

Studies in the vegetational history of North Iceland.

A radiocarbon-dated pollen diagram from Flateyjdalur

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ABSTRACT

A pollen diagram is presented from the lowest 110 cm of a 560 cm core from the mire Krosshólsmýri in Flateyjdalur. Two radiocarbon dates are used to estimate the sedimentation rate and to interpolate/extrapolate ages for events in the pollen diagram. These are 9650 and 8740 B.P. The pollen diagram represents some 2500 ¹⁴C-years, including the Late Preboreal, Boreal and Early Atlantic Chronozones and records the first stages in the local vegetational history after the deglaciation in early Preboreal.

The first phase recorded in the vegetational development is a *Salix-Ericales-herb tundra*, followed by a *Betula-Juniperus-herb tundra*. After some retreat of the spreading *Betula* woodland in the Early Atlantic Chronozone, the valley seems to become occupied by a *Betula forest tundra* about 7000 B.P.

INTRODUCTION

Flateyjdalur (dalur = valley) is located on Flateyjarskagi (skagi = peninsula) between the fjords of Eyjafjörður and Skjálfandi in central North Iceland (Fig. 1). Morphologically it is an earlier northward prolongation of Fnjóskadalur, but is now separated from it by the 200 m high threshold named Flateyjdaldsheiði (Norðdahl, 1979). The highest mountains on Flateyjarskagi reach some 1200 m, but on the average they are 700–900 m a.s.l. dissected by two main valleys, one of them being Flateyjdalur, and several tributaries.

Today the landscape of Flateyjdalur is characterized by dwarf shrub heath, birch copses and sedge

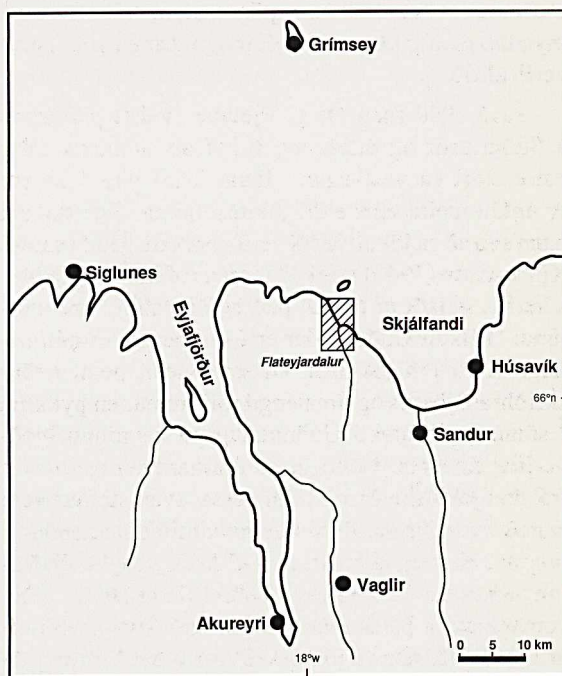


Figure 1. Map of central North Iceland. Shaded area is covered by Fig. 2. Black dots are weather stations given in Table I. — Flateyjdalur og nágrenni. Jarðfræðikortið á mynd 2 er af skyggða svæðinu. Veðurstöðvar, sem taldar eru upp í töflu I, eru sýndar með svörtum punktum.

Table I. Climatic parameters for some meteorological stations in North Iceland (Einarsson 1976). — *Veðurfarsþættir á nokkrum veðurstöðvum nyrðra.*

Station	Mean temperature °C			Mean precipit. in mm 1931–1960 ^a
	January	July	year	
Siglunes	−0,6	9,0	3,7	629
Akureyri	−1,5	10,9	3,9	474
Grimsey	−0,5	8,1	3,1	678
Vaglir	−3,0	10,1	2,6	658
Sandur	−2,3	10,0	3,1	486
Húsavík	−1,2	10,2	3,9	531

^aDays with precipitation >0.1mm were 139 at Akureyri and 137 at Húsavík. Mean number of days with frost during 1951–1960 was 151 for Akureyri.

mires (Hallgrímsson, 1976). Sparsely vegetated alluvial fans and talus slopes are abundant. This remote valley was still inhabited in the fifties, by farmers keeping sheep, horses and a few milk-cows (Sigurðsson, 1954). The vegetation of the valley is still utilized by neighbouring counties for sheep's summer-grazing. The climate is rather cool. Winters are harsh with heavy snow cover and long duration. Summers can be relatively warm, with some days having temperatures above 20 °C, but they are short, an estimate gives about 90 days with mean temperature above 7,5 °C (cf. Ragnarsson, 1977). According to the isotherm maps given in Einarsson (1976) for January and July 1931–1960, at Krosshólmýri, Flateyjaralur, the mean temperature is on the one hand between −2 and zero °C and on the other hand from 8 to 10 °C. The mean annual precipitation for this normal period is between 600 and 800 mm (Sigfúsdóttir in Einarsson 1976, p. 97, Fig. 40). Climatic parameters for the nearest meteorological stations are given in Table I (for location see Fig. 1).

Flateyjaralur is situated in one of the areas Steindórsson (1937; 1962) assumes to be a refugium, where plants survived the last glaciation. Geomorphological studies (Thorarinsson, 1937; Einarsson, 1959; Norðdahl, 1979; 1983; 1991) indicate abundance of nunataks at the maximum extent of the Weichselian

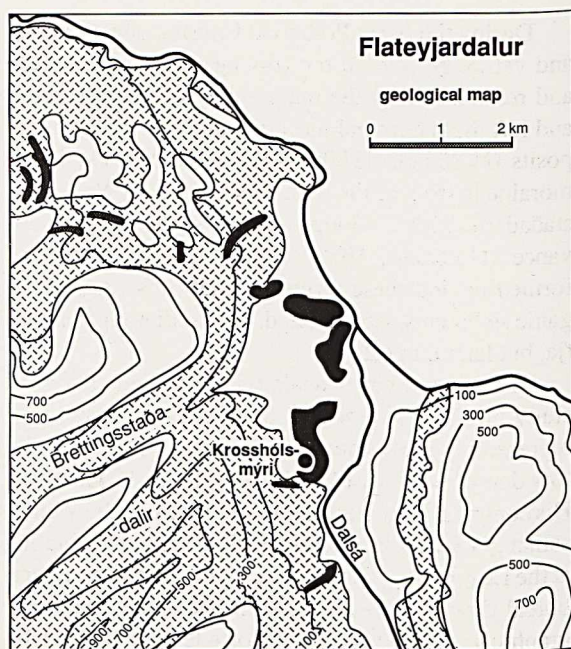


Figure 2. A simplified geological map of Flateyjaralur and location of the sediment core investigated by means of pollen analysis (black dot). Shaded area; till; black areas are moraine ridges. (Modified from Norðdahl 1979). — *Jarðfræðikort af Flateyjaralur. Borstaðurinn í Krosshólmýri er merktur með svörtum punkti, skyggð svæði sýna jökulruðning og svört jökulgarða.*

glaciation. Also considerable land areas, today below sea level, were ice-free as the sea level was lower than today in times of glacier advances during the Late Weichselian Substage (Einarsson, 1961; 1963, Norðdahl, 1979).

