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Late Weichselian Glacial Geology of the Lower Borgarfjördur Region, Western Iceland: a Preliminary Report

ÓLAFUR INGÓLFSSON[1]

ABSTRACT. Morphological and lithostratigraphical investigations have revealed two successive glacial advances of Late Weichselian age in the lower Borgarfjördur region, Western Iceland. Studies of the Melabakkar-Ásbakkar coastal cliffs have disclosed a complex of glaciomarine sediments and tills, accompanied by glaciofluvial deposits from ice marginal sources. A brief description is given for each of the major lithostratigraphical units, and a depositional model for the sequence is outlined. The first glacial advance occurred some time shortly after 12 000 radiocarbon years before present (BP), and the second one around 11 000 BP. By 10 000 BP the glaciers had retreated from the lowlands and the sea transgressed to 60 m above present sea level, where extensive marine terraces were formed.

Key words: Borgarfjördur, western Iceland, Melabakkar-Ásbakkar, glacial geology, glacial chronology, Late Weichselian

RÉSUMÉ. Des études morphologiques et lithostratigraphiques ont signalé deux crues de glaciers du Weichsel supérieur dans le sud de la région Borgarfjördur, dans l'ouest de l'Icelande. Des études des falaises côtières Melabakkar-Ásbakkar ont mises à jour un complexe de sédiments et de moraine de fond glaciomarins accompagnés de dépôts glaciofluviaux provenant des extrémités de glaciers. Chaque unité lithostratigraphique importante est brièvement décrite et un modèle du dépôt est exposé dans ses lignes générales. La première avance de glacier se déroula peu après le XII[e] millénaire (au carbone 14) avant notre ère, et la deuxième, vers le XI[e] millénaire avant notre ère. Les glaciers s'étaient retirés des terres basses avant le X[e] millénaire avant notre ère et la mer avait monté à 60 m au-dessus du niveau actuel de la mer, formant d'importantes terraces marines.

Mots clés: Borgarfjördur, ouest de l'Icelande, Melabakkar-Ásbakkar, géologie glaciale, chronologie glaciaire, Weichsel supérieur

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INTRODUCTION

The present study deals with the glacial geology of the lower Borgarfjördur region, western Iceland (Fig. 1). Its aim is (a) to establish a detailed lithostratigraphical division of the Borgarfjördur sediments and model the different Late Weichselian glacial environments, and (b) to establish a chronology for the glacial events, based on radiocarbon datings of subfossil marine mollusc shells.

The main topographical features of the area are two fjords, Borgarfjördur and Hvalfjördur, with adjacent lowlands, the Hafnarfjall-Skardsheidi massif (1055 m), and Mount Akrafjall (643 m). Ingólfsson (1984) reviewed earlier studies of the Late Weichselian glacial geology in the region and outlined important aspects of the continued research. This paper presents the results of the 1983 field season.

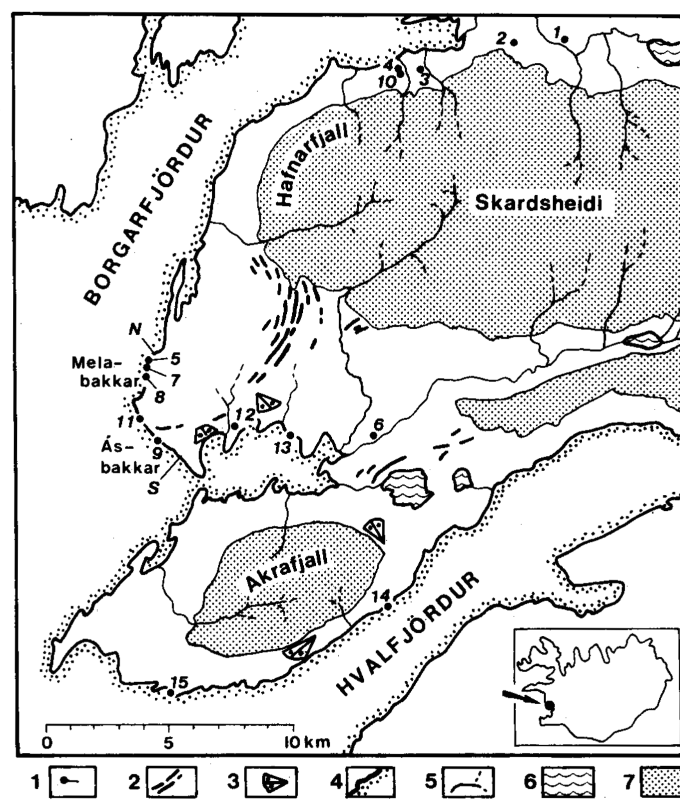

FIG. 1. Locality map. Legend: 1) location of samples in Table 1, 2) terminal moraine ridges, 3) ice-marginal delta, 4) present coastline, 5) rivers and streams, 6) lakes, 7) areas above 100 m a.s.l. The profile section of Figure 2 runs between points *N* and *S*.

