Late Quaternary Geology and Glacial History of Hornstrandir, Northwest Iceland: A Reconnaissance Study

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ABSTRACT
The northern part of the northwest (Vestfirdir) peninsula of Iceland is a basalt plateau dissected by fjords and rather short, glacially eroded valleys. Its northern coast is called Hornstrandir. Its Quaternary geology was reconnoitered by the authors in 1982 and 1983.

No signs of glacial erosion or deposition were found on the high (400–500 m) plateaux and it is therefore concluded that these were not inundated by actively eroding glaciers, at least not during the last (Weichselian) glacialation. Using altitudes of glacially unaffected plateaux as a measure of the absolute maximum thickness of the outlet glaciers, their maximum horizontal extent can be approximated. It is then found that the glaciers could only have reached about halfway to the edge of the shelf, and it is possible that they did not even reach that far. The time of general deglaciation could not be absolutely dated, but by analogy with other areas in Iceland, and around the Northeast Atlantic, it most probably took place during the latest Weichselian and earliest Flandrian. The sea then stood 26–15 m higher than today and at least in some valleys the retreat of the glaciers was interrupted by a readvance – perhaps an equivalent to the Younger Dryas readvance elsewhere. The equilibrium line altitude (ELA) at the end of the Weichselian was around or below the present 150 m level. A heavy influx of basaltic tephra, the Hæðavík tephra, took place shortly after deglaciation.

During the Little Ice Age glaciers were re-established in 7–10 cirques on northern Hornstrandir. The ELA in these cirques varied with exposure between 300 and 500 m, and some glaciers descended as much as to 150 m below their basin-floor altitudes. Lichenometric studies at one site indicate that the Little Ice Age glacial maximum was reached around 1860 AD, perhaps a little earlier. The retreat, at that place, was largely finished by 1920, when the glacier had almost disappeared. Today glaciers are found in only four cirques, but small frms exist on some high plateaux and mountain ridges.

INTRODUCTION
Hornstrandir is the northernmost part of the northwest, Vestfirdir peninsula of Iceland (Fig. 1), and is here defined as the coastal area from Ritur eastwards to Hornbjargsviti (Fig. 2).

Little has been known about the Quaternary geology and glacial history of Hornstrandir. Scattered references to glacial deposits and striae in the area can be found in the literature, but detailed stratigraphical and morphological information has been lacking. This paper attempts to fill some of the gaps. It is based on two short reconnaissance of the area, combined with extensive air-photo interpretation and a re-examination of the scattered data available in the geological literature. During one week in July 1982 CH and HN studied the Adalvík-Rekavík area in the west (Fig. 2), and during
only off Hornvik, where a northwest trending basin, overdeepened by some 50 m and with depths down to 105 m, reaches into the bay.

The general pattern of short, steeply ending valleys with well developed cirques indicates that glaciation on Hornstrandir was of a predominantly local character.

**Present climate**

Both according to the mean air temperature in July and the temperature of the sea, Hornstrandir lies within the low-arctic zone (e.g. Freuchen and Solomonsen 1959).

The climatic tree-line probably runs somewhere through central Hornstrandir (E. Einarsson 1975). At present there are two meteorological stations close to Hornstrandir and with similar exposure, one at Galtarviti south of the entrance to Isafrjardardjup, another at Hornbjargsviti immediately east of Hornbjarg (Fig. 1).

Recorded annual mean temperatures at Galtarviti and Hornbjargsviti are +3.8°C and +3.1°C, respectively, with the highest monthly mean temperatures in August, +9.6°C and +8.2°C, and the lowest in February, −0.8°C and −1.1°C (M.A. Einarsson 1976). Annual mean precipitation values at Galtarviti and Hornbjargsviti have been recorded as 1265 mm and 1373 mm, respectively. The prevailing wind direction on Hornstrandir is probably from the northeast.

Permafrost occurs on the high plateaux. On Fljótshöfði east of Látrar, 450–500 m above sea level, ice was encountered at a depth of 15–30 cm on 23rd of July 1982. Large stone polygons and stone stripes are common.

**WEICHSELIAN GLACIATION AND MARINE LEVELS**

**Research history**

The Icelandic geologist Thorvaldur Thoroddsen, travelling on Hornstrandir during the summers 1886 and 1887, made numerous observations on its geology and morphology (Thoroddsen 1892a, 1892b, 1906). He recognized that the whole landscape of the Vestfirðir peninsula is characterized by glacial erosion, and he observed glacial striae and glacial deposits at numerous localities. From a monoglacialistic point of view, he concluded that during „the Ice Age“ the area had been covered by an extensive ice cap, which he considered to have been independent of the main Icelandic ice sheet. He estimated the thickness of this ice cap to 400–500 m, and assumed that outlet glaciers from it had extended into the valleys and fjords. He noted the absence of submarine valleys on the shallow banks off the Horn-
strandir coast and, furthermore, seems to have been of the opinion that the ice cap had not extended far beyond the present coast. He also thought that the ice cap had been continuous and that nunataks could only have existed between the outlet glaciers, close to the edge of the ice cap.

Thorroldsen's views were later modified by Thórarinsson (1937), who suggested that during the last glaciation the Vestfirðir peninsula was characterized by small ice-fields on the plateaux between the fjords, while the whole central area was covered by a large continuous ice cap. Outlet glaciers flowed from the central highlands through the fjords, gradually leaving more space for local glaciers and nunataks. Thórarinsson also drew attention to observations made by Keilhbach (1933) and Iwan (1936) on the number and distribution of cirques on Vestfirðir. These become more numerous towards the mouths of valleys and fjords.