The deglaciation history of the area has been described by Norðdahl (1979; 1983; 1990). According to him Flateyjaralur became ice-free during the Late Weichselian Substage as the ice-dammed lakes in Fnjóskadalur had an outlet north across Flateyjaralshéiði and through Flateyjaralur to the sea in the bay of Skjálfandi.

During the Early Preboreal Chronozone mountain and valley glaciers in the tributary valleys advanced and reached out to the main valley of Flateyjardalur and left there terminal moraines and fluvioglacial deposits (Norðdahl, 1990; 1991). One of these is the moraine in front of the twin tributary valley Brettingsstaðadalir, which belongs to the Langhóll glacier advance (Norðdahl, 1979; 1991). In the basin that formed behind these terminal landforms (Fig. 2) organic sediments accumulated, at first diatom-rich gyttja, but later on peat.

The present paper deals with a pollen analytical study on the lower part of these organic strata, thus representing a continuation of the environmental history described by Norðdahl (1979; 1983; 1990; 1991). His contribution includes investigations on the Weichselian glaciation in central North Iceland, terminating at the Langhóll-Ljósavatn glacier advance in early Preboreal time in the Fnjóskadalur Sequence, the stratigraphical column for central North Iceland (Norðdahl, 1983; 1990). The present study is dealing with the discontinuous vegetation cover some 9650 B.P. up to the first signs of a woodland formation 7000 B.P.

FIELD WORK AND METHODS

Coring in Krosshólmýri, a former small lake, but now overgrown by mire vegetation, was carried out by Hreggviður Norðdahl and Guðmundur Hjaltason in summer 1977. The geographical location is 66°05'55''N and 17°54'20''W, altitude approximately 25 m a.s.l. (Fig. 2). The coring was done with a peat sampler of a Russian type of 5 cm diameter and 50 cm length (*cf.* Jowsey, 1966).

The sediment description and subsampling for pollen and radiocarbon analysis was done in the laboratory and only for that part of the sequence which was taken for analysis. The characterization system of Troels-Smith (1955) was used.

Another sediment sequence from an earlier coring at almost the same locality was described in the field and subsequently published in Norðdahl 1979 (p. 10, site 2). The lowest part of that sequence was ignited. The loss on ignition was about 3% in the deepest sample rising up to 20–26% 50 cm higher up in the core (Norðdahl, pers. comm.).

POLLEN ANALYSIS

Quantitative pollen samples were processed by standard methods, including warm HF treatment (e.g. alternative A in Berglund and Ralska-Jasiewiczowa, 1986). Stockmarr's *Lycopodium* spore tablets were used to determine the pollen concentration (Stockmarr, 1971). The dosage was one tablet (12500 ± 100 spores) per cm^3 of fresh sediment. Whole slides were counted, to avoid the effects of any nonrandom distribution of pollen and spores on the slide. Two to four slides had to be counted to get reliable number of pollen.

The total number of terrestrial pollen grains counted and included in $\sum A$ ranges from 160 to 500 per sample. The pollen-percentage diagram is constructed using $\sum A$ for the main part but $\sum A + \sum B \dots K$ is used for the taxa excluded from $\sum A$, i.e. spores of pteridiophytes [B] and *Sphagnum* [E], pollen of aquatic plants [C], telmatophytes [D], unidentified and exotic plants [G] (i.e. trees, which have not lived in Iceland since the Tertiary and or Lower Quaternary Period). Counts of the algae *Pediastrum* [K] are given in the same way. The PC program POLLDATA by H. J. B. Birks (1989) of the Botanical Institute in Bergen was used for construction of the diagrams.

¹⁴C DATINGS

Five cm of the diatom-gyttja were taken from the core at two levels, 555–560 and 522,5–527,5 cm for radiocarbon dating. These two samples were submitted to the Radiocarbon Dating Laboratory at the Department of Quaternary Geology in Lund in Sweden (Norðdahl, 1979). One of the samples was treated with HCl. Both had to be diluted with CO₂ from anthracite to allow dating. The $\delta^{13}\text{C}$ value of the samples was measured and a normalization due to isotopic fractionation performed. The calculation of the radiocarbon age is based on a half-life of 5568 years for ¹⁴C. The results are given as the number of years before 1950 and are not corrected for the secular ¹⁴C/¹²C variations. The dates are published in the official dating list of the laboratory (Hakansson, 1979; 1983).

When comparing the present results with datings from the period before 1970, some precaution must be

shown. At that time little attention was given to the value of $\delta^{13}\text{C}$. Because of this most datings performed in the fifties and sixties are strictly not comparable to later ones. According to Olsson (1986) an age correction is to be added to a result not normalized for the $\delta^{13}\text{C}$ deviation from -25 per mil; for a single peat sample this can vary from -145 to 95 years (*op.cit.* Table 14.1) The dates assumed to lack the $\delta^{13}\text{C}$ adjustment are indicated by an asterisk (*).

BIOMETRY OF BETULA POLLEN

All *Betula* pollen were measured with the aid of a micrometer having one ocular line of $2,1\mu\text{m}$. A size frequency diagram was constructed for each LPAZ, except for the uppermost one, where the same was done for each sample. The resulting data may later be subjected to further statistical analysis, as e.g. done by Prentice (1981). This must however wait, as the necessary reference data on the size distribution of recent *Betula* pollen in Iceland is lacking.

SEDIMENT STRATIGRAPHY AND RADIOCARBON ANALYSIS

The core from Krosshólmýri taken for radiocarbon dating and pollen analysis is 560 cm long, representing the last 9650 ^{14}C years. The lowest 110 cm is lake sediment, which could be separated into five strata (Table II). In this lowest part of the core a total of four tephra layers were visible (Table III). This part of the core was represented by three core segments, 560 – 510 , 550 – 500 and 500 – 450 cm below the mire surface.

This lowest part of the Krosshólmýri core goes too far back in time (*cf.* radiocarbon dates below) for making use of the tephrochronology (Einarsson, 1986), as the tephrochronology available for North Iceland does not go further back than the tephra layer Hekla-5 (H_5) with an age of about 6100 B.P. (Vilmundardóttir and Kaldal, 1982; *cf.* also the older datings of H_5 in Þórarinnsson 1964, made before 1960). Therefore the only use of the Krosshólmýri tephra stratigraphy (Table III) is for correlating purposes for the time being.

