artemisia, Urtica* and *Juniperus.* This *Pinus* maximum is presumed to be caused by lower local pollen production, and the bio- and lithostratigraphic record probably indicates a climatic deterioration. The results of these radiocarbon determinations are 9280±80 and 9340±140 years B.P. (T-3489A and B, soluble and unsoluble fractions) (Fig. 6). The results of the dates are in accordance with a biostratigraphic estimate indicating the late Preboreal Chronozone. The age difference between these dates and the one just below seems, however, to reflect a greater sedimentation rate than is normal.

Langaneset

The locality (Fig. 7) is a partly overgrown tarn situated just inside the Blåfjell moraines at 610 m a.s.l. lying within Precambrian basement granite. The sediment cover, mostly till, is continuous but rather thin. The youngest ice movement was towards SW out of the Sandsa basin. The subalpine vegetation is characterized by open birch *(Betula pubescens)* forest mixed with heather and grassland pasture.

The plant species recorded at the mire around the tarn indicate a rich fen vegetation, because of the presence of e.g. *Selaginella selaginoides, Tofieldia pusilla* and *Saxifraga aizoides*. A small brook drains into the basin originating from the steep mountainside southeast of the locality. Here the Ryfylke Schists are found.

Lithostratigraphy: At the base there is a grey laminated silt (Fig. 8) with macroscopic plant remains (mainly parts of leaves and mosses, and small twigs from *Betula sp.* and *Pinus*) and stones covered by brown algae gyttja.

Pollen analysis: The *La1 local zone* (Fig. 8) is defined by tree values of about 60% and with *Betula* as the dominating taxon. *Juniperus* and *Empetrum* show maxima at 11% and 6%, respectively. Both *Salix* and unidentified Ericales are present in relatively great amounts. The pioneer character of the vegetation is also indicated by the herb pollen of *Rumex, Artemisia* and *Oxyria*-type. The lower boundary of the *La2 local zone* is defined by a *Betula* rise to above 65%. Tree pollen rises through the zone to more than 80%, and *Corylus* rises in the upper part of the zone. The relatively low loss-on-ignition compared with the loss-on-ignition at the localities Såta and Sandsaosen may be caused by the fact that this basin has a greater drainage area than the other two, allowing a larger clastic sediment supply. The presence of diatoms will also contribute to this. Pollen from e.g. *Rumex, Artemisia, Sedum, Campanula,* Ranunculaceae and Rubiaceae indicate a relatively species-rich ground vegetation. *Pediastrum* has a maximum at 76,9% showing that the lake was eutrophic. The lower boundary of the *La3 local zone* is defined by a rise of *Corylus* to 28% and a depression to below 40% in *Betula* values. Tree pollen and loss-on-ignition values rise slowly through this zone, and the ratio between the main physiognomic types is stabilized in this zone. The lower boundary of the *La4 local zone* is defined by a rise in *Pinus* to 41%, an initial rise in *Alnus* and a decline in *Corylus* and *Betula* to 13% and 30%, respectively. *Alnus* rises through the zone to 5%. A mixed birch and pine forest dominated the vegetation in the period corresponding to this zone. The lower boundary of the *La5 local zone* is defined by an abrupt rise in *Alnus* to 43%, a temporary decline in *Betula* and *Pinus,* and the zone is characterised by tree pollen values at about 90%. *Alnus* grew at the locality and dominated the vegetation around the tarn.

Fig. 7. Langaneset 610 m a.s.l. is a partly overgrown tarn situated just inside the Blåfjell terminal moraines in the subalpine open birch forest. The person marks the sample site.

Radiocarbon dating: Three levels of this core were radiocarbon dated.

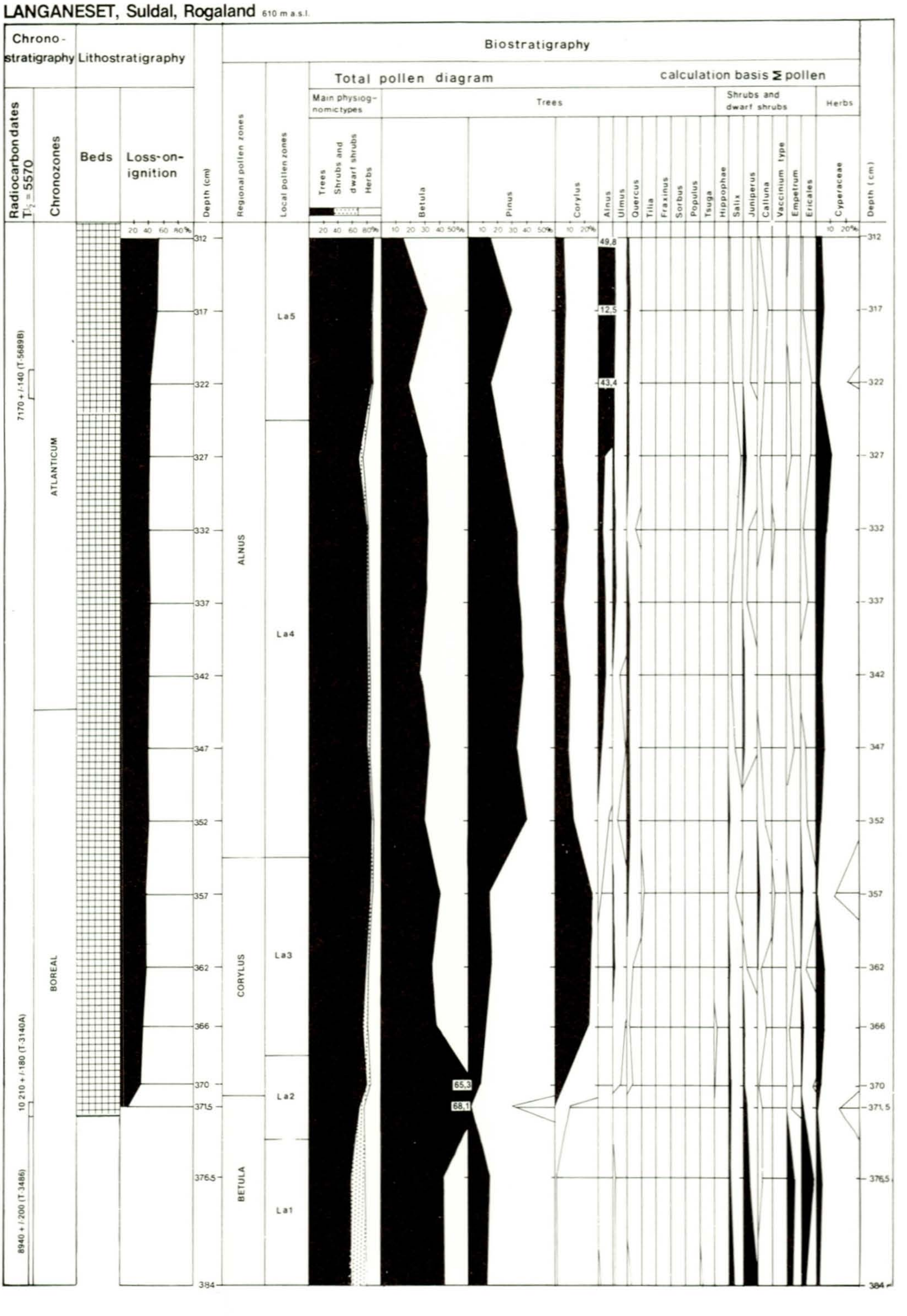
Based on pollen stratigraphy and dates from the other sites, the date of 10 210±180 years B.P. (T-3140A soluble fraction) (Fig. 8) on the basal organic sediment is more than 1000 years too old. Macroscopic remains of terrestrial plants (leaves, seeds, twigs etc.), were therefore picked from the basal grey silty clay in four new cores. The new radiocarbon date gave an age of 8940±200 years B.P. which is in accordance with the biostratigraphic estimate. This date is thus considered to give a minimum age of the deglaciation from the Blåfjell substage.