Th. Einarsson (1961) and Steindórsson (1962, 1963) suggested the possibility of relatively large ice-free areas on Vestfirðir during the Weichselian. Sugden and John (1976) used Vestfirðir as an example of glacial landscape evolution in mountains near the periphery of an ice sheet; a point of view which recognizes ice-free areas in environments with predominantly alpine-type glacial erosion. John (1975) recognized three different types of glacial erosion on Vestfirðir. He included Hornstrandir among alpine-type landscapes, where glaciation was characterized by a high density of glaciers with a low to moderate discharge. In a later paper (John 1977a) he stated that it was unlikely that there were any large...
un glaciated enclaves or plant refugia during the Weichselian, anywhere in Iceland. Contrary to this, Sighjarnarson (1983) emphasized the importance of alpine-type glacial erosion on Vestfirdir and stated that ice-free areas probably existed there throughout the Pleistocene.

Only limited work has been done on the deglaciation of the northern parts of Vestfirdir. Thoroddsen (1892a) suggested two major stages in the deglaciation. During an earlier phase the glaciers had retreated and the sea transgressed to 60–70 m above present sea level, with shorelines and terraces at those altitudes forming in the outermost coastal areas while the glaciers still remained in the valleys and fjords. During a later phase, when the glaciers retreated from the lowlands, shorelines and terraces were formed at 16–30 m above present sea level. Thoroddsen (1892a) reported features indicating ancient sea levels at 65 m above the present one in Reykjavik, at 30 m at Látrar in Adalvík and at 16 m in Hornvík.

Kjartansson (1969) observed raised beaches in Hornvík and on the eastern flank of Kogur. He mapped outcrops of till in Haelavík and Hlöðuvík, and alluvial and eolian deposits on most of the Hornstrandir lowlands. He also observed glacial striae around Hornvík, showing downvalley movements of the glaciers.

John (1974) stated that the highest marine terraces in the area north and west of Jökulfirðir reached only 10 m above present sea level, but Simonarson (1979), who reviewed the geology of Hornstrandir, reported a marine terrace at 16–20 m above the present sea level in Hornvík, and suggested a similar elevation for a marine terrace in Adalvík.

The present study
The maximum glaciation

As mentioned above, the morphology of Hornstrandir is characterized by unconnected short U-shaped valleys, with cirques in their sides and at their heads. The morphology indicates that cirque glaciers coalesced to form outlet glaciers which reached beyond the present coastline. But the high plateaux show no sign of having been inundated by active glaciers and are usually covered by mature block fields consisting of local bedrock (Fig. 3). The very flat surfaces of these plateaux contrast sharply with extensive lower areas which have been intensely eroded by glaciers (Fig. 4), and with cirques and different nivation features below the plateau edges (Figs. 4 and 7).

Today most of the shelf around Hornstrandir is shallower than 100 m. Thus it may have been dry, or at least under very shallow water, during the Weichselian maximum glaciation — provided that this coincided with the maximum glaciation elsewhere around the North Atlantic and with the contemporaneous global sea level low.

An empirically derived absolute upper limit of actively eroding ice at sites near the present coast, defined as plateau surfaces without signs of glacial erosion, plus the assumption that the ice was grounded, allows us to approximate the outer edge of the glaciated area at the maximum situation. Giving the large outlet glacier from the Vestfirdir ice cap, which must have existed in Ísafjarðarjúp, an Antarctic type B overall gradient and a surface profile of a 60–100 km long Greenland outlet glacier (Buckley 1969; as used for central North Iceland by Norddahl 1983), it can be
assumed that the only part of western and northern Hornstrandir which could have been affected by that outlet glacier and its tributaries would be the Adalvik area. Some ice may have flowed into that area from Jökulfirðir, through the slightly less than 300 m high passes to the east. If the Adalvik glaciers are given a minimum gradient of 25 m/km (empirically derived from lateral channels in North Iceland by Norddahl 1983) the glacier terminus outside Adalvik will have fallen some 6–10 km off the outermost capes (Fig. 5). That is still 10–25 km inside the present 100 m depth curve on the shelf. The same gradient has been used for reconstructing the outer limits of the glaciers coming out of Fjöðuvík, Hlóuvík, Hælavík and Hornvík. These could hardly have been affected by the Ísafjarðardjúp glacier, but were built up by coalescing cirque glaciers, so they probably did not reach as far out as the Adalvik glacier. Thus their positions marked in Fig. 5 would seem to be maximum assumptions. Fig. 5 shows a maximum concept as there are no indications that the ice-surface reached all the way up to the plateau edges. But the often steep, if not vertical mountainsides are usually far from optimal for the preservation of lateral features.

The high plateaux and the steeper mountains reaching above the surface of actively eroding glaciers are indicated in Fig. 5. However, to a large extent these plateaux were probably covered by thin inactive and/or cold based ice-fields. This is indicated by the existence there even today of perennial snow fields or small firns (Fig. 3).

The general ELA during the maximum glaciation probably was below 150 m above present sea level, as all cirques along the outer coast with their floors around that altitude were glaciated. The unknown stand of sea level in relation to land at that time does, however, complicate the question of the relative altitude of the ELA.

Thus, at the time of maximum glaciation ice-free areas on what is dry land today could have existed as (1) steep nunataks south of Hlóuvík, Hælavík and Hornvík, (2) narrow rims between plateau edges and the ice fields up there and (3) ice-free slopes between outlet glaciers and the plateau edges. These habitats could no doubt have supported some vegetation. If ice-free marginal areas of the shelf were dry land, vegetation probably persisted there too.
Late glacial oscillations and final deglaciation.

During the late glacial period, in a wide and, as regards Horastrandir, not absolutely dated sense, but roughly comprising the Late Weichselian - Early Flandrian of Mangerud et al. (1974), the glaciers retreated and finally disappeared. In Haelvik and Adalvik there are clear indications of an early retreat on to presently dry land, followed by a renewed glacial advance, and then by the final deglaciation. The local evidence is as follows:

Haelvik: High up on Haelvikurbjarg (Fig. 7), around or above the 200 m level, lie three poorly developed cirques facing the bay. The uppermost recognizable lateral deposits laid down by the glacier coming from the valley inside Haelvik are met with around the 150 m level. There is another, very distinct lateral terrace at about 55 m. It has a low gradient and ends with a northwardly convex terminus about 500 m inside the west end of Haelvikurbjarg.