Two radiocarbon dates have been obtained from

Table II. Lithostratigraphy for the sediment at Krosshólmýri — *Jarðlagaskipan neðst í Krosshólmýri*

Depth below surface, cm	Number of layer	Description of sediments
(450)–485	5	Detritus, greyish yellowbrown. Composition: $\text{Ld}^2_3, \text{Dg}1, \text{Ag}+$. Lower boundary diffuse.
485–524	4	Detritus, greyish yellow, slightly firmer than layer 3. Composition: $\text{Ld}^2_3, \text{Dg}1, \text{Ag}+$. Lower boundary sharp.
524–531	3	Detritus, greyish brown, lighter than layer 2, rich in diatoms. Composition: $\text{Ld}^2_2, \text{Lso}1, \text{Dg}1, \text{Ag}+$. Lower boundary sharp.
531–552	2	Detritus, greyish brown with bands of slightly different colour, rich in diatoms. Composition: $\text{Lso}2, \text{Ld}^2_1, \text{Dg}1, \text{Ag}+$. Lower boundary sharp.
552–560	1	Detritus, greyish white, rich in diatoms. Showing fine lamellae. Composition: $\text{Lso}3, \text{Ag}1, \text{Ld}^0+$, $\text{Dg}+$. Base not seen.

Table III. Tephra stratigraphy at Krosshólmýri. — *Gjóskulög neðst í Krosshólmýrarkjarnanum.*

Depth below surface, cm	Thickn. in mm	Description of tephra	Abb.	Est. age years BP
497,8–499,7	19	Black fine-sandy tephra	S3	8060
509,5–510,5	10	Black tephra	S2	8350
548	-	Light coloured, discontinuous tephra horizon	L1	9400
553,4–554	6	Black fine-sandy tephra	S1	9550

the core (Table IV). The date Lu-1433 is the oldest hitherto obtained for an organic sediment of Holocene age in Iceland. It postdates the last glacier advance in central North Iceland, and may be considered as a minimum age for the glacier retreat in the Preboreal Chronozone (Norðdahl, 1979; 1991).

Assuming the same sedimentation rate of $0,035$

Table IV. Radiocarbon dates from Flateyjardalur — Geislakolsaldursgreiningar frá Flateyjardal.

Lab. no.	Depth, cm	¹⁴ C-age BP.	δ ¹³ C (×0.1%)	Pretreatm.
Lu-1996	522,5–527,5	8740 ± 95	-18.8	HCl (mildly)
Lu-1433	555–560	9650 ± 120	-17.3	none

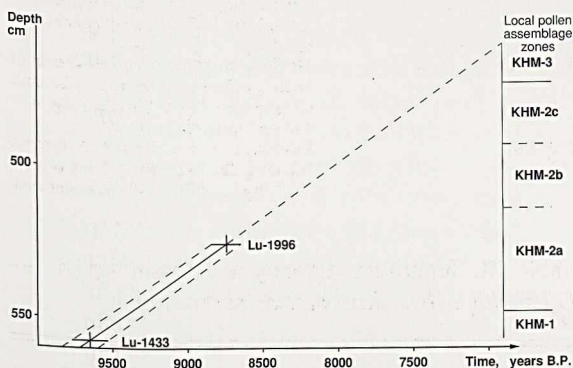


Figure 3. Plot of sediment accumulation rate. Depth of sediment used for each radiocarbon sample and one standard deviation shown by vertical and horizontal lines respectively. Fully drawn line is based on interpolation; stippled segment on extrapolation. Tephra thickness is excluded in the sediment column, as it is considered an instantaneous thickening event. — Grafið sýnir setþykkun í fyrrum stöðuvatni, þar sem Krosshólmýri er nú. Grafið er byggt á geislakolsaldursgreiningum. Þykkt hvers sýnis er sýnd með lóðréttum línunum, láréttar línur eru staðalfrávik geislakolsmælinganna. Reiknaður aldur á atburðum í gróðurfarssögunni er byggður á þessu grafi.

cm/¹⁴C-year, before and after Lu-1996, gives 6900 B.P. for the youngest pollen sample analysed. According to the two dates the deposition time is 28,5 (1 σ range 22–35) ¹⁴C-years per cm, i.e. the deposition rate is 3,5 (1 σ range 2,9–4,5) cm per 100 ¹⁴C-years,

which is similar to that in the ¹⁴C-dated lake sediment in the adjoining Skagafjörður district (the author's unpublished data from lake Vatnskotsvatn, for location see Fig. 6). In Fig. 3 a sediment accumulation rate curve (time/depth curve) is given for Krosshólmýri, based on the two radiocarbon dates available.

POLLEN AND SPORE STRATIGRAPHY

Twenty three pollen spectra represent the pollen diagram from Krosshólmýri in Fig. 4. This comprises the lowest part of the Krosshólmýri core, or the sequence between 450 cm and 560 cm below mire surface. For ease of description, discussion and comparison of the diagram, the diagram has been divided into Local Pollen Assemblage Zones (LPAZ), based upon the fossil pollen and spore content. These are given an abbreviation of three letters in the site name, **Krosshólmýri** — **KHM** —, followed by an Arabic numeral, numbered from the oldest to the youngest.

KHM 1 (547,5–560 cm). Pollen samples number 1–4. This zone is characterized by high values of *Salix* pollen, attaining 47 % in sample 1. The Cruciferae and *Ranunculus* pollen are high too, reaching 20 % and 14 % respectively at their maxima within the zone. *Empetrum cf. E. nigrum* pollen reach their highest values in this zone, as do the Ericaceae undiff. pollen. Cyperaceae pollen values rise throughout the zone to about 24 %. The spores of *Lycopodium annotinum*, *L. alpinum* and *L. selago* are all fairly well represented in the zone. *Betula* pollen values are low, just reaching 4 %.

The aquatic vegetation is sparsely represented by pollen of *Myriophyllum alterniflorum*, *Hippuris vulgaris* and the group *Eu-Potamogeton* type. A single spore of *Isoetes echinospora* appeared in only one sample.

The zone is named the *Salix* - *Ericales* - Cruciferae - *Ranunculus* - *Lycopodium* Local Pollen Assemblage Zone.

KHM 2 (469,5–547,5 cm). Pollen samples number 5–20. This zone is characterized by an continuous *Juniperus* curve (6,6–26,4 %), showing two maxima in the subzones KHM 2a and KHM 2c. *Betula* pollen

values (7-36 %) are steadily increasing within the first two subzones, decreasing to a distinct minimum in subzone KHM 2c. Both Gramineae and Cyperaceae pollen are well represented throughout the zone. Three subzones are recognized, KHM 2a, KHM 2b and KHM 2c.