The uppermost date (7170±140 years B.P.) gives the age of the *Alnus* immigration at the locality. The pollen flora with a dominance of *Alnus* and the ^{14}C date support an early Atlantic age.

Øvre Storvatn

This locality (Fig. 9) is a mire (an overgrown tarn) situated in the high mountain area, at an altitude of 980 m a.s.l. The bedrock is dominantly gneiss. The sediment cover is relatively sparse and is found mainly in depressions in the landscape. The youngest ice move-

LANGANESET, Suldal, Rogaland 610 m a.s.l.



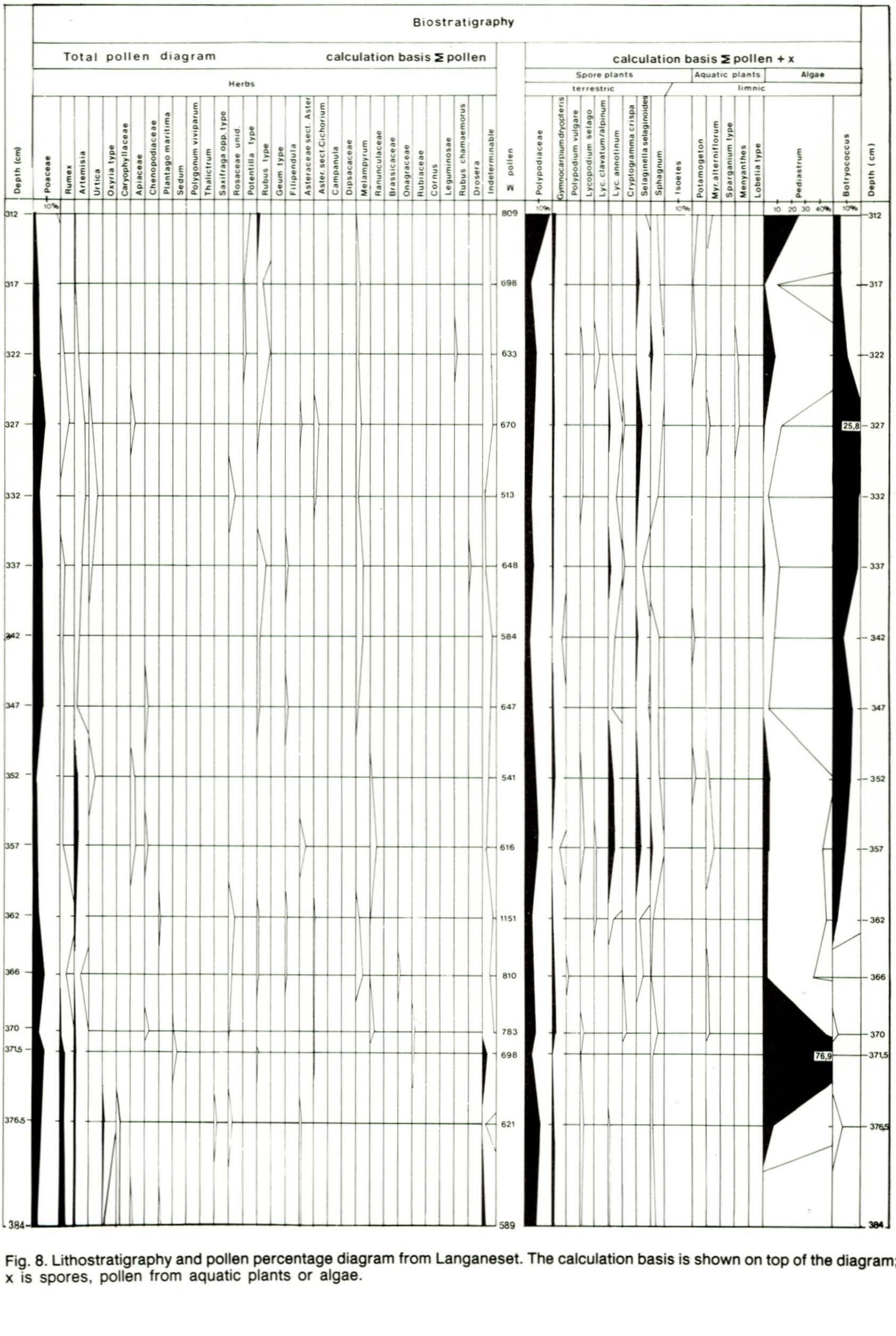


Fig. 8. Lithostratigraphy and pollen percentage diagram from Langaneset. The calculation basis is shown on top of the diagram; x is spores, pollen from aquatic plants or algae.

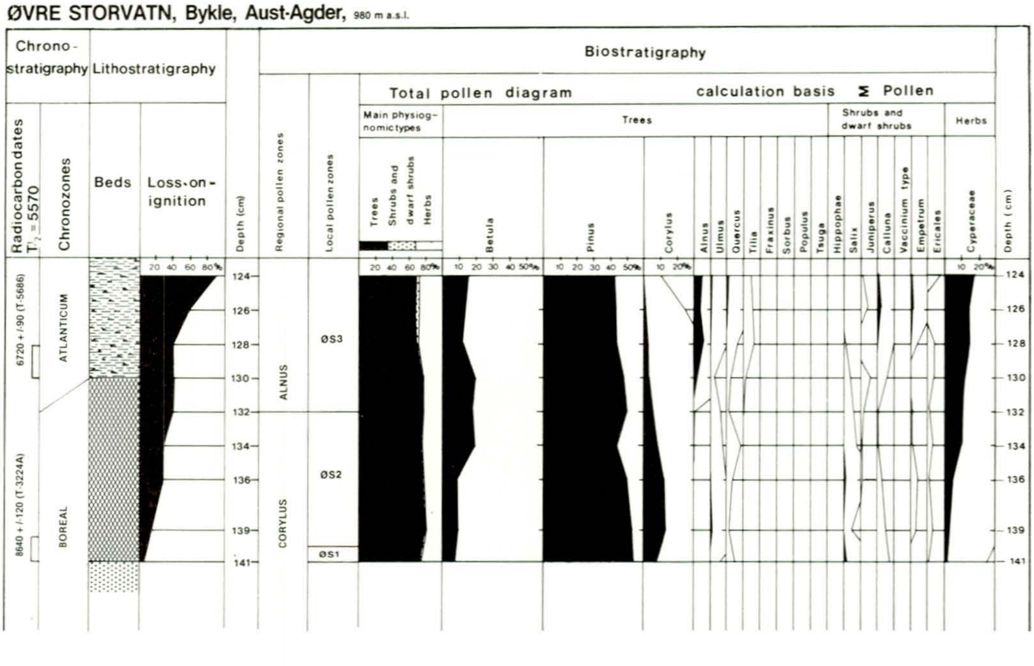
Fig. 9. Øvre Storvatn 980 m a.s.l. is a mire (an overgrown tarn) situated in the high mountain area far inside and north of any recorded terminal moraines of presumed Preboreal age. The sediment cover is relatively sparse, found mainly in depressions and the vegetation is low alpine. The person marks the sample site.