Along the coast in Haelvik there are three cliff sections, kept open by the present marine erosion. They are numbered 1, 2 and 3 on Fig. 7. The stratigraphy of section 1 is shown in Fig. 8. The lower part of it consists of 5 m of compact, silty till, rich in boulders. In the upper part of this till is a concentration of boulders in the silty matrix (Fig. 9), interpreted as waterlain clasts. Then follows 3 m of silt, completely barren as regards both mollusc shells and foraminifera. The silt has been contorted by an overriding glacier, which deposited about 5 m of compact, silty and boulder rich till, very similar to that in the lower part of the section. The upper till was later abraded by the sea which then, according to the altitude of the abrasion terrace inland from this section and the border between abraded and non-abraded areas around it, reached 26-27 m above present sea level.

Sections 2 and 3 (Figs. 7 and 10) show that some time, probably rather a short time after the final deglaciation (the last glacier here is represented by a sandy and gravelly supraglacial till), sea level had regressed down to or below its present level. This is indicated (section 3) by the deposition of laminated lacustrine/fluvial silt with a distinctly non-marine lacustrine/fluvial diatom spectra, below 1 m above present sea level. It was paralleled by the deposition of lacustrine sand and silt at section 2, containing lacustrine/fluvial-type diatoms. All this probably took place in what was then a system of kettleholes. Contemporaneously with the lacustrine/fluvial deposition at section 3 a sudden and heavy influx of tephra took place. This tephra, hereafter named the Haelvik tephra and further discussed below, was deposited in the lacustrine environment at section 3 (with about 1 m of silt with a slight gyttja content on its top; Figs. 10 and 12), but as an eolian sediment at section 2. This shows that the water at section 2 had disappeared when there was still water up to the same
level at section 3, which supports the kettlehole concept.

Most of the lower part of the valley inside Hælavík, above the 26–27 m limit, is characterized by a well developed hummocky topography. It can be followed along the valley up towards the outer limits of the area covered by ice during the Little Ice Age, in the Fannaráli cirque at the head of the valley.

In summary, the geological data from Hælavík indicate: (1) That at the time when the lateral deposits on the eastern side of Hælavík were deposited the Hælavík glacier was at least 150 m thick near the present coastline. According to the low marine limit its terminus was probably grounded. The lower till in section 1 was most probably deposited by this glacier. (2) The retreat of the glacier to inside the present coastline took place when sea level stood at least above the present 5–8 m level, as indicated by the silt covered waterlain part of the lower till. (3) Then the glacier readvanced, deposited the upper till in section 1 and contorted the underlying silt. This glacier was about 55 m thick at the present coastline, judged by the altitude of the lateral terrace on the eastern side of Hælavík, which represents the youngest ice advance there. The supraglacial till in sections 2 and 3 must represent this last glacier advance. (4) There was then a regression of the sea from the 26–27 m marine limit to below the 1 m level, as evidenced by deposition of lacustrine/fluvial sediments on top of the till in section 3.

Hlíðuvík: Along the coast of eastern Hlíðuvík there is an about 10 m high cliff, partly overgrown but well exposed along some stretches. Two separate units are exposed in this section. The lower one is a till and the upper one a predominantly coarse-grained beach sediment. The till is boulder rich, compact and silty, similar to the tills exposed in section 1 at Hælavík. There is a concentration of very large boulders (≥1 m diameter) at the western part of the section; these may derive from a medial moraine. Only one till bed is found, and the surface of it has been abraded by a sea standing 10–15
m higher than today. This represents the marine limit here. The beach sediments were deposited on top of the till and later also onto the face of the cliff.

The valley inside Hlöðuvík is about 4 km long and 2 km wide. Its lower parts are characterized by hummocky deposits similar to those inside Hafnirfjörður (Fig. 7). Six well developed cirques face this valley, compared to only one well developed cirque inside Hafnirfjörður (Fannarlag). On the eastern side there are two cirques (see Fig. 7) with their floors around 150 m and 200 m above sea level, respectively. They are fronted by small moraines. The moraines are weathered and surrounded by a mature vegetation cover, indicating that these cirques have not been glaciated for a long time. The higher situated cirques at the head of the valley (with floors at 300–350 m) have much less vegetation. The moraines and other surfaces within them look much fresher, and they contained glaciers during the Little Ice Age (Fig. 13).

Evidence from Hlöðuvík shows that the outlet glacier there, fed by six cirque glaciers, advanced beyond the present coastline and deposited the till. When it withdrew the sea stood about 10–15 m higher than today. This means that the Hlöðuvík glacier must have retained its advanced position somewhat longer than the Hafnirfjörður glacier 2 km to the east, which retreated inside the present coastline when sea level stood about 26–27 m higher than today. This discrepancy could be due to the much larger accumulation area feeding the Hlöðuvík glacier, making it react slower to climatic improvement than the Hafnirfjörður glacier.

Submarine Adalvík: According to the Icelandic Hydrographic Survey (1977), two concentric zones of shallow banks exist at the entrance to Adalvík (Fig. 6).
The outermost zone A is the least well defined. At most it is about 2 km wide, running from Straumnes southeasterwards to a position 4 km northwest of Ritur. It has a semicircular appearance, with its concave side towards Adalvík. The water depths on the banks are 33–40 m, whereas immediately inside the depths are between 42 and 44 m and outside between 42 and 47 m.

Some 2–3 km inside zone A there is another zone with shallow banks, zone B. It is narrower than zone A, only 0.5–1.0 km wide, and runs from Látrarfjall southwestwards to Ritur. It is also semicircular with the concave side towards Adalvík. The water depths on these banks are between 16 and 22 m. Inside depths are between 25 and 31 m and immediately outside between 24 and 36 m.

What these banks are made of is not known, but their semicircular appearance, with the concave side towards land, seems to suggest a glacial origin. It should also be noted that zone A is „anchored“ with its northern flank at Straumnes, whereas zone B is „anchored“ in a similar way with its southern flank on Ritur. Accordingly both zones lie in positions where the lateral confinement of a glacier advancing seawards from Adalvík would diminish drastically. Any further advance beyond each of these positions would need a greatly increased supply of ice compared with what was needed for the advance up to these positions. Also, at the zone A position, the glacier in Adalvík may have coalesced with the glacier coming out of Ísafjarðardjúp. This can be inferred from the way in which the banks constituting zone A end towards the south — without any obvious „anchoring“ point.