KHM 2a (513,5-547,5 cm). Pollen samples number 5-11. The subzone is characterized by steadily increasing *Juniperus* pollen values from 7 to 26 %. *Betula* pollen values act in the same way. *Salix* and Cyperaceae pollen values are decreasing. Gramineae pollen are well represented attaining values of 28 %. The herb pollen of *Potentilla*, *Galium* and Cruciferae have a sparse but continuous representation. Other herb pollen have both sparse and discontinuous representation. *Lycopodium annotinum* spore frequencies vary between 4 and 11 %.

In this subzone *Eu-Potamogeton* pollen type has a maximum attaining values of 40 %. Otherwise the aquatics have the same composition as in KHM-1.

The subzone is named the *Juniperus - Betula - Salix - Cyperaceae* Local Pollen Assemblage Subzone.

KHM 2b (489,5-513,5 cm). Pollen samples number 12-16. This subzone is characterized by the first *Betula* maximum of 36 %. The pollen values of *Juniperus* are between 4 and 9 %, which is a minimum for the zone. The pollen frequency of *Thalictrum alpinum* rises at the beginning of the subzone to 4 % and is rather constant between 2 and 4 % within the subzone. Both Polypodiaceae undiff. and *Dryopteris linneana* (*Gymnocarpium dryopteris*) have a constant representation of 2-5 % throughout the subzone.

In the zone spores of *Isoetes echinospora* appear again, but are very sparse like all the other aquatic pollen types.

The subzone is named the *Betula - Gramineae - Thalictrum alpinum - Polypodiaceae* undiff. Local Pollen Assemblage Subzone.

KHM 2c (469,5-489,5 cm). Pollen samples number 17-20. This subzone is characterized by the second *Juniperus* maximum at the beginning of the subzone, but *Juniperus* pollen values are decreasing throughout the zone. *Salix* pollen values are still decreasing from about 6 % to below 1 %. *Betula* has a minimum value of 10 % in the middle of the subzone.

Cyperaceae gain a maximum value of 47 %. *Galium*, *Thalictrum alpinum*, *Rumex* type and *Potentilla* are the herb pollen showing sparse but a continuous representation. The same is the case for Polypodiaceae undiff. spore frequencies, while *Dryopteris linneana* has somewhat greater values of about 4 %.

Isoetes echinospora shows a distinct maximum within the zone as does *Eu-Potamogeton* type.

The subzone is named the *Juniperus - Cyperaceae - Rumex* type Local Pollen Assemblage Subzone.

KHM 3 (457-469,5 cm). Pollen samples number 21-23. This zone is characterized by increasing *Betula* pollen values, exceeding 50 % at the upper limit of the zone. *Juniperus* pollen values are decreasing, as are Cyperaceae. Among the herbs Cyperaceae and Gramineae are most abundant but *Rumex* type, *Potentilla*, *Ranunculus*, *Thalictrum alpinum* and Compositae Liguliflorae are constantly but sparsely represented. All the Pteridiophytes except *Lycopodium selago* are represented as in the preceding zones.

Of the aquatics *Myriophyllum alterniflorum*, *Eu-Potamogeton* type, *Hippuris vulgaris* and *Isoetes echinospora* are all represented.

The zone is named the *Betula* Local Pollen Assemblage Zone.

SIZE MEASUREMENTS OF SUBFOSSIL BETULA POLLEN

According to Stefánsson's Flora (1948) *Betula* is represented in Iceland by three indigenous species and one hybrid: *Betula pubescens* Ehrh., *B. coriacea* Gunnarss., *B. nana* L. and the hybrid *B. nana* L. x *pubescens* Ehrh. Löve (1945) mentions *B. callosa* Notö too, but assumes that *B. tortuosa* Led. (syn. *B. pubescens*) is the most abundant tree or shrub. Bjarnason (1945) suggested some of the *Betula* in Northwest Iceland to be of the western type *B. glandulosa*, having immigrated from Greenland. A reconnaissance on the Icelandic birch woodland led to some finds of species having the character of *B. verrucosa*. This is assumed to be a later immigrant to the Icelandic flora (Sigurðsson, 1977).

The problem of separating pollen of tree birch (*B. pubescens* type) from the ecologically different

KROSSHÓLSMÝRI-FLATEYJARDALUR

analyst: Margrét Hallsdóttir

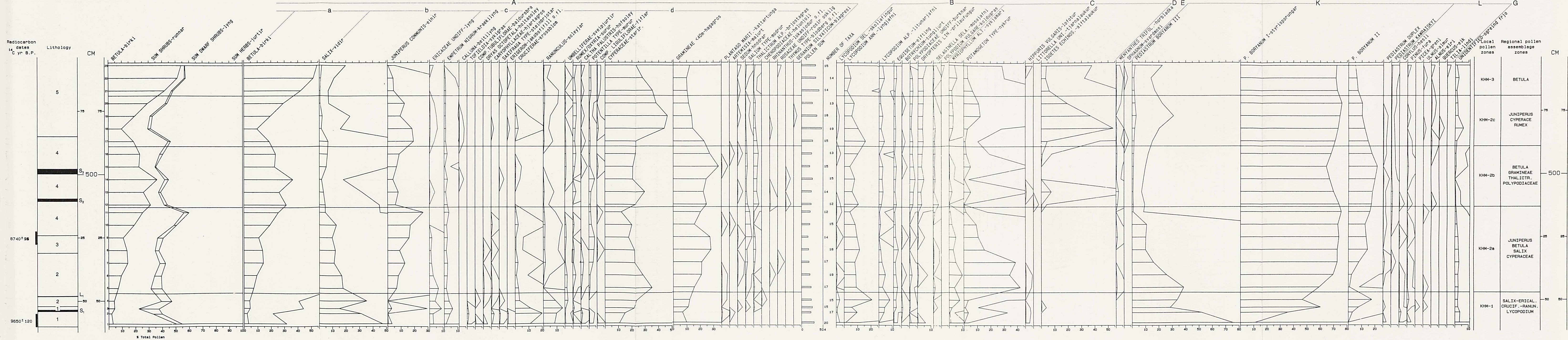


Figure 4. Pollen percentage diagram for Krosshólsmýri, Flateyjarðalur, North Iceland.
Mynd 4. Frjólurir Krosshólsmýrarsniðsins á Flateyjarðal.

(dwarf-)shrub *B. nana* has been met in two ways. Firstly by measuring the largest diameter of all unbroken *Betula* pollen grains (cf. Usinger, 1978) and secondly by taking into account the morphological characteristics of the *Betula* pollen grains (cf. Berglund, 1966). The latter method was applied to samples 11, 12, 14, 16–18, 20 and 21. Pollen of *Betula nana* type do not exceed 2,3 % of the terrestrial pollen sum in these samples. In sample 6 the first pollen grain appeared which without doubt can be referred to as of a tree birch type.

