The Late Weichselian glacial geology of the Melabakkur-Ásbakkur coastal cliffs, Borgarfjördur, W-Iceland

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ABSTRACT
A 5 km long coastal section in the lower Borgarfjördur region, W-Iceland, was investigated with regard to stratigraphical, sedimentological and structural features, in order to clarify Late Weichselian events. Fossil molluscs were sampled for dating purposes and as environmental indicators. The investigation revealed a 145 m thick sequence of glacial and littoral sediments, deposited in an isostatically depressed basin, where waterdepth and proximity to an ice margin and source of meltwater input were the major controls of lithofacies distribution and stratigraphical associations. Three major units of glaciomarine sediments make up more than half the strata. They are separated by meltwater sediments and tills. Sedimentological and structural data indicate two separate glacial advances out of the Borgarfjördur main valley into the basin. The first advance occurred around 12,000 14C years BP, the second one some time after 11,400 BP. Some time prior to 10,000 BP the glacier retreated and the sea transgressed the isostatically depressed lowlands. These results suggest a more extensive glaciation in W-Iceland during the latest part of the Late Weichselian than hitherto assumed. Some recent models for subarctic glaciomarine fjord sedimentation, and for glacioclimatic deformations, are discussed in the light of the present study.

INTRODUCTION
The coastal lowlands of the lower Borgarfjördur area, W-Iceland (Fig. 1) are blanketed by Late Weichselian glacial and glaciomarine sediments and Late Weichselian to early Holocene littoral sands and gravels (Bárðarson 1923, Ashwell 1975, Ingólfsson 1985). The regional marine limit is represented by marine terraces and shorelines at 60 to 70 m above present sea level. There are indications in the outer coastal areas of an older marine maximum at 80-90 m a.s.l. The Melabakkur-Ásbakkur coastal cliffs are the most continuous section in the area. They are roughly 5 km long and up to 30 m high, and transect a terminal moraine zone, the Skorholtsmellar moraines (Fig. 1). A survey of the geological literature (Ingólfsson 1984) showed that opinions on the Late Weichselian geology and glacial history

![Fig. 1. Locality map. Legend: (1) Terminal moraine ridges, (2) ancient strandlines at 60–70 m above present sea level, (3) glacial striae: a: oldest, b: younger, c: youngest, (4) ice-marginal delta, (5) farm, (6) present coastline, (7) lake, (8) areas above 100 m a.s.l. The coastal profile in Fig. 2 runs between points N and S.](image-url)
of Borgarfjördur are controversial, and that detailed studies on the stratigraphy, sedimentology and morphology of the deposits have been lacking. The Melabakkar-Ásbakkar cliffs are sensu strictu the type locality for Einarsson's (1961, 1968) Álfanes Stadial, correlated with the Older Dryas of Scandinavia (Einarsson 1979) as the Álfanes glacial advance was radiocarbon dated by a molluske sample from these cliffs (Einarsson 1971).

I have studied the Melabakkar-Ásbakkar cliffs in order to identify glacial episodes, by investigating sedimentological and structural properties and stratigraphical relations of the sediments, to provide a depositional model for the sequence. Because of the long, almost continuous section, the geomorphic setting and the preserved subfossil marine mollusks and barnacles in the sediments, the Melabakkar-Ásbakkar cliffs could give important information on depositional environments in a glaciated fjord/bay setting, and also reflect changes in the proximity of the depositional basin to a glacier margin. The present study discusses some recent models for glaciomarine sedimentation and for glaciotectonism. A preliminary report on the glacial stratigraphy and chronology was given by Íggólfsson (1985).

The field work was carried out in 1980, 1983 and 1984. The cliffs are actively eroded by the sea during high tides and westerly storms, which causes difficulties when mapping them, due to their nearly vertical stand and the risk of large scale slumping. The field mapping was thus partly conducted on photographs covering the cliffs in scale 1:200. This allows the recognition of major lithofacies, stratigraphic boundaries and deformational features. Accessible sections were described and measured.

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Fig. 2. Melabakkar-Ásbakkar coastal profile. Legend: (1) bedrock, (2) Ásbakkar diamicton, (3) Ás beds, (4) units of interbedded sands and diamictons, intrabedded in the Ásbakkar diamicton, (5) the Látrar beds cross stratified sand facies, (6) the Látrar beds interbedded silt and sand facies, (7) Melar diamicton, (8) boulders, (9) Landhólimi sands, (10) Ásgil gravels, (11) Melabakkar silts and sands, (12) Melagil gravels and sands, (13) location and no. of radiocarbon dated samples in Table III, (14) section covered, (15) major joints, (16) elastic wedges, (17) normal faults, (18) glaciotectonic deformations, (19) major thrust faults, (20) direction of glaciotectonic thrust, (21) paleocurrent direction, (22) direction of glacial striae on bedrock substratum, (23) location of logs in Fig. 3.