SUMMARY OF MAIN RESULTS

1. Glacial geomorphology and strandlines

The Hafnarfjall-Skardsheidi massif is characterized by glacially sculptured ridges, corries and horns. There is no indication that any extensive ice cap covered the massif during any part of the Weichselian. The corries held cirque glaciers, which to some extent fed valley glaciers, but the whole upper part of the massif probably always projected above the ice streams in the valleys. The upper part of Mount Akrafjall was also ice free and divided the Hvalfjördur ice stream.

On the lowlands, distinct terminal moraines and ice-marginal deltas mark the extension of glaciers during the Late

[1]University of Lund, Department of Quaternary Geology, Sölvegatan 13, S-223 62 Lund, Sweden.

Weichselian glacial advances (Fig. 1). Striated bedrock underlying the sediments show that the glaciers extended beyond the present coastline prior to the readvances recognized in the sediments.

Extensive marine terraces exist at about 60 m above the present sea level. Less developed strandlines are found at 90 m, 40 m and 20 m. The 90 m strandline was developed during a time of glacial occupation, but the strandlines at lower elevations postdate the final glacial retreat.

2. *Lithostratigraphy and Late Weichselian environments*

The most important section in the area is the Melabakkar-Ásbakkar coastal cliffs, a roughly 5 km long and 15-30 m high almost continuous section, cutting through a terminal moraine zone. The following brief description illustrates the lithofacies present and outlines the depositional model proposed for the Late Weichselian environments (Fig. 2).

- *Lower glaciomarine silt*: A compact stratified to massive silt with frequent dropstones. Subfossil mollusc shells are frequent in its lower part. Dislocation structures, such as overturned to recumbent folds, thrust faults, and boudinage structures occur in the upper part, indicating overrunning by an advancing glacier.
- *Interbedded flow till and outwash*: A complex association of silt, sand and gravel, with occasional clasts, interbedded in the lower glaciomarine silt. Usually the units are concentrically layered with lobate forms, though non-stratified diamictons also occur. They are interpreted as having been deposited from the snout of a grounded glacier onto the glaciomarine sediments.
- *Submarine glaciofluvial sand and gravel*: This unit has a lower silty sand facies grading upward to an alternating silt, sand and gravel facies. Glaciotectonic deformations occur throughout the unit. It was deposited from meltwater streams entering a marine environment, in front of an advancing glacier. The grading from sand to gravel is interpreted as due to an increasing proximity of the advancing glacier front, and the deformations imply that the sediments were in turn overrun by the glacier.
- *Waterlain till and outwash*: This is an association of stratified silt, sand and gravel, which in structure and texture is similar to the flow till but has a larger lateral extension and a larger number of large clasts. Caps of diamict and diamict lenses occur frequently. It was produced by undermelt and meltwater activity beneath a partly floating, retreating glacier.
- *Upper glaciomarine silt*: A compact stratified silt with dropstones, deposited conformably on the waterlain till and outwash. Subfossil mollusc shells occur. Occasional laminae and thin beds of rippled sand, as well as roll-up structures, could indicate occasional inflow of meltwater into the depositional environment.
- *Lodgement till*: An unstratified, overconsolidated diamict, composed of angular to subrounded cobbles and boulders embedded in a sandy-silty matrix. The contact with the substratum is erosional, and frequently clasts are thrust down into the substratum, causing deformation and shearing. It was deposited by lodgement beneath an actively moving glacier.
- *Glaciofluvial deposits*: The glaciofluvial deposits are highly variable in both structure and texture. Sand and gravel are the most common grain sizes, commonly displaying crossed bedding and other current-induced structures in rather poorly defined horizontal beds. These sediments were deposited at the glacier margin from meltwater streams entering a marine environment and occupy a similar stratigraphic position as the lodgement till.
- *Marine and littoral sediments*: This unit consists of a lower silt facies, with occasional subfossil mollusc shells, grading upward into alternating silt and sandbeds and finally into a horizontally bedded sand facies with burrows. The unit was deposited during a period beginning with a high sea level and followed by marine regression after the glaciers had retreated from the lowlands.