The results of the size measurements are given in absolute number of pollen per score (size class) in a size frequency diagram in Fig. 5. The scores range from 8 to 17 ocular lines corresponding to 16,8 μm –35,7 μm . Size frequency curves were drawn for each of the uppermost three samples separately, but below sample 21 they were grouped in accordance with the Local Pollen Assemblage Zones and Subzones.

Investigations on size distribution of recent *Betula* pollen grains from Iceland have so far not been carried out. Such reference material is needed for a more comprehensive statistical analysis, cf. Prentice (1981). Therefore the curves presented from Flateyjardalur tell us little more than that there has been a succession, from a vegetation assemblage producing small and few pollen grains, probably *B. nana*, to an assemblage producing both larger and more numerous pollen grains, most likely an assemblage with *B. pubescens*. Investigations outside Iceland have shown that pollen of tree birch is larger than that of *B. nana* (cf. Berglund and Digerfeldt 1970). For British *Betula* species Birks (1968) gives the size range 14,3–23,4 μm for *B. nana* and 18,2–28,6 μm for *B. pubescens*.

It is obvious that in the first group in Flateyjardalur there is not the same population as in the uppermost three samples. The distribution pattern of this group is rather weak, probably due to the few grains present in the lowest LPAZ. None of the following six curves are showing any tendency of bimodal distribution, as would be the case if both *B. nana* and *B. tortuosa* were represented (Birks 1968). On the other hand the size distribution of the next subzone, KHM-2a (Fig. 5), shows a positively skewed distribution, indicating an assemblage where *B. nana* is the most

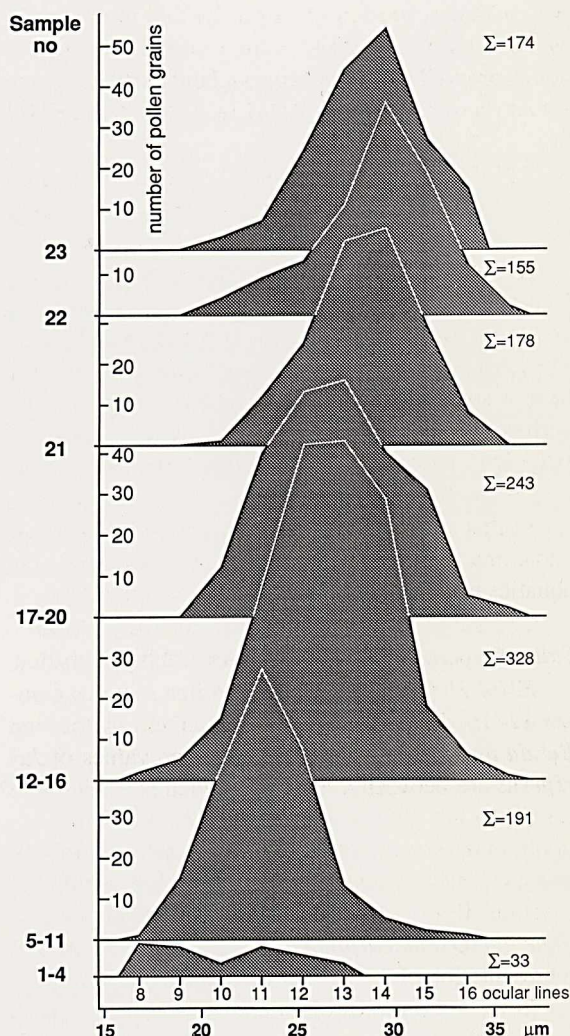


Figure 5. Size frequency plots for *Betula* pollen grains in the Krosshólmseyri sediment sequence. — *Stærðardreifing Betula frjókorna (birki/fjalldrapi) í Krosshólmseyrarsniðinu.*

prominent species of the two in the vegetation, contrary to the three uppermost samples showing a negatively skewed distribution, indicating an assemblage of both *B. nana* and the tree birch type *B. pubescens* with the latter type more prominent.

INTERPRETATION OF THE POLLEN DIAGRAM

Before any attempt is made to interpret the pollen analytical data, one aspect of the question about the origin of the Icelandic flora shall be briefly mentioned. At the time of retreat of the glacier from the Krosshólsmýri site, Flateyjardalur was already ice-free since several millennia. Thus the conditions for an establishment of a vegetation cover in the former bed of Brettingstaðadalir- glacier were not the same as for the pioneer vegetation proper, recovering several millennia earlier, i.e. after the long duration of the Weichselian glaciation. Because of this difference, the very first signs of a pioneer vegetation, probably some kind of herb communities (cf. Fredskild 1973), is not to be expected in the deepest part of the Krosshólsmýri sediment core. In Flateyjardalur the floral elements already had got several millennia to immigrate and establish themselves, perhaps from a nearby refugium (Steindórsson, 1962 cf. Norðdahl 1991), perhaps from some distant regions in Iceland, or even from remote continents. A difference of this kind in origin and or immigration routes is impossible to distinguish or infer about from the Krosshólsmýri core alone. Therefore this investigation can not answer questions about the origin of the Icelandic flora, which might seem controversial, as this is the oldest organic sediment of Holocene age in Iceland hitherto radiocarbon dated, as well as containing evidence about a local vegetational succession.

KHM 1, Salix-Ericales-Cruciferae-Ranunculus-Lycopodium Local Pollen Assemblage Zone. Estimated age ca 9700–9400 B.P. *Salix* is already flourishing and so is *Empetrum nigrum* and Ericaceae undiff. too. The high *Salix* percentages may be attributed to scrub, snowbed communities, or both (Faegri 1953). This zone is showing the most diversity in pollen taxa, probably indicating little competition and thus a variety of plant species, which later on were not able to share place and live together as the vegetation cover became more dense. *Tofieldia* and Chenopodiaceae appear in this zone only, *Plantago maritima*, *Erigeron*, and *Saxifraga* type are all represented here, but have a sparse occurrence later on. Otherwise *Ranunculus*

and Cruciferae are the best represented herb group. A very local origin of those groups is not to be precluded, as both do include the limnic species, i.e. *Ranunculus reptans*, *R. hyperboreus*, *R. confervoides* and *Subularia aquatica*.

The few *Betula* pollen grains in this zone are all rather small (Fig. 5), thus most probably derived from *B. nana*. As the (dwarf-) shrub type of *Betula* is known for dispersing its pollen badly and a percentage of 2–6 may indicate local stands (cf. Andrews *et al.*, 1980) it might have been locally present.