Zone A lies 2–5 km inside the outermost position of the ice front, as it was calculated using plateau surfaces unaffected by glacial erosion as upper limits for ice thickness (Fig. 5). However, as that position is very tentative and based on the very maximum concept, it is
likely that zone A in reality represents the true Weichselian maximum position of the ice front outside Ádalvík.

Stadarvatn and Thverdalur: At southeastern Ádalvík, glacial strie (direction from 164°) at 140 m altitude on the west end of the Hvarfnúpur mountain (Figs 6 and 11) show that an actively eroding glacier of at least that thickness at one time expanded from the mouth of the Stadarvatn valley. Younger stages of this glacier are indicated by the following features:

(1) On the southern slopes of the Stadarvatn valley, about 1 km west of the lake, there is a set of subglacially engorged eskers (Sugden and John 1976, p. 331) running perpendicular to the slope (Fig. 11).

(2) Between the west end of Hvarfnúpur and the mouth of Thverdalur a higher set of lateral deposits are found between 70 m and 50 m altitude (Fig. 11). The sediments are rather coarse supraglacial till with hummocky surface, and with irregular drainage channels trending down towards the valley.

(3) Directly below follows another set of lateral deposits, situated approximately between 50 m and 35 m. These are less hummocky, contain more glaciofluvial material and the drainage channels here run parallel to the main valley.

(4) These two sets of lateral deposits seem to correspond to a terminal moraine zone, about 500 m wide, at the mouth of Thverdalur, deposited by a glacier in that valley and with superimposed drainage channels running outwards from Thverdalur. The proximal part of the moraine zone lies around 70 m and the distal part between 40 m and 25 m. The distal slope is steep which could indicate either a deposition against a glacier in the Stadarvatn valley or erosion by such a glacier.

(5) The final recession of Stadarvatn glacier to behind the present coastline and to the conspicuous Stadarvatn moraines, just west of the lake (Fig. 11), was related to a sea level about 15 m higher than today. This is indicated by (a) the altitude of the inner part of a wide abrasion terrace in front of the Stadarvatn moraines, coinciding with a change from clearly supramarine till to a sandy, gravelly cover on and around these ridges, and (b) a distinct beach cliff below the mouth of Thverdalur. These features are found between 17 m and 14 m, the approximate level of the local marine limit.

A section along the stream draining Stadarvatn, slightly west of the lake (section in Fig. 8, position in Fig. 11), shows, from bottom and up, a rather sandy till covered by a bed of glaciofluvial sand and gravel, about 1 m thick. The upper bed is gravelly in its lower and upper parts, but sandy in the middle. It lies roughly 16–17 m above present sea level, which corresponds to the marine limit, and thus sea level probably stood below the 16–17 m level when the sand/gravel bed was deposited. The glaciofluvial sediments are covered by another sandy till, about 5 m thick, with large boulders on its surface. How far the glacier depositing the upper till reached can not be determined, only that after a probable initial deglaciation, at a sea level below 16 m, the Stadarvatn glacier readvanced. There are two alternative interpretations of the glacial geology here:

(1) That a first retreat of the glacier into the Stadarvatn basin took place when sea level stood rather low (see stratigraphy at Láttrar described below). Later the glacier readvanced across the glaciofluvial deposits on top of the lower till, without disturbing them, to beyond the present coastline, forming the lateral terraces at 50–35 m. Probably sea level was rising at the time. Later the glacier started to disintegrate, the subglacially engorged eskers were deposited, and the active front of the glacier retreated to a position immediately west of
Stadarvatn. There, with a sea level around 15 m higher than today, it remained for a while, depositing the Stadarvatn moraine ridges and the upper till bed.

(2) A simpler interpretation of the data includes downwasting of one body of ice from the higher to the lower lateral terraces and only one retreat of the glacier to behind the present coastline. This was then followed by a short oscillation of the ice front. Sea level would then seem to have transgressed to the 15 m level rather synchronously with this glacial readvance as the ridges composed of the upper till are abraded to that level.

The very approximate position of the glacier front during formation of the lower set of lateral terraces at Hvarfnupur is indicated as zone C in Fig. 6. The Stadarvatn moraine zone (Fig. 11) and a probable contemporaneous moraine in lower Thverdalur are indicated as zone D.

Látrar and Reikavik: A lateral terrace can be traced along the mountainside west and north of Látrar in northern Adalvík. Its surface lies around 25 m above present sea level at Látrar, where the terrace is about 200 m wide, and it rises to 40 m near the junction with the Reikavik valley (gradient 10 m/km), there being about 50 m wide. At Látrar the terrace has an at least 10 m thick lower bed of sandy, silty till, with many rounded stones and boulders, and an upper 15 m thick unit of glaciofluvial sediments, mostly horizontally bedded gravelly sand with beds of well rounded stones and boulders. The glaciofluvial sediments were deposited close to or above sea level, which at the onset of deposition probably stood around or below the present 10 m level. The thickness of these sediments indicate that the base level, i.e. sea level, gradually rose to about 25 m above the present sea level.

A branch of the glacier covering the lowlands behind Látrar drained northwestwards through the Reikavik valley (Figs. 2 and 5), and was reinforced there by two local cirque glaciers. The altitude (17–19 m) of the
distal part of an alluvial cone or elevated sandur below one of these cirques (Grasadalur) on the south side of Rekavikurvatn, and a similar altitude of the upper surface of a much dissected glaciofluvial deposit at the southern end of Rekavikurvatn, indicate the approximate base level at the time of deglaciation. It could not be ascertained whether the Rekavikurvatn basin contained inactive ice when these sediments were deposited. However, an inactive ice body must have been left in the small basin (Hólsavatn) east of Rekavikurvatn, or the sediment pile between the two lake basins could not have been deposited. There are also remnants of a terminal moraine on the north shore of easternmost Rekavikurvatn, deposited by a glacier coming from the east. On the watershed between the Rekavik valley and the Látrar lowlands an interlobate drainage pattern illustrates the separation of the two ice bodies.