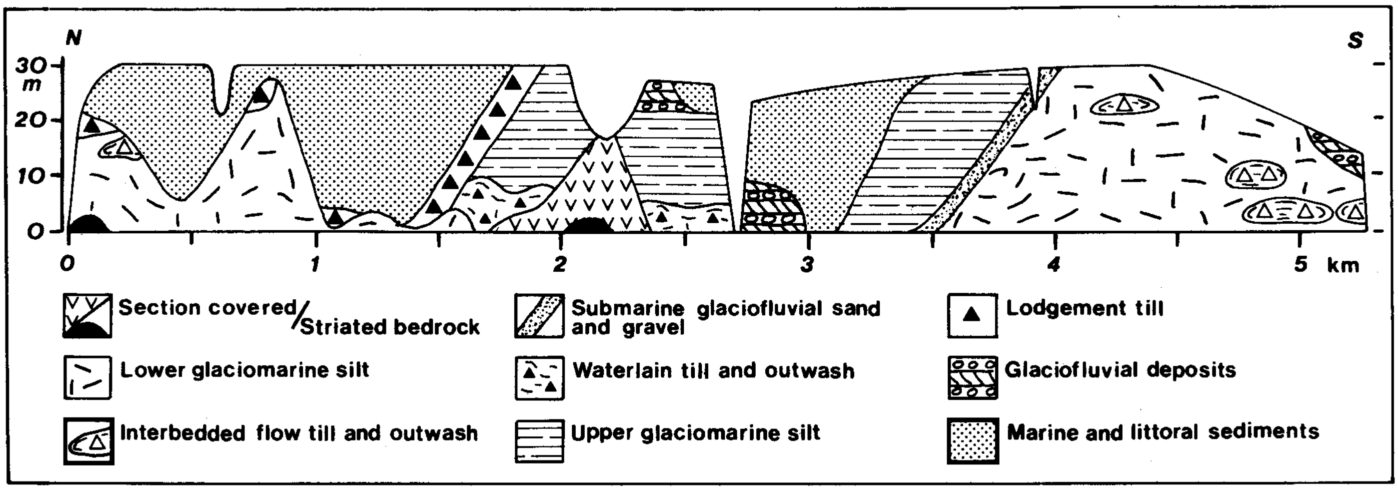

FIG. 2. Diagrammatic profile section of the Melagakkar-Ásbakkar coastal cliffs

TABLE 1. Radiocarbon dates of subfossil marine shells collected from the lower Borgarfjördur region

Location no. (Fig. 1)	Site name	M above sea level	^{14}C date, years BP	Species	Reference no. of date
1	Andakílsárvirkjun	16-24	12 240 ± 200	*Macoma calcarea* (Chemn.), *Mya truncata* Linné, *Hiatella arctica* (Linné), *Lunatia pallida* (Broderip and Sowerby)	I-1825
2	Hreppur	18-23	12 100 ± 250	*Macoma calcarea* (Chemn.), *Hiatella arctica* (Linné), *Mya truncata* Linné, *Balanus* spp.	S-289
3	Árdalur	25-30	12 100 ± 150	*Chlamys islandica* (Müller), *Nucula tenuis* (Montagu), *Astarte montagui* (Dillwyn), *Mya truncata* Linné, *Cardium fasciatum* (Montagu), *Macoma calcarea* (Chemn.), *Hiatella arctica* (Linné), *Margarites groenlandicus* (Chemn.)	S-290
4	Grjóteyri	15-21	12 800 ± 220	*Macoma calcarea* (Chemn.), *Hiatella arctica* (Linné), *Mya truncata* Linné, cf. *Neptunea antiqua* (Linné), *Trophon clathratus* (Linné), *Balanus* spp.	S-291
5	Melar	5	12 290 ± 160	*Chlamys islandica* (Müller)	U-641
6	Laxá	25	12 105 ± 110	*Hiatella arctica* (Linné)	Lu-2055
7	Melaleiti	2	12 465 ± 110	*Chlamys islandica* (Müller)	Lu-2193
8	Melaleiti	4	12 095 ± 120	*Chlamys islandica* (Müller), *Mya truncata* (Linné)	Lu-2192
9	Ásbakkar	2-3	12 505 ± 110	*Chlamys islandica* (Müller)	Lu-2195
10	Grjóteyri	19-20	12 465 ± 110	*Macoma calcarea* (Chemn.), *Hiatella arctica* (Linné), *Mya truncata* Linné	Lu-2194
11	Ásbakkar-Ásgil	3-4	11 615 ± 130	*Chlamys islandica* (Müller), *Mya truncata* Linné, *Buccinum* spp, *Balanus* spp.	Lu-2196
12	Súluá	2-3	10 965 ± 80	*Mya truncata* Linné	Lu-2056
13	Skipanes	11-13	10 005 ± 90	*Chlamys islandica* (Müller)	Lu-2197
14	Gröf	5-6	12 475 ± 110	*Hiatella arctica* (Linné)	Lu-2339
15	Heynes	2-3	11 065 ± 140	*Macoma calcarea* (Chemn.), *Hiatella arctica* (Linné), *Balanus* spp.	Lu-2338