ment was towards the SW. The locality is situated well inside and north of any recorded terminal moraines of presumed Preboreal age (Fig. 1). The low alpine vegetation is characterized by heather- and grassmoor. The plant species recorded at the mire indicate a poor fen vegetation because of the presence of e.g. *Eriophorum angustifolium* and *Carex vaginata.*

Lithostratigraphy: At the base there is sorted sand coarsening upwards (Fig. 10) covered by dark brown detritus gyttja with a decreasing content of sand upwards and followed by brown *Eriophorum* peat at the top. Angular sand and gravel particles are found at all levels in the organic sediments. These are probably a product of frost weathering and sheetwash.

Pollen analysis: The *ØS1 local zone* (Fig. 10) is defined by 8% Rumex, 3% Salix and a herb pollen flora with pioneer taxa like *Artemisia, Urtica,* Caryophyllaceae and *Thalictrum.* Characteristic of the zone are tree pollen values of 75%. *Pinus* is the main constituent with 56%, while *Betula* and *Corylus* are present with relatively small values (9 and 10%, respectively). Loss-on-ignition is 6%. The pollen record indicates a low alpine pioneer vegetation. The lower boundary of the *ØS2 local zone* is defined by a decrease of *Rumex* to 3%, and an increase of tree pollen to around 80%. This increase is primary caused by a rise in *Corylus* to 14%. The lower boundary of the *ØS3 local zone* is defined by an initial rise of *Alnus. Pinus* is the main constituent among the tree pollen with values between 52% and 43%. *Betula* constitutes between 20% and

ØVRE STORVATN, Bykle, Aust-Agder, 980 m a.s.l.



13%. *Corylus* gradually declines and Cyperaceae gradually increases through the zone.

Radiocarbon dating: Two levels of this core were radiocarbon dated.

The pioneer character of the pollen flora indicates that the sandy gyttja was depositd shortly after deglaciation. The date from the lower part of this bed (8640±120 years B.P.) (Fig. 10) was performed on the NaOH soluble fraction, as contamination of both old carbon from the minerogenic part of the sediment, and younger carbon from the vertical rootlets which penetrated the sediment, was considered possible. The obtained age is in agreement with the estimated age based on the pollen record, indicating a Boreal age. This age is also supported by the basal date at Skreivatn described next. Contamination of the soluble fraction by carbon derived from the disintegrated part of the rootlets is therefore considered to be negligible. This date gives a minimum age for the deglaciation of the high mountain area in the investigated area.

The upper dated level comprises the rise in *Alnus,* and was carried out to determine the age of the Boreal/Atlantic boundary. The result of the determination (6720±90 years B.P.) is somewhat younger than expected from the pollen record (see p. 70).

Fig. 11. Skreivatn 1030 m a.s.l. is a mire (an overgrown tarn) situated in the high mountain area far inside and north of any recorded terminal moraines of presumed Preboreal age. The sediment cover is thin and scattered and the vegetation is low alpine. The person marks the sample site.

Skreivatn

This locality is a mire (an overgrown tarn) situated in the high mountain area 1030 m a.s.l. (Fig. 11) on granitic gneiss. The landscape is

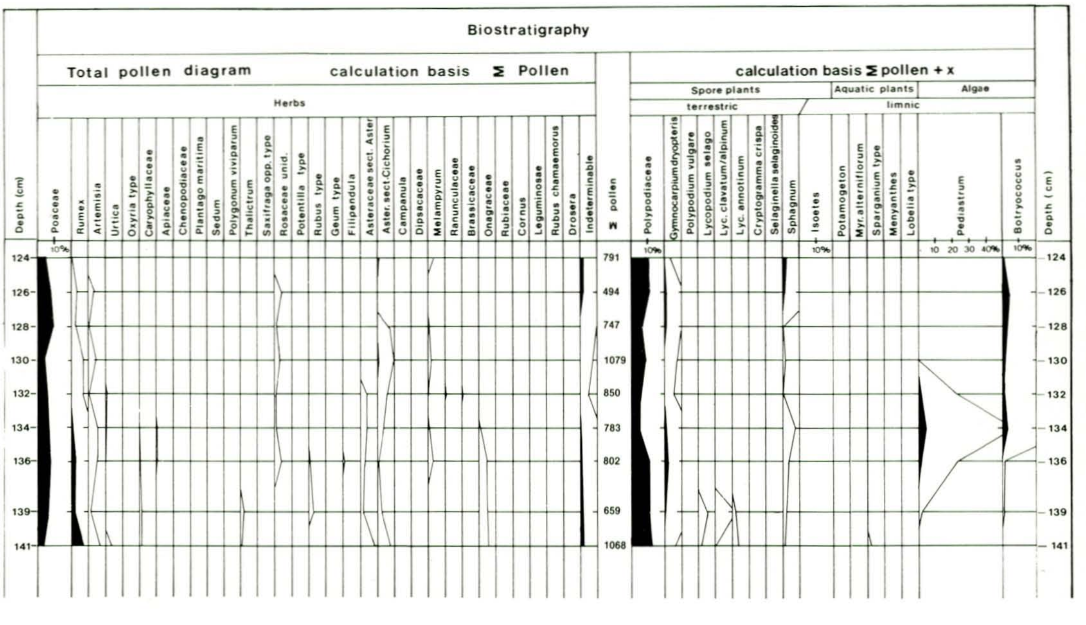
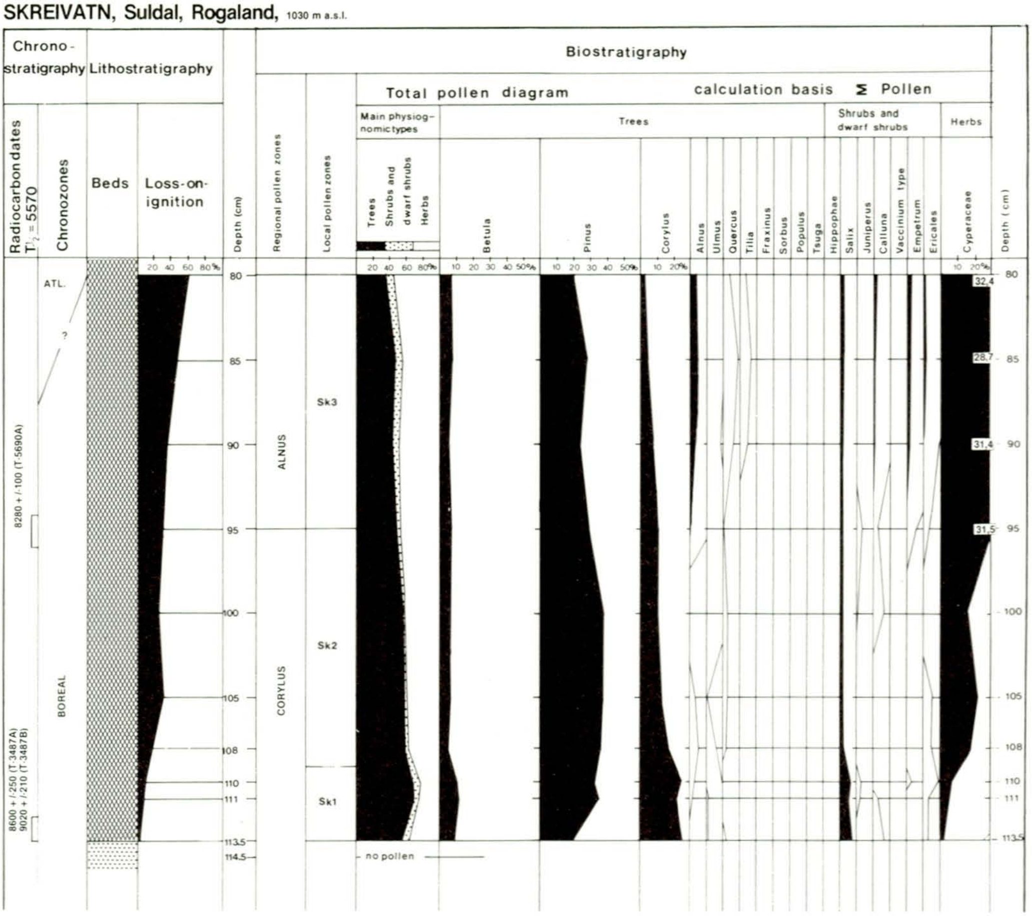