We re-examined Thoroddsen’s (1892a) evidence of an ancient strandline at 63 m above present sea level inside Rekavik and came to the conclusion that the feature in question is a bedrock structure, without any relevance to ancient sea levels.

No clear indications on the marine limit around northern Adalvík were found, but the above mentioned data and the rather diffuse border between abraded and non-abraded glacial features inland from Látrar places it somewhat between 15 m and 25 m above present sea level.

**Summary and correlation of the late glacial events**

The most complete late glacial sequence is probably found in Haelavík. Morphological and stratigraphical features there reveal the following sequence of events: (1) An initial glacial retreat was followed by (2) the deposition of marine silt to at least 8 m above present sea level and (3) by a glacial readvance, whereafter (4) the final deglaciation took place, when the sea stood 26–27 m higher than today. Deglaciation was (5) followed by regression of the sea to or below the present sea level.

Another fairly complete glacial geological sequence is revealed in the Stadarvatn valley of southern Adalvík, where two glacial advances are probably documented. One interpretation of the geology there suggests a development similar to that in Haelavík. But the final deglaciation at Stadarvatn took place when the sea stood only 15 m higher than today, which indicates a later deglaciation than in Haelavík, perhaps contemporaneously with that of Hlóðuvík.

We correlate the lateral terrace at Látrar with the short lower lateral terrace north of Stadarvatn (zone C in Fig. 6). The stratigraphy of the Látrar terrace may suggest a transgression from < 10 m up to 20–25 m above present sea level, i.e. to a level similar to the marine limit in Haelavík.

The ELA during some part of the late glacial has been around or lower than 150 m above present sea level. This is inferred from the altitude of the low level cirques which were glaciated at that time. Such are found in Hornvík, Hlóðuvík (Fig. 7) and at southeastern Adalvík, but also at places along the outer coast, near Ritur and Straumnes. A good example is shown in Fig. 11.

**Dating the full glacial to late glacial sequence**

No shell bearing sediments from the full glacial or late glacial periods were found on Hornstrandr. Probably most fine grained sediments from that time lie below present sea level, with the exception of the shell- and foraminifera-free silt in section 1 at Haelavík. Nor have we found any other material which could be absolutely dated, as the gyttja silt in sections 2 and 3 at Haelavík contains too little organic matter and too few pollen. Thus the age of the glacial deposits can only be suggested by analogy with other areas.

New interpretations of data from Northeast Greenland (Funder 1982, 1984, Hjort and Björck 1984) suggest the nonexistence of any extensive Early or Middle Weichselian glaciation there and tentatively place the Weichselian maximum around 20,000–18,000 years BP. Data from Svalbard (Miller 1982) may be interpreted in the same way.

Norddahl (1983) suggested that the glacial maximum in central North Iceland dated from before 18,000–24,000 BP, but his oldest glacial stages are not necessarily of Weichselian age. In fact, the Weichselian maximum has never been properly defined or absolutely dated anywhere in Iceland, so there seems to be no reason to, initially, suggest any other age for it on Hornstrandr than the classical 20,000–18,000 BP one, as proposed for Iceland in general by Tr. Einarsson (1966) and Th. Einarsson (1973).

The best clue to the age of the final deglaciation, of at least northern Hornstrandr, is the deposition at or near present sea level of lacustrine/fluvial sediments which, although with an erosional discontinuity, follow directly upon the till in section 3 at Haelavík. These mirror the regression after the final deglaciation, from the 26 m level (section 1 at Haelavík) down to present sea level. From other parts of Iceland we know that already around 9000 BP the relative sea level had come down to or below its present level (Thórarinsson 1956, 1964, Th. Einarsson 1956, 1964, 1968). If applied on Hornstrandr
this would indicate (1) that, at least in Haelvik, the glacier had retreated behind the present coastline around or before 9500 BP, and this (2) in turn would suggest that the upper till at Haelvik may date from the Younger Dryas. Whether the lower till is also of latest Weichselian age or if it represents the Weichselian maximum can not be said.

The Haelvik tephra

The blackish Haelvik tephra (Fig. 12) first appears with a very sharp lower contact, in both lacustrine/fluvial (section 3 at Haelvik) and eolian sediments (section 2). In the latter case, deposited as a low dune consisting almost entirely of tephra, its thickness is approximately 0.5 m. In both the lacustrine/fluvial and the terrestrial sediments it gradually disappears upwards in the sections.

According to the reasoning in the preceding chapter the age of the lacustrine/fluvial sediments where the tephra appears is around 9000 years or somewhat younger. The tephra is basaltic, and its chemical and chronological relationship to other tephras on Iceland and to tephra beds deposited as deep-sea sediments (e.g. Kellogg et al. 1978, Ruddiman and McIntyre 1981) and on land in western Norway (Mangerud et al. 1984) will be the scope of a special study. It is possible that the tephra can be found elsewhere on the Vestfirdir peninsula, and if found in connection with dateable organic material it could constitute an important marker horizon.

LITTLE ICE AGE CLIMATE AND GLACIATION

Research history

Thórarinsson (1969) outlined the climatic oscillations in Iceland since the colonization in the 9th century AD. According to him, the Little Ice Age cooling began already in the early 13th century and culminated in the 18th and 19th centuries. He based his conclusions on a multidisciplinary study involving geological, archaeological and historical evidence. Studies of the O18/O16 ratios in ice-cores from the Greenland ice sheet have yielded similar results (Dansgaard et al. 1975).

Meteorological evidence.