Samples no. 1-4 from Ashwell (1975). Sample no. 5 from Olsson *et al.* (1969). All samples are referred to 0.95 NBS oxalic acid standard, samples 1-5 using the value of 5570 years for the half life of ^{14}C and samples 6-15 using the value of 5568 for the half life of ^{14}C. The base year is 1950. Corrections for $^{13}C/^{12}C$ ratios and apparent age of living marine organisms have been made for samples 6-15.

3. Glacial chronology and a summary of deglaciation history

The chronology is based on a total of 15 radiocarbon dates of subfossil marine shells collected from the sediments (Fig. 1, Table 1).

A total of 11 radiocarbon dates from the lower glaciomarine silt place its age between 12 800 BP and 12 000 BP. During its deposition sea level stood 60 m or more above the present sea level. These dates also give the minimum age of the initial deglaciation of the coastal W-Iceland. At some time shortly after 12 000 BP the glaciers readvanced, overran and deformed the glaciomarine silt and deposited flow till and outwash sediments in a proglacial marine environment.

According to one radiocarbon date from the upper glaciomarine silt, the glaciers had retreated to the tributary valleys around 11 600 BP and in the course of retreat deposited the waterlain till and outwash. The sea level during this phase was still high, and the upper glaciomarine silt was deposited conformably on the waterlain till and outwash. At some time around 11 000 BP a second glacial readvance occurred, and lodgement till and glaciofluvial deposits were deposited in the Melabakkar-Ásbakkar section. This advance is dated by two radiocarbon dates from subfossil high-arctic mollusc assemblages preserved in sediments deposited distally to the glacier margins.

Some time before 10 000 BP the glaciers retreated and finally disappeared from the lowlands. The sea transgressed to 60 m above present sea level, where it remained long enough to allow extensive marine terraces to be formed. One radiocarbon date from the littoral sediments places its age at about 10 000 BP.

DISCUSSION

The picture of the glacial stratigraphy and chronology of the Borgarfjördur region presented here has several interesting aspects which will be developed further:

1. The coastal sections offer unique opportunities to study glacial environments from sedimentological and structural points of view. Continued studies can contribute evidence on how the deposition of stratified diamicts relate to different glacial environments and on the formation and stratigraphical implications of different glaciotectonic phenomena.

2. The glacial stratigraphy and chronology presented here differ markedly from previous interpretations of the Borgarfjördur strata (Ingólfsson, 1984), which will have consequences for the general picture of the Late Weichselian in Iceland. That the last glacial advance in the region occurred during the Younger Dryas chronozone of Mangerud *et al.* (1974) indicates much more extensive glaciation and a harsher climate than hitherto assumed for W-Iceland during that period (*cf.* Einarsson, 1968; Andersen, 1981).

3. The changes in relative sea level inferred from this investigation will result in a more detailed and chronologically better controlled displacement curve than hitherto presented for any part of Iceland.

4. The current research can also contribute to the general discussion on Weichselian glacier variations in the North Atlantic region (e.g., Andrews and Barry, 1978; Boulton, 1979; Hjort, 1981; Andersen, 1981; Funder, 1982; Norddahl, 1983; Hjort and Björck, 1984).

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