Fig. 10. Lithostratigraphy and pollen percentage diagram from Øvre Storvatn. The calculation basis is shown on top of the diagram; x is spores, pollen from aquatic plants or algae.

SKREIVATN, Suldal, Rogaland, 1030 m a.s.l.



fairly flat in the vicinity of the locality and the sediment cover is thin and scattered. The youngest ice movement was towards west. The locality is situated far east and north of any recorded terminal moraines of presumed Preboreal age. The scattered low alpine vegetation is characterized by heather- and grassmoor. The plant species recorded at the mire indicate a poor fen vegetation because of the presence of e.g. *Viola palustris* and *Carex magellanica*.

Lithostratigraphy: At the base there is sorted sand (Fig. 12) covered by brown detritus gyttja with a decreasing content of minerogenic matter upwards.

Pollen analysis: The *Sk1 local zone* is defined by high *Rumex* values (16,6% in the basal sediment), by *Salix* (8% in the basal sediment) dominating the shrubs and dwarf shrubs and a herb pollen flora with pioneer taxa like *Artemisia* and Caryophyllaceae (Fig. 12). Tree pollen have a maximum of 72% in the middle of the zone. *Pinus* and *Corylus* are the prominent tree pollen, *Pinus* showing a rise in the bottom of the zone, where loss-on-ignition is 4%. The pollen record indicates a low alpine pioneer vegetation. The lower boundary of the *Sk2 local zone* is defined by an increase in Cyperaceae to 19% and in Poaceae to 11%, while *Rumex* and *Salix* decline to 4 and 2%, respectively. *Pinus* dominates the tree pollen with values just below 40%, while *Corylus* declines. The pollen record indicates a low alpine grassmoor. The lower boundary of the *Sk3 local zone* is defined by an increase in Cyperaceae to 31.5% and the initial *Alnus* ri-

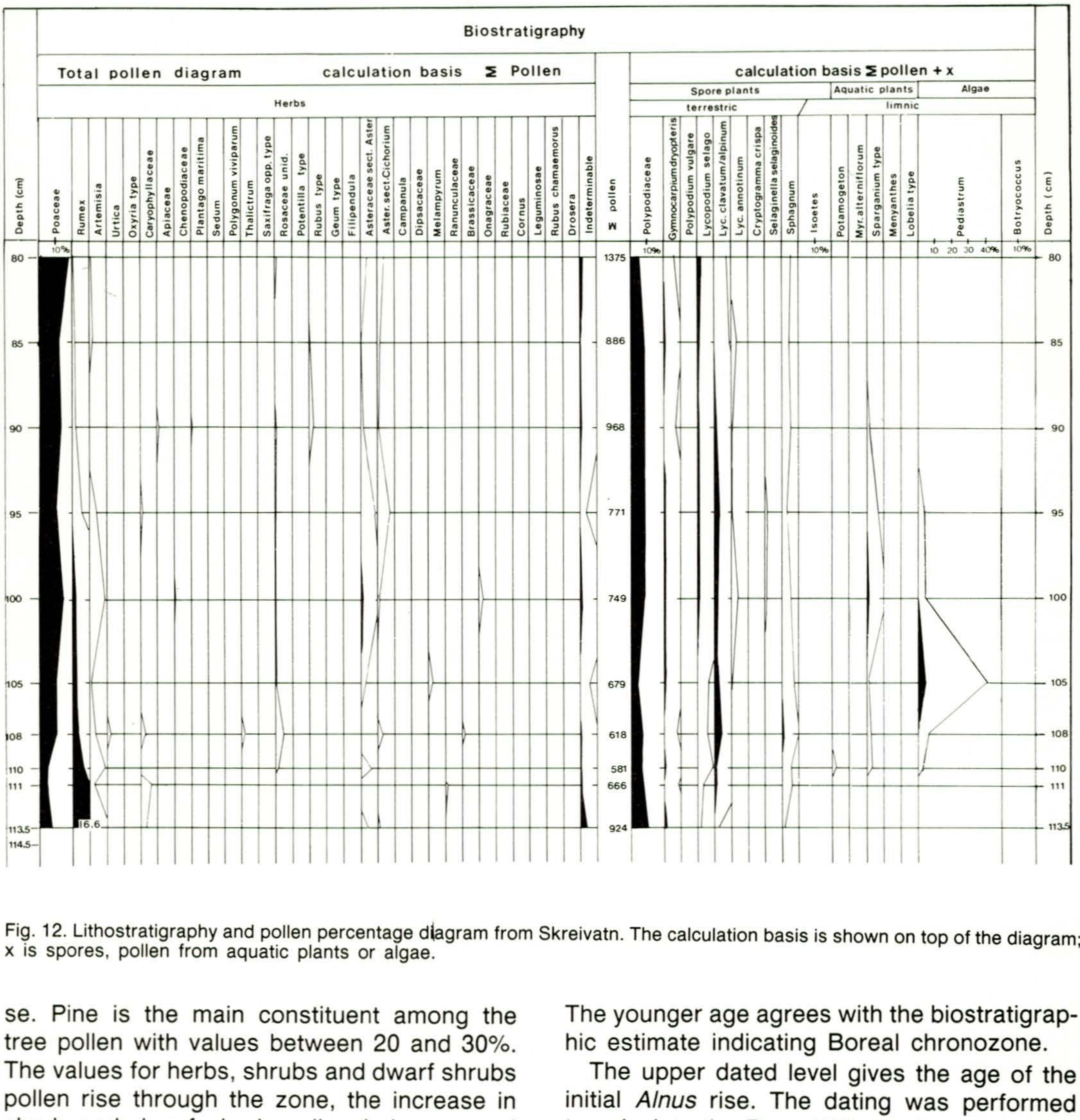


Fig. 12. Lithostratigraphy and pollen percentage diagram from Skreivatn. The calculation basis is shown on top of the diagram; x is spores, pollen from aquatic plants or algae.

se. Pine is the main constituent among the tree pollen with values between 20 and 30%. The values for herbs, shrubs and dwarf shrubs pollen rise through the zone, the increase in shrub and dwarf shrub pollen being caused by a rise in heather. Herb pollen (especially Cyperaceae and Poaceae) dominate the top of the zone. The pollen record indicates a low alpine grassmoor vegetation.