In the lake *Myriophyllum alterniflorum*, *Hippuris vulgaris* and some species of *Eu-Potamogeton* were flowering and *Isoetes echinospora* may have been present. However as only one spore was found in sample 3 and *Isoetes* does not reappear until in sample 12 a contamination can not be precluded. The green algae *Pediastrum boryanum* flourish, most certainly there are several varieties, also *P. duplex* has arrived to the lake.

A radiocarbon date at the beginning of the sequence (Lu-1433), and an interpolation of the two dates from the sediment core, place this first Local Pollen Assemblage Zone at the end of the Early Preboreal and the beginning of the Late Preboreal Chronozones (*sensu* Mangerud *et al.*, 1974).

KHM 2a, Juniperus-Betula-Salix-Cyperaceae Local Pollen Assemblage Subzone. Estimated age ca 9400–8400 B.P. *Juniperus* and *Betula* are both expanding. The size frequency diagram (Fig. 5) shows a positively skewed distribution, suggesting that tree birch arrived in this subzone, maybe not until the latter half of the subzone. Towards the end of the subzone a *Betula* pollen percentage of 25 indicates that some birch copses have developed, although the dwarf birch *B. nana* is locally present too. As mentioned before the first pollen of *Betula pubescens* type was found in sample 6. However until more work is done, especially on macrofossils so as to preclude effects of long distance transport of pollen (cf. Fredskild 1973), the precise age of tree birch in the flora of Flateyjardalur is not known. *Lycopodium annotinum* is still the best represented of the Lycopodiaceae and of the pteridophytes as a whole, suggesting widespread heaths. As yet the vegetation has the character of a dwarf shrub

tundra, as indicated by the mean pollen influx ranging between 74 and 106 pollen per cm² and ¹⁴C-year (cf. Birks and Birks, 1980).

At the beginning of this zone *Eu-Potamogeton* has a breakthrough, flourishing intensively. *Pediastrum kawraiskyi* is new amongst the green algae. Otherwise the lake vegetation is unchanged.

By means of interpolation and extrapolation of the sedimentation rate, based on the two radiocarbon dates available, the duration of this subzone is estimated to be about one millennium, spanning the main part of the Late Preboreal and the Early Boreal Chronozones.

KHM 2b, Betula-Gramineae-Thalictrum alpinum-Polypodiaceae undiff. Local Pollen Assemblage Subzone. Estimated age ca 8400–7850 B.P. In this subzone both the shrubs of *Salix* and *Juniperus* seem to recede for a while to the spreading birch copses, which now form a shelter for *Dryopteris linneana* (*Gymnocarpium dryopteris*) and other Polypodiaceae species. Herbs and Graminids are still frequent, indicating an open and mosaic character of the vegetation with peatlands, grass heaths and birch copses.

The lake vegetation seems to be suffering, as the pollen and spore production is minimal, but the green algae show small changes. *Isoetes echinospora* reappears.

The sedimentation rate places this subzone roughly in the Late Boreal Chronozone.

KHM 2c, Juniperus-Cyperaceae-Rumex type Local Pollen Assemblage Subzone. Estimated age ca 7850–7250 B.P. The shrub vegetation, particularly *Juniperus*, recovers some of its former place. *Juniperus* is generally assumed to be a poor ecological indicator, having a wide ecological amplitude. However the best climatic conditions for juniper are offered by humid, maritime climate (cf. discussion in Vasari and Vasari, 1968). According to the increasing values of Cyperaceae the peatland seems to expand somewhat, which suggests more oceanic climate, wetter and or cooler with less evaporation. Maybe the relatively rich soils of the eutrophic stage of the peat formation favoured this vigorous growth of *Juniperus*. Later on as the peatland became more acid and reached the mesotrophic stage, *Betula* was able to displace *Juniperus*, at least on the more drier parts.

In the lake *Isoetes echinospora* flourishes and both *Myriophyllum alterniflorum* and *Eu-Potamogeton* are gaining. As *Isoetes echinospora* prefers a sandy bottom, this might indicate some submergence of the former littoral zone of the lake. In the sediment core there is no evidence of increased input of minerogenic material at this level and therefore soil erosion can hardly be the reason for this *Isoetes* expansion (cf. Vuorela, 1980), yet further analyses on the sediment are needed to preclude this.

The sedimentation rate (Fig. 3) places this subzone within the Early Atlantic Chronozone.

KHM 3, Betula undiff. Local Pollen Assemblage Zone. Estimated age ca 7250–6900 B.P. In this zone birch scrubs/trees seem to become the dominant component of the tall and wooded elements of the vegetation, at least *Betula pubescens* type pollen has replaced both the shrub and the dwarf shrub pollen at Krosshólmýri. The AP/NAP ratio exceeds 1 for the first time, which according to investigations on recent material in Scotland (Birks, 1973) may indicate birch woodland. By contradiction the pollen influx values of ca 400 pollen grains per cm² and ¹⁴C-year in this zone indicate that tundra existed in Flateyjardalur at this time (cf. table I in Hicks, 1986). At this point it may be useful to stress that the pollen influx values for Krosshólmýri are based on extrapolations of the sedimentation rate, which may be unreliable. Secondly the pollen influx values used for comparison are derived from continental sites, i.e. from Canada and northern Scandinavia (Birks and Birks, 1980; Hicks, 1986), with widespread backland of boreal forests. Therefore these values might not be suitable for an ocean island far from any great pollen producers, as the conifer forests. Also evidence from Greenland (Fredskild, 1973; 1983) shows a marked difference between the coast and inland regarding pollen influx. At this time, i.e. about 7000 B.P., the seashore was near Krosshólmýri, as it still is today (Fig. 2). Coastal influence could explain the low pollen influx values for a birch woodland, suggested by the percentage values of *Betula* pollen grains. Widespread bryophyte and or lichen communities, prominent in the Icelandic landscape today, would also lead to low pollen influx values.

Herbs and Graminids have frequencies about 40 %, suggesting an open character of the woodland, or some mosaic of woodland, heath and most probably a widespread peatland. The peatland seems to be receding, as may be inferred from the declining Cyperaceae values. This suggests a drier and maybe a warmer climate.

In the lake the three taxa, *Myriophyllum alterniflorum*, *Eu-Potamogeton* and *Isoetes echinospora*, seem to become stabilized. The green algae production is at the level of about 1500 coenobia per cm² per ¹⁴C-year, which judging from Greenland data means that the lake has become poor (Fredskild, 1983).

The sedimentation rate places this subzone at the shift of the Early and the Middle Atlantic Chronozone.