2. mynd. Strandsnúð Mela- og Ásbakka.
<table>
<thead>
<tr>
<th>Facies code</th>
<th>Lithofacies</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmu</td>
<td>Diamicton, matrix-supported, unstratified</td>
<td>Massive to weakly stratified (stratification less than 10% of unit thickness), silt-sand-gravel-boulder admixture</td>
</tr>
<tr>
<td>Dms</td>
<td>Diamicton, matrix-supported, stratified</td>
<td>Clear textural differentiation or structure within a diamicton</td>
</tr>
<tr>
<td>Dcu</td>
<td>Diamicton, clast-supported, unstratified</td>
<td>Massive silt-sand-gravel-boulder admixture with clast-to-clast contact gravel and boulder clasts</td>
</tr>
<tr>
<td>Gu</td>
<td>Gravel, massive to crudely stratified</td>
<td>Crude horizontal stratification, imbrication, minor sand and silt lenses may occur</td>
</tr>
<tr>
<td>Gs</td>
<td>Gravel, stratified</td>
<td>Clear stratification, often alternating openwork and matrix-rich gravels, normal grading, imbrication, minor silt- and sand-lenses</td>
</tr>
<tr>
<td>Ggn/Ggr</td>
<td>Gravel, normal/reversed grading</td>
<td></td>
</tr>
<tr>
<td>Gp</td>
<td>Gravel, stratified</td>
<td>Planar cross-stratification, angular to tangential based foresets, alternating clast- and matrix supported foresets, reactivation surfaces</td>
</tr>
<tr>
<td>G(l)</td>
<td>Gravel</td>
<td>Lag deposits</td>
</tr>
<tr>
<td>B</td>
<td>Boulders</td>
<td>Lag deposits</td>
</tr>
<tr>
<td>Su</td>
<td>Sand, massive to weakly stratified</td>
<td>Poorly sorted, may be silty or gravelly, minor intrabeds of sorted sand and silt, dish structures</td>
</tr>
<tr>
<td>Ss</td>
<td>Sand, stratified</td>
<td>Planar-parallel bedding, clear stratification, fine to coarse sand, normal grading, occasional rippled surfaces, intralaminae of silt, occasional gravel trains</td>
</tr>
<tr>
<td>Sp</td>
<td>Sand, stratified</td>
<td>Planar cross-stratification, angular to tangential based, normal graded foresets, poorly sorted, may be silty, sometimes interbedded gravel trains or diamicton lenses, reactivation surfaces</td>
</tr>
<tr>
<td>St</td>
<td>Sand, stratified</td>
<td>Trough cross-stratification, poorly sorted, pebbly</td>
</tr>
<tr>
<td>Sl</td>
<td>Sand, laminated</td>
<td>Fine sand to poorly sorted sand, laminated to thin-bedded, usually interbedded with silt. Soft sediment deformations, palaeocurrent indication structures</td>
</tr>
<tr>
<td>Fu</td>
<td>Fines (silt, clay), unstratified</td>
<td>Massive to weakly stratified, usually sandy. Discontinuous intralaminae of sand</td>
</tr>
<tr>
<td>Fl</td>
<td>Fines (silt, clay), planar parallel lamination, laminated sometimes sandy, usually interbedded with sorted sand, occasional rippled surfaces, soft sediment deformations</td>
<td></td>
</tr>
</tbody>
</table>
in greater details. Bedding type, thickness, contacts, sedimentary structures, texture, defomational features, fossils, and vertical and lateral facies relations, were used to define and interpret the stratigraphic units. Subfossil molluscs were sampled for dating purposes and used as an aid in the environmental interpretations.

The textural analysis of the sediments was done in the field, with a laboratory check of selected samples. The grain-size scale used is the Udden-Wentworth graded scale (Blatt, Middleton and Murray 1972, p. 46). The term "gravels", if not specified, includes granules, pebbles and cobbles. For documentation and interpretation of the sedimentological data a modified version of the lithologic code of Midll (1977) and Eyles et al. (1983) was used (Table 1). I omit the interpretative parenthized last letter of the Eyles et al. (1983) code, except when describing regionally extensive lag concentration deposits (G(i)). Chronostratigraphical terminology used is in accordance with Monger and Berglund (1978).

STRATIGRAPHY AND FACIES RELATIONSHIPS

A profile section of the Melavakkar-Áshakkar cliffs is shown as Fig. 2. The base of the profile is the high tidal stand. The lower contact of the sequence where observed is striated bedrock, bearing witness to a glacial episode when the glaciers extended beyond the present coast, prior to the glacial events registered in the strata. The age of this oldest glacial episode is not known. All

Fig. 3. Lithologic logs from the cliffs. For locations and correlations see Fig. 2. Lithologic code in Table I. Inserted figure: A composite vertical section (not to scale) showing lithofacies, stratigraphy and facies interpretations.