Radiocarbon dating: Two levels of this core were radiocarbondated.

Two dates were performed at the base of the brown gyttja giving ages of 8600±250 and 9020±210 years B.P. (NaOH soluble and insoluble fractions, respectively) (Fig. 12). The dates are interpreted to give the age of the first organic material deposited in the basin, thus giving a minimum age of deglaciation. The younger age agrees with the biostratigraphic estimate indicating Boreal chronozone.

The upper dated level gives the age of the initial *Alnus* rise. The dating was performed to calculate the Boreal/Atlantic boundary. The result of 8280±100 years B.P. (NaOH soluble fraction) is in accordance with the pollen record (see p.70) indicating a late Boreal age.

Løyning

The locality is a partly overgrown tarn located in a dead-ice kettle in till (Fig. 13). The sediment cover is continuous and abundant compared with the other localities investigated. It is situated 720 m a.s.l. in the Setesdal valley just outside the mouth of Vatnedalen, a tributary valley from the western mountains, and at the foot of a prominent, approximately 60m thick medial moraine ridge deposited between

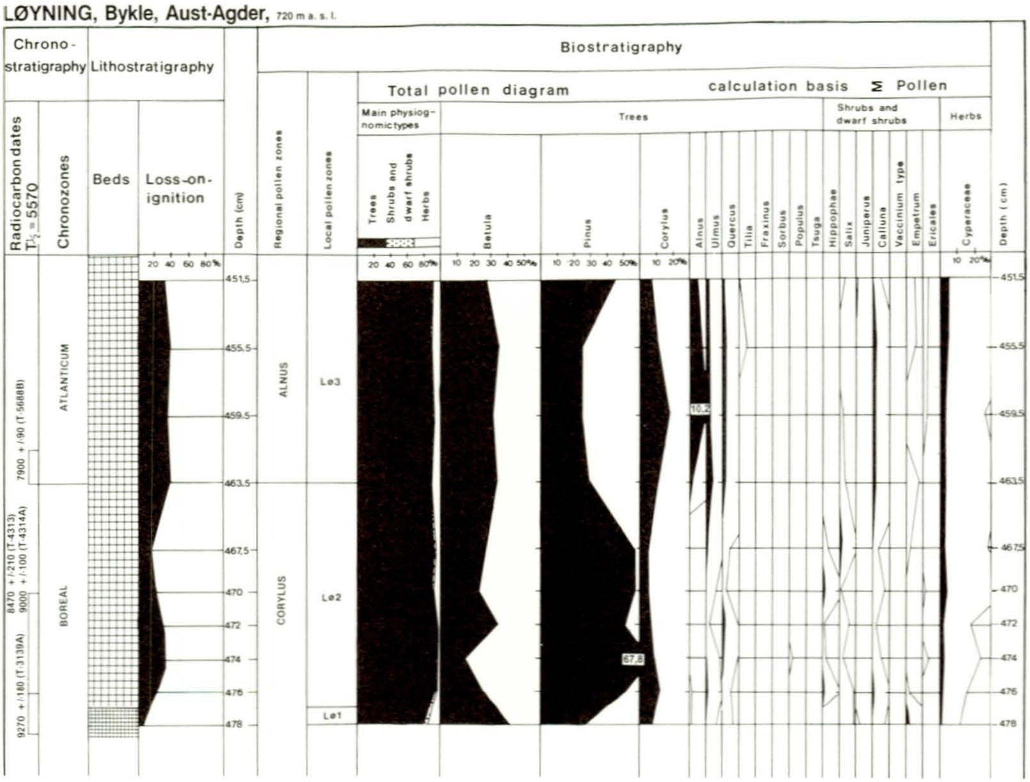
Fig. 13. Løyning 720 m a.s.l. is a partly overgrown tarn in the Setesdal valley far inside and north of any recorded terminal moraines of presumed Preboreal age. The sediment cover is continuous and abundant and the vegetation is dense boreal forest.

glaciers in the Vatnedalen and Setesdalen valleys (Blystad 1978). The youngest ice movements were towards SE and E. The bedrock is Precambrian basement granitic-granodioritic gneiss. The vegetation is dense forest with *Pinus sylvestris* as the dominant species mixed with some *Betula pubescens* and *Picea abies.* The plant species recorded at the mire around the tarn indicate an intermediate fen vegetation because of the presence of e.g. *Selaginella selaginoides* and *Pinguicula vulgaris.*

Lithostratigraphy: Penetration during boring was measured to 550 cm, the loss of sediment during coring amounts to 72 cm which most probably consisted of sand which was proven by sounding. At the base of the core a thin layer of coarse sand occurred covered by brown sitly gyttja with macroscopic remains of *Pinus* (Fig. 14) covered by layered algae gyttja.

Pollen analysis: The *Lø1 local zone* (Fig. 14) is rather poor in pollen. This zone is defined by relatively high values of *Saxifraga oppositi-*

LØYNING, Bykle, Aust-Agder, 720 m a. s. l.



folia-type (6%) and *Empetrum* (2%). Tree values constitute 80% with *Betula* as the dominating taxon. Loss-on-ignition is low (6%). The herb pollen flora including *Rumex* and *Artemisia* indicates a light demanding pioneer flora. The lower boundary of the *Lø2 local zone* is defined by an increase in *Pinus* to 52%, the presence of *Hippophae* in a continuous curve (maximum values more than 1%) and the disappearance of *Saxifraga oppositifolia*-type. Tree pollen values rise to more than 92%. The pollen content indicates a dense pine forest mixed with some birch. The lower boundary of the *Lø3 local zone* is defined by the rise of *Alnus* to 2%, of *Ulmus* and *Quercus* to 4% and 3%, respectively. *Betula* and *Pinus* pollen dominate the tree pollen values with 33 and 30%, respectively, and *Corylus* has a maximum in the zone. The pollen content indicates a pine birch mixed forest with *Corylus* and *Alnus* growing at dry and moist localities, respectively.

Radiocarbon dating: Three levels of this core were radiocarbon dated.

The basal date is 9270±180 years B.P. (NaOH soluble fraction) (Fig. 14), older than assumed when judged from the *Corylus* rise (see p. 70) and from the adopted deglaciation model. Two new dates were therefore performed above this basal date to evaluate the time of deglaciation. The results of these are 8470±210 (plant remains) and 9000±100 years B.P. (NaOH soluble fraction). The age of the plant remains is considered reliable, because radiocarbon dates on plant remains generally are reliable and the age is in accordance with the biostratigraphy. It shows that the date on the bottom sample probably is too old.