Regular meteorological observations in Iceland began in 1845, when an observation post was established at Stykkishólmur (Fig. 1). Eythórsson (1949), summing up the observations, noted that the mean annual temperature there reached its minimum between 1859 and 1888, with +2.7°C (mean values for the periods 1901–1930 and 1931–1960 were +3.4°C and 4.2°C (Eythórsson 1949, M. Á. Einarsson 1976). Thordarson (1911) published annual mean temperatures for Stykkishólmur, and Adalvik on Hornstrandir, for 1874–1901. The mean for Stykkishólmur was then +3.0°C (M1) and for Adalvik +1.1°C (M1). According to M. Á. Einarsson (1976) the mean annual temperature at Hornbjargsviti during the period 1931–1960 was 1.1°C lower than at Stykkishólmur. He noted that fluctuation trends of temperature at Stykkishólmur have been detectable all over Iceland. Thus it seems (1) that the annual mean temperature on Hornstrandir is 1.0–1.5°C lower than at Stykkishólmur, (2) that temperature fluctuations on Hornstrandir probably are roughly in phase with the rest of Iceland, so that (3) the Little Ice Age temperature minimum on Hornstrandir (at least for the period after 1845) should have been reached sometime between 1860 and 1890. However, it is not certain that the temperature minimum exactly coincided with the Little Ice Age maximum glaciation, as precipitation fluctuations have to be taken into consideration too. We have no precipitation values from Hornstrandir covering this period.

Glaciological evidence.

On northern Vestfirdir there are two types of glaciers which can provide information on the Little Ice Age climate and glacier oscillations; (1) the Drangajökull ice cap and its outlet glaciers, and (2) the small cirque glaciers.

(1) Drangajökull: The outlet glaciers from Drangajökull (Fig. 1) have been monitored since 1931, and found to be sensitive to small-scale climatic variations (Eythórsson 1935, 1949, Thórarinson 1943, Bout et al. 1955, John 1977b, Rist 1983). Eythórsson (1935) came to the conclusion that these outlet glaciers reached their maximum extent in historical time, probably even in post-Weichselian time, during two separate readvances culminating around 1756 and 1840. According to John (1975, 1977b) the Reykjafjöll outlet glacier on the north side of Drangajökull reached its most advanced position around 1850 rather than around 1756. He recognized three moraines from the Little Ice Age, which he „dated“ to 1840–1850, 1860–1870 and 1914–1920.

(2) Cirques: Little is known about glacier growth in the cirques on Hornstrandir during the Little Ice Age. Thordarson (1906, 1911) reported that in 1886 and 1887 large snow fields and old firns were common close to sea level in Adalvik and Fljótsvik, although he could not
identify any active glaciers at such low elevations. He estimated the altitude of the "snow line" on eastern Drangajökull to 400 m. This can be compared with the more recent estimate of 700–800 m for the equilibrium line altitude (ELA) there (Th. Einarsson 1968). Old local names for cirques on Hornstrandir suggest at least perennial firms, or glaciers (e.g. Jökkladalur: Glacier valleys, Fannarlaug: Site of snow fields). John (1977b) found that most of the cirque glaciers in the uplands of northern Vestfirdir have prominent moraines. He suggested that these moraines often mark the maximum advance of the Little Ice Age glaciers, but where multiple moraine sequences occur, some may date from an earlier Neoglacial advance.

The present study

Most of the cirques on Hornstrandir, some of which have floors as low as 150 m above present sea level, show no sign of having been glaciated since the end of the Weichselian. The moraines in front of them are well weathered, the vegetation cover within them is more or less complete, and peat formation has often taken place in their basins.

However, there are a few exceptions. In Hlóudvik, Haavavík and Hornvík there are 7 cirques which show clear signs of having been glaciated recently. The cirques inside Hornvík, Haavavík and Hlóudvik (shown without question marks in Fig. 13) have one to several fresh looking moraines in front of them. The areas behind these moraines also look very fresh and the vegetation cover there is sparse. This is not an effect of altitude, as extensive vegetation cover often occurs at higher altitudes near the cirques, and at similar exposures.

Inside Hlóudvik and Haelavík the floors of these cirques lie around 300–350 m above sea level, but they lie as high as 500 m inside Hornvík (Fig. 13). The Hornvík cirques are surrounded by the highest mountains on Hornstrandir, which probably causes some precipitation shadow. This is also suggested by our conclusions, that during the Little Ice Age the glaciers in the more exposed cirques in Hlóudvik and Haelavík reached 150 m below the altitude of their floors (Fig. 13), whereas those inside Hornvík only reached some 50 m below their floors. Thus during the Little Ice Age (for dating, see below) the ELA in the cirques was down at, or somewhat below, 300–350 m in the Haelavík/Hlóudvik area, but not much below 500 m at Hornvík. This can be compared with Thoroddsen’s (1906, 1911) approximation of 400 m for the eastern part of Drangajökull.

The total glaciated area on northern and western Hornstrandir during the Little Ice Age was 8–10 km². Lichenometry of the Fannarlaug cirque.

A reconnaissance study of lichen growth was carried out on fresh moraines and other surfaces which were covered by the Little Ice Age glacier in the Fannarlaug cirque, at the head of the valley inside Haelavík. Today there is no glacier in this cirque (Figs. 7 and 14). Lichens used were of Ritzocarpon alpicola and Ritzocarpon geographicum agg. type, and thalli of the different species are used together in the calculations. Thalli diameters were measured using the diameter of the largest inscribed circle (Lock et al. 1979, p. 8). Distances between moraines and other surfaces on which thalli were studied were measured by counting steps during walking.

Innes (1982) showed that R. alpicola and R. geographicum agg. have somewhat different growth rates, but in a preliminary study like ours that difference should not matter too much. Gordon and Sharp (1983), in a study on southern Iceland, found that for R. geographicum agg. the growth rate since the late 19th century was approximately linear, and Caseldine (1983) came to the same conclusion as regards central North Iceland.

Our results are presented in Fig. 15, where the mean values for the five largest thalli (M₃) on each surface (numbered as in Fig. 7) are shown together with the size interval covered by them. In two cases (points 5 and 7) single unexpectedly large and perhaps coalescent thalli
were encountered. These have not been used in the ordinary $M_j$ calculations, but are indicated by dashed lines, and with such $M_j$ values as would result from their inclusions shown as open circles.