COMPARISON WITH OTHER SITES IN NORTH ICELAND

The present knowledge of the pollen stratigraphy and vegetation history of North Iceland (e.g. Einarsson 1985) is largely based on the pioneer work by Einarsson (1961), where six pollen diagrams from peat sections (at Torfalækur, Varmahlíð, Sólheimagerði and Moldhaugar) were published. This was supported by one radiocarbon date and tephrochronology, the latter making all stratigraphical correlation in Iceland fairly easy. Two of these sections (Sólheimagerði and Moldhaugar, Fig. 6) go farther back in time than the tephra layer H₅ dated at ca 6100 B.P. (Vilmundardóttir and Kaldal, 1982). Of special interest for this study are the three pollen diagrams from Moldhaugar showing the first *Betula* maximum in Einarsson's pollen zone A, comparable with a part of the Local Pollen Assemblage Zone KHM-2. Pollen zone A at Moldhaugar predates the radiocarbon age of 7920±170* B.P. (Heidelberg) (Einarsson, 1961). The age of the upper zone boundary of KHM-2b, where the first *Betula* maximum was reached in Krosshólmýri, is estimated 7850 B.P. Thus the general chronological trend is in a fairly good agreement.

In Þórarinnsson's pollen diagram from Naustamýri, farther south in Eyjafjörður (Fig. 6), one *Betula* maximum is seen below H₅, this is assumed to represent dwarf-birch heath (Þórarinnsson, 1955).

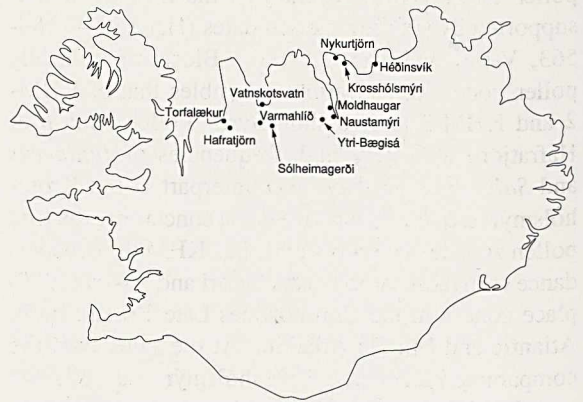


Figure 6. Sites in North Iceland investigated by means of pollen analysis. Torfalækur (peat, Einarsson, 1961); Hafratjörn (gyttja, Vasari 1972; 1973, Vasari and Vasari, 1990); Varmahlíð (peat, Einarsson, 1961); Vatskotsvatn (gyttja, Hallsdóttir, 1979); Sólheimagerði (peat, Einarsson, 1961); Ytri-Bægisá (peat, Bartley, 1973); Moldhaugar (peat, Einarsson 1961); Naustamýri (peat, Þórarinnsson, 1955); Nykurtjörn (gyttja, unpubl.); Krosshólmýri; Hédinsvík (peat, Straka, 1956). — *Staðir á Norðurlandi, þar sem frjógreind hafa verið lífræn jarðlög (ýmist mór eða vatnaset).*

From Ytri-Bægisá Bartley (1973) published a pollen diagram from a peat section spanning the last 8850 ± 120* (NPL-160) B.P. Chronologically the deepest part of the peat section at Ytri-Bægisá corresponds to the upper part of the Krosshólmýri sediment core dealt with here. Biostratigraphically these two sections are fairly easy to compare, assuming YB-1 with high values of *Juniperus* pollen to be equivalent to KHM-2 and YB-2a corresponding to KHM-3. The upper zone boundary of YB-2a is dated to 6840 ± 95* B.P. (Bartley, 1973).

Still farther west Vasari (1972; 1973) and Vasari and Vasari, (1990) have published pollen and macrofossil diagrams from Hafratjörn (Fig. 6). Besides both

pollen and macrofossil analysis the investigation is supported by six radiocarbon dates (Hel-558 — Hel-563, Vasari and Vasari 1990). Biostratigraphically pollen zone *c* at Hafratjörn resembles that of KHM-2 and KHM-3 at Krosshólmsmýri. Pollen zone *b* at Hafratjörn with very high frequencies of *Juniperus* and *Salix* does not have a counterpart at the Krosshólmsmýri sequence, and vice versa concerning the first pollen zone at Krosshólmsmýri, i.e. KHM-1. In accordance with radiocarbon dates Vasari and Vasari (1990) place zone *c* in the Chronozones Late Boreal, Early Atlantic and Middle Atlantic. At the same time the comparable biozones at Krosshólmsmýri, i.e. KHM-2 and KHM-3, have a somewhat longer duration backwards in time, spanning a part of the Late Preboreal, Boreal, Early Atlantic and the beginning of the Middle Atlantic Chronozone.

At Hafratjörn the first *Betula* maximum is dated to 8040 ± 150 B.P., which is consistent with KHM-2b at Krosshólmsmýri. *Betula alba* fruits appear in the sediment for the first time somewhat later, yet still in the Early Atlantic Chronozone (Vasari and Vasari, 1990). Thus the very first *Betula* appearance at Hafratjörn may be due to *Betula nana*, as evidenced by the macrofossils (Vasari and Vasari 1990). Yet a long distance transport can not be excluded, as at the time of the first *Betula* maximum at Hafratjörn the *Betula* pollen frequencies are already passing 50 % in Skagafjörður (the author's unpublished pollen diagram from the lake Vatnaskotsvatn, Hallsdóttir, 1979).

INFERRED CLIMATIC CHANGE IN THE EARLY ATLANTIC CHRONOZONE

Probably due to delayed immigration of *Betula pubescens* in western North Iceland, the vegetational succession of the westernmost locality Hafratjörn is standing somewhat by itself, with *Salix* and *Juniperus* being the main pollen producers at the beginning of the Late Boreal Chronozone. At the other localities *Juniperus* increases together with *Betula*, but often more rapidly (Vatnaskotsvatn and Ytri-Bægisá). *Juniperus* pollen were not yet identified at the time of analysis of the sequence at Moldhaugar, i.e. in the fifties (pers. comm. Þorleifur Einarsson; cf. Einarsson, 1961 and

Þórarinnsson 1955).

A successional pattern like this is well known from outside Iceland, e.g. in the British Isles (Pennington, 1974; Bennett, et al., 1990), where it characterizes the change from tundra to forested landscape. As the pioneer tree, the birch, immigrates, it soon shades out the light demanding juniper. This has been shown in Southwest Iceland (Vasari, 1972; 1973, Hallsdóttir, 1987) as well as in North Iceland. The latter region shows some peculiarity, as just before the disappearance of juniper something happens, which makes juniper recover its former place as the formerly expanding birch woodland contracts (LPAZ KHM-2c). As far as can be inferred from the present material, the unpublished pollen diagram from Vatnaskotsvatn (Hallsdóttir, 1979) supported by six radiocarbon datings (Hakansson, 1980), and the already published data (i.e. Moldhaugar: Einarsson, 1961; Ytri-Bægisá: Bartley, 1973; Hafratjörn: Vasari and Vasari, 1990), these changes seem to be synchronous at all the sites concerned, falling within the Early Atlantic Chronozone.