The upper date (7900±90 years B.P., insoluble fraction) gives the minimum age of the *Alnus* rise. The determination was performed to determine the Boreal/Atlantic boundary. The obtained age is in accordance with the pollen evidence.

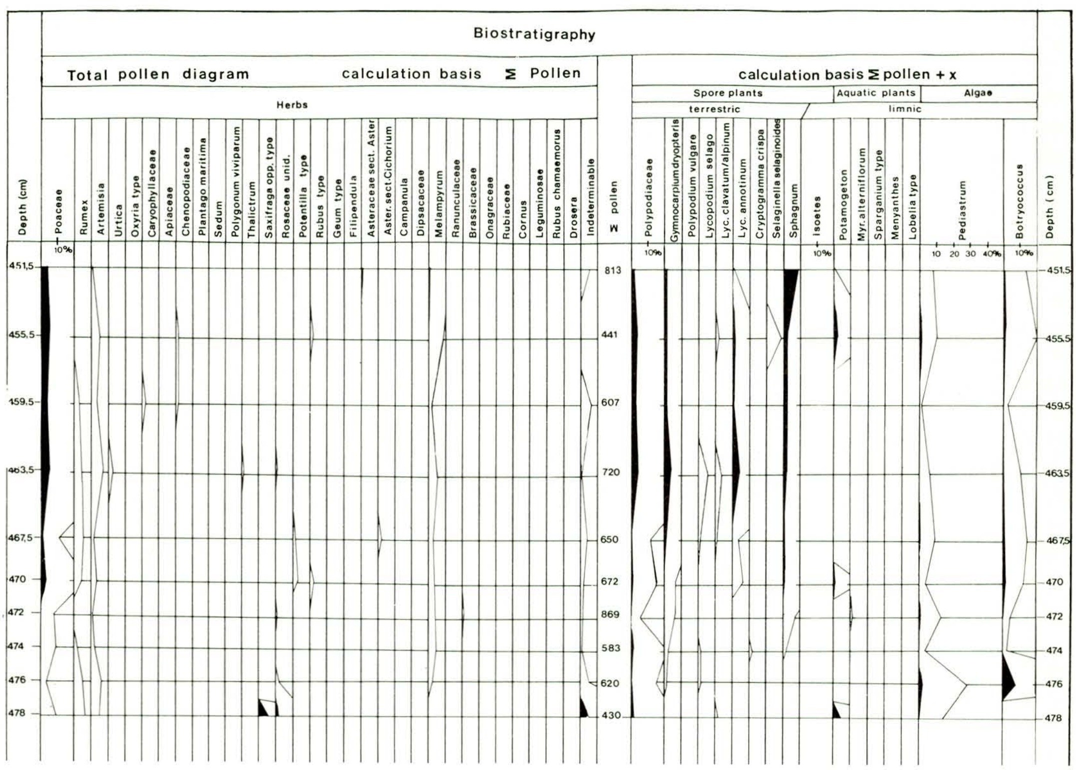


Fig. 14. Lithostratigraphy and pollen percentage diagram from Løyning. The calculation basis is shown on top of the diagram; x is spores, pollen from aquatic plants or algae.

Deglaciation chronology and correlations

Some of the radiocarbon datings of lacustrine sediments in this study are considered to be too old. Blystad & Selsing (in manus) conclude (cf. Table 1):

— Old carbon has presumably contaminated the insoluble fractions of the dated samples from Såta and Skreivatn.

— The 'old' date at Såta of 9510±150 years B.P. compared with the *Corylus* rise is presumably caused by a hiatus in the sediment at level 204 cm.

— At Langaneset the date of 10 210±180 years B.P. which is too old compared with a pollen analytic estimate is probably caused by a hard water effect.

— At Løyning the dates 9270±180 and 9000±100 years B.P. on the soluble fraction are older than expected, as estimated from the *Corylus* rise (see p. 70). It is possible that redeposition of interstadial organic sediments and/or a reservoir effect have caused the observed dating error. Blystad (1981) has described interstadial organic sediments at a nearby locality.

Inherent in the theory of minimum date chronology is the assumption that the lacustrine sediments overlying glacial materials were deposited soon after deglaciation. This, however, is not always the case. In most cases some time span may exist between the deglaciation and the deposition of the first organic sediment in a basin. Cotter et al. (1984) reported estimates of the time lag between deglaciation and organic-rich sediment deposition ranging from 4000 years to no significant time. Sutherland (1980) estimated from 50 to 200 years younging of the basal dates in Scottish lakes. Sutherland based his figures on an estimate of how long time it took to have enough organic material for dating if production started immediately after deglaciation. If there is an additional time lag between deglaciation and organic production it will mainly depend on altitude and geological conditions. High trophic status will favour growth of algae, which are often a significant contribution of organic matter to the basal organic sediments. The trophic conditions depend on the geological conditions. The altitude of the basin is important, as the organic production in the basin, and in the vicinity of the basin, largely depends on local climate.

Based on these assumptions, we would expect the dates of the basal sediments at Såta, Sandsaosen, Langaneset and Løyning to be closer to the actual time of deglaciation, than is the case for the two high mountain localities. We expect a delay of less than 100 years for localities Såta, Sandsaosen, Langaneset and Løyning and about 200 years for localities Øvre Storvatn and Skreivatn. For the localities Såta, Sandsaosen, Langaneset and Løyning this younging effect is not accounted for in the establishment of chronology and we will call attention to this different handling of the localities.

Naming of the informal climatostratigraphic units defined in this study is done in accordance with the recommendations from the Norwegian Committee on stratigraphy (NSK) (Nystuen 1986). In this area, Anundsen (1972) described morainic ridges belonging to what ha named the Trollgaren and Blåfjell substages. These are inn a strict sense morphostratigraphic units (morphodems), deposited in a certain period of time (Span). The informal climatostratigraphic units proposed here are units where the boundaries are defined by indications of climatic changes, which caused the Trollgaren and Blåfjell glacial advances. It is recommended that double use of names should be avoided; hence the corresponding climatostratigraphic units should be named differently. We therefore propose names related to the actual locality or to a nearby geographic name.

As a result of our investigations we have divided the deglaciation sequence into 4 informal climatostratigraphic units: the Skute thermomer (oldest), the Fidja cryomer, the Sandsaos thermomer and the Sandsa cryomer. The terms thermomer and cryomer are chosen according to Lüttig (1965). The names are accepted by the Norwegian Committee on Stratigraphy.

The Skute thermomer

Deglaciation from the Younger Dryas moraines is elucidated by the date of 10 100±280 years B.P. (T-3488A) on the soluble fraction from the first organic material deposited at Såta. The beginning of the Skute thermomer is correlated with the deglaciation from the Ski moraines (Sørensen 1983) and with a marked vegetational response to the early Holocene climatic amelioration at Sandvikvatn in northern Rogaland (Paus 1988).