The measurement at point 0 was made on a striated rock surface outcropping through the snow (1877 1983) in the innermost part of the cirque, at an altitude of about 350 m. The lowest point (no. 8), within the area of fresh surfaces which were clearly covered by ice during the Little Ice Age, lies at about 200 m above present sea level. Point no. 9 is at the same altitude. No. 10 is a calibration sample from the much older Late Weichselian glacial hummocky terrain further downvalley (Fig. 7). Its $M_j$ consists of the largest thalli found between 85 m and present sea level.

The rather stepwise decrease in thalli diameter between points 6 and 5 and points 3 and 2 together with the short distances between these moraines probably indicate temporary standstills of the glacier front at moraines 5 and 2, or at least a decreased rate of recession. The reason that the $M_j$ for point no. 8 is smaller than for point no. 7 is probably that the former surface is situated below and in front of a rather steep slope (Fig. 7), a typical snow-drift site. Therefore the ridge at point no. 7 was freed from ice or long lasting snow cover, preventing lichen colonization, before the point no. 8 area. The steep decrease in lichen diameter from point no. 9 to points no. 8 and 7, and the fact that $M_j$ at point no. 9 is also larger than that in the calibration area, suggests that point no. 9 is indeed situated just outside the area reached by the Little Ice Age glacier.

The maximum thalli diameter on the Little Ice Age moraines at Fannarlág is roughly 60 mm ($M_j$: 57.6 mm). Moraines from about 1895 in front of Breidamerkurjökull in southern Iceland have maximum thalli diameters of 50 and 54 mm and $M_j$'s around 45 mm (Gordon and Sharp 1983). Moraines of similar age from Sólheimajökull, also on the south coast, have maximum diameters of about 50 mm (Jaksch 1975), and on the 1887 moraines at Skálafljótjökull in the southeast, the maximum thalli diameter is close to 80 mm (Gordon and Sharp 1983). Depending on the method of calculation (using maximum thalli or $M_j$'s) this gives annual growth rates between 0.5 and 0.9 mm/yr. The harsher climate on Hornstrandir can be supposed to suppress lichen growth compared with southern Iceland (e.g. Beschel 1961, Webber and Andrews 1973), as is also indicated by the low growth rate in central North Iceland (about 0.5 mm/yr; Caseldine 1983). A 0.5 mm/yr growth rate would date the outermost Little Ice Age moraines in Fannarlág to about 1860, and a lower growth rate would give them an even older age.

There are no data in the scattered references to the
Little Ice Age glaciation on Hornstrandir quite usable in this context (Thoroddsen 1906, 1911), but according to Eythórsson (1935), Þórarinsson (1943) and John (1977b) the oldest moraines in front of some of the outlet glaciers from the nearby Drangajökull (25 km southeast of Fannarlag) date from the middle of the 18th century, in front of others from 1840—1850. This agrees reasonably well with our tentative dating of the outermost Fannarlag moraines to 1860 or older.

The M, value of about 28 mm at point 0 indicates that some time has passed since the glacier disappeared. If a colonization time of at least 5 years is used and a growth rate of 0.5 mm/yr, a deglaciation date around 1920 is reached.

PRESENT GLACIATION

Today only four cirques within the studied area of Hornstrandir contain glaciers. Three of these lie inside Hornvik, with their floors around the 500 m level, and one inside Hlóuvík with its floor around the 300 m level (Fig. 13). The Hlóuvík glacier is exceptional, since several higher situated cirques in its neighbourhood are unglaciated. In all, the total area of the four cirque glaciers on northern Hornstrandir today is only 1.0—1.5 km². To this come an undefined number of small ice-cored perennial snowdrifts and firm at various, mostly high, altitudes. The cirques containing ice today contained much larger (Hlóuvík) or somewhat larger (Hornvik) glaciers during the Little Ice Age (Fig. 13).

The present ELA for cirques on northernmost Hornstrandir lies around or slightly above 500 m. The general glaciation limit lies above 600 m. This should be compared with an ELA, in an open position, at 700—800 m on Drangajökull (Th. Einarsson 1968).

LATE FLANDRIAN TRANSGRESSION

Today’s sea level on Hornstrandir has risen in comparison with earlier parts of the Flandrian. This is indicated by the coastal erosion of the low level fluvial/lacustrine sediments in Hlóuvík – with simultaneous deposition of very coarse beach material onto parts of the cliff face. Distinct erosional cuts in the fronts of talus cones, especially below Kúgur north of Fljótavík (Fig. 16) probably also indicate a presently rising sea level.

SUMMARY AND DISCUSSION

(1) During the last (Weichselian) glaciation the Vestfirðir peninsula was probably covered by an independent ice cap (Thoroddsen 1906, Þórarinsson 1937, Th. Einarsson 1968, John 1977a, Sigurvinsson 1983). The
evidence from Hornstrandir, in a peripheral position with regard to the Vestfirðir peninsula, suggests that during the Weichselian glaciation the high plateaux were not covered by active glaciers, as no signs of glacial erosion or deposition were found there. Possibly the plateaux were covered by thin, inactive and/or cold based glaciers or firns. Using the maximum value for the thickness of active glaciers, an approximation of their maximum horizontal extent leads to the conclusion that during the Weichselian maximum glaciation they could not have extended more than some 6–10 km off the present coast. We suggest that two concentric zones of shallow banks at the entrance to Adalvík may be of glacial origin, and that the outermost bank possibly represents the Weichselian maximum position of the ice front. According to our concept the ice extent here, during the Weichselian maximum, was much more limited than proposed by Andersen (1981). The nunataks, plateau edges and slopes could probably have provided some refuge for plants and animals.

(2) During deglaciation the sea level reached 26–15 m higher than today. Morphological and stratigraphical evidence shows that the general retreat of the glaciers was interrupted by a readvance before final deglaciation of the area. Despite extensive search we did not find any organic material to absolutely date the deglaciation, but on the basis of analogy with other areas in Iceland, we propose that the readvance occurred during the Younger Dryas period.