The reason for this must be looked for amongst the climatic parameters affecting the water regime of the soils occupied by birch trees and maybe the protecting snow cover in winter time. Badly drained and water soaked soils are as a habitat not suitable for birch woodland formation, but favourable for *Salix* and in certain cases for juniper too. An increase in humidity, increased precipitation and or lower temperatures, resulting in more wetness in the environment, are well known factors contributing to expansion of mires, which is consistent with the rising Cyperaceae curve at Krosshólmsmýri. Also evidence for a rising water level in the former lake Krosshólmsmýri can be inferred from the sudden expansion of *Isoetes echinospora* on the lake bottom of that time. The climatic change responsible for these changes in environmental factors may possibly be ascribed to changes in ocean currents at the north coast. Perhaps LPAZ KHM-2c denotes a period, where a branch of the Gulf Stream became stronger and reached further east along the north coast. This would result in more precipitation at the north coast, as well as higher temperatures and less snow during the winter. Wet and unstable winters

with varying snow cover are inhospitable for any tree vegetation.

CONCLUDING REMARKS

A pollen diagram for the period 9650 B.P. to 6900 B.P. at Krosshólmýri, Flateyjarðalur in central North Iceland, is presented. Three Local Pollen Assemblage Zones are described. The first one, a *Salix-Ericales*-herb assemblage, is so far unique for North Iceland. Following that there is a *Betula-Juniperus*-herb assemblage, and lastly a tree birch assemblage indicating a woodland vegetation about 7000 B.P. Size measurements on all *Betula* pollen grains are given in size frequency diagrams, thus giving some idea about *Betula nana* and *B. pubescens* proportions in the landscape of the early Holocene. All age estimates are based on the two radiocarbon dates available and are shown graphically by means of a time/depth curve.

Fluctuations in the *Juniperus* pollen curve are assumed to derive from climatic changes resulting in paludification and expanding mires. As a reason for this, changes in the ocean current pattern north of Iceland are suggested.

The pollen diagram from Krosshólmýri has the best time resolution of all the pollen localities published up to now, with about one sample per century. Therefore we may expect to see some fluctuations there in more detail than elsewhere. Such fluctuations can be masked out at the other sites, because of larger time spans between samples due to slower sedimentation rate or fewer samples per equivalent time spans as the sampling interval is too great. Consequently a more comprehensive vegetational history is obtained, which gives a basis for more decisive interpretations than elsewhere in Iceland, although the general picture seems to be similar. Last but not least Krosshólmýri predates the previously investigated localities and adds about 800 ¹⁴C years to the Holocene vegetational history of Iceland.

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ÁGRIP

GRÓÐURFARSSAGA NORÐURLANDS FRJÓLÍNURIT FRÁ FLATEYJARDAL

Daljökklar hörfuðu úr þverdölum Flateyjardals snemma á nútíma. Kuldakastið, sem framrásinni olli, er kennt við Langhól og Ljósavatn. Í bæli jöklanna, sem gengu fram úr Brettingsstaðadölum, varð til lítið stöðuvatn, þar sem nú heitir Krosshólsmýri (Mynd 2). Frjókorn, sem varðveist hafa í setlögnum, sem söfnuðust þar fyrir, skráðu sögu gróðursins. Setlögin hafa verið aldursgreind með geislakolsaðferðinni og gefur hún lágmarksaldur á setmynduninni 9650 ± 120 ár. Neðstu 110 cm voru frjöggreindir. Við útreikning á setþykknun er stuðst við tvær aldursgreiningar, sem gerðar voru á setinu. Hafi setþykknun verið jafnhröð allan tímann, þá spanna þessir 110 cm um 2500 ára tímabil (Mynd 3). Fjögur eldgos settu spor sín í setlögin, þrjú basísk og eitt súrt.

Í byrjun skildu gróðurlendi Flateyjardals eftir sig frjóbelti í setinu, sem einkennist af víði, lyngi og jurtafrjóji (Mynd 4). Aðalfrjóframleiðendur jurtakyns voru af krossblóma- og sóleyjaætt. Næsta frjóbelti er

þrískipt og ráða þar mestu sveiflur í línuritum birkis og einis. Birkið virðist koma til sögunnar fyrir um 9000 árum, þó gætir birkifrjóa nokkuð í neðstu og elstu sýnunum en þau gætu verið af fjalldrapa (Mynd 5). Í fyrstu þrifust birki og einir hlið við hlið, en svo kom að því að einirinn varð að láta í minni pokann í samkeppninni um búsvæði. Einirinn var á undanhaldi þar til fyrir um 8000 árum, að hann náði sér á strik á nýjan leik, líklega vegna þess að veðráttu breyttist um tíma (í u.þ.b. 6 aldir), þannig að birkið átti erfitt uppdráttar. Fyrir rúmum 7000 árum var birkið á ný orðið mesti frjóframleiðandinn í gróðurlendum dalsins, ennþá vantaði samt nokkuð upp á, að þéttur birkiskógur dafnaði, sem sést á því að ýmis jurtafrjó og jafnagró skiluðu sér dável í frjófallinu út í vatnið. Birkiskógur eða kjarr, mýrlendi og mólendi settu svip á dalinn, þegar hér var komið sögu.

Í vatninu þrifust síkjamari, lófótur og nykrutegundir strax frá upphafi, en seinna kom álftalaukur til sögunnar, e.t.v. í tengslum við umhverfisbreytingar, sem komu í kjölfar þess, að birkikjarrinu hrakaði, þegar veðráttu varð úrkomusamari og eða jarðvegur blotnaði af völdum lægri árshita.

Frjógreining borkjarnans úr Krosshólsmýri hefur bætt nokkrum öldum framan við gróðurfarssögu Norðurlands, en segja má með vissu að enn vanti þó upphafið. Flateyjardalur hafði verið jökulvana um hríð áður en smájökklar gengu þar fram á nýjan leik og hörfuðu síðan í upphafi nútíma. Saga Krosshólsmýrarkjarnans nær allt aftur til þeirrar hörfunar.



Kirkjuból á Langjökli, 9. júlí 1986. Á myndinni eru, talið frá vinstri: Elís Másson, Eyjólfur Sigmarsson, Valur Jóhannesson og Bjarni Bjarnason. Ljós. Pétur Þorleifsson.

The Kirkjuból hut, Langjökull. Photo. Pétur Þorleifsson.