Sivertssen (1985) reported on radiocarbon dating of the basal organic sediment in Flåtevatn, 570 m a.s.l., Etne, Hordaland, which provided a date of 9570±140 years B.P. The site is located inside the Younger Dryas terminal moraines (Anundsen 1972) and thus gives a minimum age of the deglaciation. This age is, however, too young compared with the Såta age of deglaciation from the Younger Dryas ice of 10 100±280 years B.P.

Further north on the Norwegian coast the Skute thermomer is correlated with the Luster Interstadial in the area between Jostedalsbreen and Jotunheimen (10.200±200 years B.P. to 9800±200 years B.P.), a period of extensive glacial recession (Vorren 1973).

The Fidja cryomer

The dating of 10 100±280 years B.P. from basal organic sediment at Såta gives a maximum age for the Fidja cryomer. The change of the pollen composition at the level 207 cm in the Såta pollen diagram (Fig. 4) is presumed to indicate a climatic deterioration correlated with the formation of the Trollgaren terminal moraines. The radiocarbon date of 9610±210 years B.P. (T-3847A) on the soluble fraction on the level 205.5-207.5 cm gives the minimum age of the change in the vegetation mentioned above. The age of the Fidja cryomer is probably close to the mean value 9850 years B.P. of the two radiocarbon dates mentioned here. At Sandsaosen, situated between the Trollgaren and the Blåfjell terminal moraines, the date of the basal sediment is 9650±90 years B.P. (T-3141A), thus providing a minimum age for the Fidja cryomer. This age agrees well with the dating and the interpretation of the Fidja cryomer at Såta.

Larsen et al. (1984) recorded that the Younger Dryas cirque glaciers developed 50 to 180 years after the vegetation responded to the climatic deterioration in the Nordfjord area, western Norway. Assuming that the Fidja cryomer was due to a glacier readvance and that it is comparable with the formation of cirque glaciers, it is presumed to have occurred at 9800-9700 ^{14}C years B.P., as interpreted from the information from Såta. During this time the Såta area was a nunatak surrounded by glaciers in the lower lying areas.

The estimated age of the Fidja cryomer is 100-200 years older than indicated by Anundsen (1985, Fig. 14). A basal gyttje from Busnes, in the innermost Hardangerfjord is dated to 9720±330 years B.P. which dates the Eidfjord-Osa substage (Anundsen & Simonsen 1967). The minimum age for this stadial comes from a date on *Juniperus* wood from a fluvioglacial delta deposit and is 9680±90 years B.P. (Rye 1970). These dates indicate that at least part of the Eidfjord-Osa substage is contemporaneous with the Fidja cryomer. The terminal moraines of the Eidfjord-Osa substage and the Trollgaren substage are morphostratigraphically correlated, and there are also correlations with early Preboreal events in eastern Norway and further north on the Norwegian coast (Andersen 1968, 1975, Vorren 1973, Bergstrøm 1975, Sørensen 1983, Fareth 1987, Rye et al. 1987).

The Sandsaos thermomer

The date of 9610±210 years B.P. at Såta is presumed to give the age of the retreat of the Trollgaren glacier at that locality. The dating of the basal organic sediment at Sandsaosen (9650±90 years B.P., T-3141A), too, gives a minimum age for the Fidja cryomer. This date gives the age of a relatively high loss-on-ignition, presumably caused by a climatic amelioration and/or a high input of organic matter from an established vegetation. The poorly sorted sand below this radiocarbon dated organic sediment is presumably a deglaciation sand deposited at the beginning of the Sandsaos thermomer.

At Såta the date of 9510±150 years B.P. (T-3847A) for the level 203,5-205,0 cm gives a maximum age of the upper limit of the Sandsaos thermomer. At Sandsaosen the dates 9280±80 and 9340±140 years B.P. (T-3489 A and B) gives the age of the upper limit of the Sandsaos thermomer.

Based on these dates the lower and upper limits of the Sandsaos thermomer are dated to 9700 and 9300 years B.P., respectively.

This event may perhaps be correlated with the period during which the Hauerseter and Minnesund sandurdelta were deposited in the Oslofjord area (Sørensen 1983). Sørensen presumes that increased meltwater activity must have resulted from a marked climatic amelioration during this period.

The Sandsa cryomer

At Sandsaosen the Sandsa cryomer is maximum-dated to 9280±80 and 9340±140 years B.P. (Fig. 6). The dates give the age of a maximum in *Pinus* presumed to be caused by a lowering of the local pollen production followed by a minimum in loss-on-ignition and a maximum in *Artemisia, Urtica* and *Juniperus*. These changes were presumably caused by a climatic deterioration correlated with the formation of the Blåfjell terminal moraines. The Sandsa cryomer is also maximum-dated at Såta giving 9510±150 years B.P. (Fig. 4). Based on these dates, we conclude that the lower boundary of the Sandsa cryomer should be placed at ca. 9300 years B.P.

The deglaciation of the Blåfjell glaciers is disclosed in the pollen diagrams from the three westernmost localities, Såta, Sandsaosen and Langaneset. In the three pollen diagrams (Figs. 4, 6 and 8) *Betula* has a marked double specter maximum, and between these two specters the *Corylus* rise occurs. The pollen diagram from Langaneset shows that these alterations happened shortly after deglaciation.

Deglaciation from the Blåfjell terminal moraines is dated at Langaneset to 8940±200 years B.P. on macroscopic remains of terrestrial plants which are believed to have grown near the melting glacier margin. Thus, the date is presumed to give an age close to the age of deglaciation at Langaneset. This locality, however, lay 2,5 km inside the terminal moraine and more than 100 metres below the lateral moraines of the Blåfjell glacier. The climatic amelioration which caused the deglaciation had thus lasted for some time when Langaneset was deglaciated. Based on these considerations, we conclude that the Sandsa cryomer occurred at approximately 9300-9100 years B.P. and that the glacier retreated from Langaneset at about 9000 years B.P. During the Sandsa cryomer the Sandsaosen area was surrounded by glaciers to the north and to the south.

The age of the Sandsa cryomer is correlated with climatically controlled Preboreal readvances or stillstands along the Norwegian coast: Vorren 1973, Andersen 1975, Bergstrøm 1975, Sveian et al. 1979, Andersen et al. 1981, Sørensen 1983, Kvamme 1984, Nesje 1984, Rye et al. 1987.

The final deglaciation of southern Norway

The deglaciation of the high mountain area is elucidated at the localities Øvre Storvatn and Skreivatn. At these localities the first organic material deposited is dated to, respectively, 8600±250 and 8640±120 years B.P. (Figs. 10 and 12). Both dates give the minimum age of deglaciation. Allowing for some time between deglaciation and the production of dateable material (e.g. Sutherland 1980), we tentatively conclude that the area was deglaciated at ca. 8800 years B.P. The age of deglaciation at the two localities is presumed to give the age of the deglaciation of the whole of the high mountain area between Suldal in the west and Setesdal in the east also because the two sites are located near the area of the last ice divide in this area (Blystad 1978).

Based on pollen analysis and a radiocarbon date at Hardangervidda, Moe (1977) inferred deglaciation of the area by 8900-9000 years B.P. This locality is located near the ice divide in the area (Vorren 1979) and the geological evidence indicates that the mountain area of Hardangervidda was deglaciated at the same time as the mountain area between Suldal and Setesdal.