(3) Shortly after the final deglaciation, a heavy influx of basaltic tephra took place. This tephra, the Hælaðvik tephrta, will be a scope of a separate study as it could constitute an important marker horizon, if found in connection with dateable material elsewhere. The tephra could also open the possibility to link the Hornstrandir record with the deep-sea record, as important deep-sea cores with tephra horizons have been taken from the surrounding seas (Kellogg 1980, Kellogg et al. 1978, Ruddiman and McIntyre 1981). Efforts are being made to extend the well dated tephotoochronological record back to Late Weichselian time, to allow for correlation of marine and terrestrial data (Mangerud et al. 1984).

(4) During the Little Ice Age, glaciers were re-established in 7–10 cirques on northern Hornstrandir, with a total glaciated area of 8–10 km². The ELA in the glaciated cirques varied with exposure, between 300 and 500 m above present sea level. There were no glaciers on western Hornstrandir during the Little Ice Age. Today, four cirques on northern Hornstrandir contain small glaciers, with a total area of maximum 1.5 km². Lichenometric studies at one site indicate that the maximum extent of the Little Ice Age glacier there was reached around or before AD 1860 and that the glacier had almost disappeared by AD 1920.

(5) Coastal erosion of talus cones and of lacustrine/fluvial sediments is interpreted as indicating that sea level has risen in comparison with earlier parts of the Flandrian. This is in contrast to Tr. Emnarsson (1946, L. 35, Ær. 25)
1972), who proposed that sea level had remained constant on the Vestfirðir peninsula for a considerable period of time, and to Thoroddsen (1892a) who held the view that marine regression was in progress in the area.

(6) It is evident from the present investigation that a reconstruction of the glacial history of Hornstrandir cannot be but tentative, as correlations are difficult to make due to few and scattered sections, often low preservation potential of geomorphological features and a lack of datable organic material in the Late Weichselian/Early Flandrian sequence. Our knowledge of the glacial history of the North Atlantic in general, and of areas around the Greenland Sea in particular, has gradually increased during the past few years (Boulton 1979, Boulton et al. 1982, Funder 1982, 1984, Hjort 1981, 1985, Hjort and Björck 1984, Ruddiman and McIntyre 1981). Hornstrandir is affected by the same weather system which brings precipitation to northeastern Greenland, and thus all information from northern and western Greenland is valuable when reconstructions of the palaeoenvironments in the Greenland Sea area are attempted.

(7) Our concept of the glacial history and sea level changes on Hornstrandir is summarized in Fig. 17.

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Ágrip

Sjókvarter jarðfræði og jökulnarsaga Hornstranda

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**Raunvísin í Íslandi

Hornstrándir eru um margt þugavert sveði frá sjónarhorni ísálar- og jökuljárðafreið. Hornstrándir eru innan marka sömu vedurfarðarfer, sem beru úrkomað á Nordsæltan Grænlendi og valda jöklabreytingum þar, og það er þugavert að víta að hve miklu leyti jöklabreytingar sitt hvoru megin við Grænlandssundin eru samstig. Þá hafa verið teknir borkjarnar úr þæginni norður- og vestur á Vatnajökullum, sem gefið hafa upplýsingar um vedurfarðbreytingar, og froðleg það er að kanna hvort þaðar niðurstöðvar fást af Hornströnum. Einnig hefur síð stofnaði verið nefndur að Hornströnum hafi á jökultíma verið þaisla sveði, er verið hafi gríðastaður þannadu og fyrirtækja.

Raunvísin í Íslandi er byggð á könnunum heimildar, fulltum flugmyndar og þegjja við hindraðu á Hornströnum, á sveðinum milli Hælavikurhjarg og Aðalviku.

Við fundum engin ummerki eftir virka jökla á þásalitínum (ófán við 400–500 m), þó að vel sé hussanganleg að þar hafi á jökultíma verið óvirkir og eða botnfornir þunniir jöklar. Við þællum álykkt skrijðjökla á jökultíma og reiknuðum út hve langt út fyrir núverandi strið þær kunni að hafa skrifð. Samkvæmt niðurstöðum um okkar hafa þær í mestalagi náð um hálfa leit út að landgrunnsmórkum (5. mynd). Jökulumarmörk, er sost jökulskeið stöð sem hæst, hafa verið niður við 150 m yfir núverandi jásavarmál, en nú eru jökulumarmörk á Hornströnum ofan við 500 m. Skrá niðurstöðum okkar hafa vart verið stór íslætt sveði á Hornströnum er sost jökulseïka stöð hæst. Fryst og fremsk het verið einstök jökulsóknir, rímar með jökurum Ísafjarðartangi og bæjar fjalshliðarofan við skrijðjökullana. Ef til vill hefur hluti landgrunnsins verið þurr, íslætt land.


Á Litlu Ísóldum mynduðust jöklar í 7 til 10 hvilftum á norðurhluta Hornstranda (13. mynd). Jökulnarmórk voru dálfrð mismunandi eftir legu hvílftanna, á blínum 300 m til 500 m, en sumir jöklanna gengu fram úr skálam sínum allt að 150 m niður fyrir hvíllatáttum. Við gerðum tilraun til að meta hverar hámarksút-breidsla jökla varð á Hornströndum á Litlu Ísóld með fleittumælingum (Lichenometry) á jökulgöðum í Fannarlágr (7., 13., 14. og 15. mynd) í Hælavík. Níðurstöður okkar benda til að hámarksút-breidsla jökulsins þar hafi verið um 1860 e. Kr., ef til vill litlu fyrri. Hörfunarhráða jökulsins áætluðum við allt að 30 m á ári, en hann var hörfinn um 1920. Flattarmál jökla á Litlu Ísóld á norðurhluta Hornstranda var 8–10 km². Nú eru jöklar í fjörum hvílfum, alls 1.0–1.5 km² að flattarmál.


Við ætlum okkur að vinna áfram að rannsóknun á Hælavíkurgjóskum og freista þess að tengja hana við þekkt gjoskulg í útahafsþjónum og á Íslandi.