The deglaciation of the inland valley Setesdalen is elucidated from Løyning. The apparent age of the basal organic sediment, 9270±180 years B.P. (Fig. 14), is older than presumed when judged from the *Corylus* rise and from the adopted deglaciation model. The sedimentation rate calculated by the dates of 8470±210 and 9000±100 years B.P. confirms that the age of the bottom sample is too old. The age difference between the two last mentioned radiocarbon dates is more than 500 years. If the age difference between the true age and the apparent age of the basal organic sediment is of the same order, the true age of this sediment is 8800-8700 years B.P.

The period that elapsed between the deglaciation and the first organic sediment deposited is less in Setesdalen than in the high mountain area. It is impossible to give an exact value for this time span, but probably deglaciation in the Setesdalen valley occurred before 8700 years B.P.

This result indicates an almost simultaneous deglaciation of the high mountain area and the Setesdalen valley. Based on a study of glacial flow and sediments, Blystad (1978) assumed that the mountain area was deglaciated prior to Setesdalen. This is not in contrast with our results if the time difference between deglaciation in the mountain area and in Setesdalen is too small to be disclosed by the radiocarbon dating method. Our results also seem to contrast with results in the areas around the last ice divide in central southern Norway where the mountains and uplands were largely ice-free at the same time as ice masses still existed in the valleys (Bergersen & Garnes 1983, see also Carlson et al. 1979). In this area, however, the last ice divide crossed prominent valley systems (Garnes & Bergersen 1980) and one would expect the described deglaciation progress. In the Setesdalen area with an ice divide in the mountain area parallel to the adjacent valley results, with a simultaneous or a nearly simultaneous deglaciation of the mountain area and the valley, are reasonable.

It was concluded that the final deglaciation of southern Norway most likely occurred before 8500 years B.P. (e.g. Bergstrøm 1975, Andersen 1980). It is assumed that the final deglaciation in southern Norway were located to areas where the ice sheet was active and thickest during the later part of deglaciation. Nesje et al. (1987) showed that the maximum ice sheet was thin over the high mountain areas during Late Weichselian and the investigation by Dahl (1987) indicated that the Younger Dryas ice cap lay below the highest mountain peaks in Hemsedalsfjellene, central south Norway. This is in accordance with Garnes (1973), Hole (1979) and Bergersen (1984) who discussed ice free areas in Jotunheimen during Allerød and/or Younger Dryas. In general, the areas of maximum ice thickness are thought to be in the areas of the last ice divide but dependent on the underlying topography; for location of the ice divide based on evidence of glacial flow (striations, erratics, etc.), see Damsgaard (1967), Vorren (1977), Blystad (1978), Bergersen & Garnes (1983) and Sollid & Reite (1983). Andrews (1987) commented that an examination of the Greenland and the Antarctic ice sheets indicated that the areas of greatest ice thickness do not coincide with ice divides. He reported that ice divides tend to be located over plateaux or mountain chains where the ice is relatively thin. These comments are brief without providing details of e.g. which phase of the ice sheet he is writing about. Therefore, it is difficult to compare these results with our investigation on the final deglaciation in the mountain area.

The ice sheet is also presumed to be thick in areas where the last active ice during the deglaciation is recorded. The last active ice is recorded as local ice domes which existed at several places along and near the ice divide (e.g. Vorren 1979). The largest ice dome of the continental ice sheet was situated in Jotunheimen (Carlson et al. 1979, Sollid & Reite 1983) and during the final stages of deglaciation high mountain ice streams from this dome followed the valleys and encountered remnants of the ice sheet in the valleys (Carlson et al. op. cit.). These remnants of ice were more or less stagnant (Garnes 1979), and Bergersen & Garnes (1983) showed that during the youngest phase of deglaciation most of the mountains and uplands were ice-free and large ice masses existed in the valleys. It is plausible therefore that the deglaciation of the ice dome in Jotunheimen and the adjacent valleys marked the termination of deglaciation of southern Norway.

Three radiocarbon dates giving minimum ages for deglaciation are reported from the Jotunheimen area; two from Skåbu (695 m a.s.l.) adjacent to the ice divide give minimum ages of the last ice movement (9080±140 and 8780±210 years B.P., Alstadsæter 1979), and there is also a date of 8660±80 years B.P., T-4455 (Aas & Faarlund 1988) on a pine-log from Smådalen, Lom, 1220 m a.s.l. These dates indicate that deglaciation of Jotunheimen and the adjacent valleys occurred between 9080±140 and 8660±80 years B.P. As the first-mentioned age is most likely too old because of the hard-water effect (Garnes & Bergersen 1980), one may conclude that the final deglaciation occurred earlier than 8700-8600 years B.P. in this area.

There is also a radicarbon date from the ice divide area in Hemsedalsfjellene to the south of Jotunheimen which gives a minimum age of deglaciation: 9090±100 years B.P. (T-6488, Dahl 1987). This locality is located more than 1100 m a.s.l. and was deglaciated during the Younger Dryas chronozone (Dahl op.cit.).

This conclusion shows that it is reasonable to assume that the final deglaciation of other mountain areas in southern Norway occurred at the same time as in the investigated area between Suldal and Setesdal. Southern Norway was deglaciated before 8700-8600 years B.P., most probably at 8800 years B.P., with only stagnant or buried dead ice still existing by this time.

The oldest radiocarbon dates of human sites in the southern Norwegian mountain areas are in the northern part and they are younger towards the south (see Selsing 1986 Fig. 1). The results of the dating of deglaciation in the area between Suldal and Setesdal give, as we expected, no indication of any significant difference in the time of deglaciation between this area and Hardangervidda and Lærdalsfjellene farther north, as was proposed by A.B. Johansen (pers. comm. 1978).

Summary

Deglaciation of the Younger Dryas ice occurred at 10 1000±280 years B.P. (T-3488A) at about 720 m a.s.l. The Skute thermomer occurred at 10 100-9800 years B.P. and was characterized by high *Betula* values and high values of herb, shrub and dwarf shrub, e.g. *Salix, Empetrum, Rumex* and *Artemisia* reflecting an open pioneer vegetation. The Fidja cryomer occurred at 9800-9700 years B.P. and was characterized by a climatic deterioration indicated by a depression of *Betula,* by low values in tree pollen and by maxima in *Juniperus* and *Rumex.* The Sandsaos thermomer occurred at 9700-9300 years B.P. and was characterized by a small rise in tree pollen and an open pioneer vegetation with e.g. *Empetrum, Rumex* and *Salix.* The Sandsa cryomer occurred at 9300-9100 years B.P. and was characterized by a climatic deterioration indicated by a presumed lowering of the local pollen production. These cryomers and thermomers are correlated with Preboreal events around the Norwegian coast.

The high mountain area east and north of terminal moraines of presumed Preboreal age was deglaciated by 8800 years B.P. This was contemporaneous with the deglaciation of Hardangervidda (Moe 1977). It is presumed that deglaciation of other mountain areas in southern Norway occurred basically at the same time as in the investigated area or 100-200 years later.

The results of the radiocarbon determinations at the inland valley of Setesdalen indicate deglaciation at about the same time as in the high mountain area. This indicates that the final deglaciation of southern Norway occurred by 8800 years B.P. or 100-200 years later.

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