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descriptions give locations as the distance in m from the northernmost point of the cliffs. Point 0 in Fig. 2.

THE ÅSBAKKAR DIAMICTON: A GLACIOMARINE FACIES ASSOCIATION

The lowermost stratigraphical unit in the sequence, resting on striated bedrock, is composed of two major lithofacies of diamicton (Dms, Dmu) and a number of intrabedded units of diamictons, sands and gravels (Logs A and H, Fig. 3). The Åsbakkar diamicton makes up the bulk of the cliffs over long stretches (Fig. 2). All its lithofacies can be seen in the Åsbakkar-part of the section.

Facies Dms

Description:
The lowest lithofacies is a fossiliferous, matrix supported, vaguely to clearly stratified silt diamicton with occasional gravel and pebble clasts (Fig. 10A). The stratification is due to occasional laminae and thin interbeds of medium sorted to nonsorted sand (Sl, Ss). The diamicton is light gray to slightly bluish gray in color, compact to lithified. The grain size of the matrix (samples 1 and 2, Fig. 4) is silt with a minor content of sand. A thin section study of a third sample showed that 85% of the matrix was silt with interstitial altered volcanic glass fragments, and 15% sand grains and granules. Facies Dms is rich in subfossil marine molluscs and barnacles, which are not in situ, primarily due to postdepositional deformation of the sediments.

Fig. 4. Grain size distribution for selected samples from the sequence. Samples from (1) Åsbakkar diamicton, (2) Látrar beds, (3) Melabakkar silts and sands, (4) Ás beds. (5) Asgil gravels, (6) Melagil gravels and sands. Samples described in the text refer to figures within the triangle.
4. mynd. Kornastárbaradreifing nokkurra sýna frá bókurnum.

The shells are evenly distributed in the sediments, except in the random beds of gravely sand (sample 6, Fig. 4) where concentrations of shells that have been subject to transport occur. The transport has probably only been slight as paired valves were found, and external ornamentation, siphon sheath, periostra-

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>GLACIOMARINE UNIT</th>
<th>RECENT DISTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Lusitanian</strong></td>
<td><strong>Boreal</strong></td>
<td><strong>Arctic</strong></td>
</tr>
<tr>
<td>Natella (Tectanata) affinis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trophon (Boreotrophon) truncatus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Culina fusiformis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccinum undatum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nucula (Leionucula) tenus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlamys (Chlamys) islandica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tridonta (Tridonta) elliptica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tridonta (Nicania) montagu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macoma (Macoma) calcaria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiatella (Hiatella) arctica</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mya (Mya) truncula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanus (Balanus) balanus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balanus sp.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Rare, fragments only; ** Present; *** Common; **** Very common

TABLE II.


TAFLA II: Fornskeljar úr melo- og Asbókum: Tegund, staðsetning, landfræðileg dreifing f dag.

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Fig. 5. Major processes operating in a fjord/bay glaciomarine environment. Compiled and modified from Boulton and Deynoux (1981), Elverhøi (1984), Powell (1984), Eyles et al. (1985), Stevens (1985).

5. mynd. Setmyndin í sjó framan við jökulsárað.

Fig. 6. Melabakkar-Ásbakkar glaciomarine lithofacies. (A) Ásbakkar diamict at 800 m. Broken line shows contact with the overlying Melar diamicton. Arrow points at en echelon patterned joints; (B) A body of interbedded stratified diamictons and sands, intrabedded in facies Dmu of the Ásbakkar diamicton at 3000 m; (C) The Látrar beds at 2600 m: transition from planar cross stratified esker fan sediments, over stratified diamicton to interbedded laminated slits and sands. The exposure cuts facies Sp parallel to foreset strike. Note the upwards trend towards planar parallel stratification; (D) The Melabakkar slits and sands at 500 m: a transition from glaciomarine slits to sublittoral sands.

6. mynd. Ásínd jökulsávarseta í bókkunum.
cum and ligament are often preserved, even though the shells may be broken. Whole individuals of Balaena balaena were also found. The fossil fauna assemblage (Table II) is a mixture of epifaunal and infaunal species.

**Interpretation:**
The sedimentological and palaeontological data suggest a shallow water, low salinity, boreal to mid-Arctic fjord environment. The indistinct rhythmic character of the sediments suggests that sedimentation occurred primarily from turbid overflows and suspension (Fig. 5) but stratification may have been destroyed by bioturbation. The laminae and thin beds of sand cannot be related to seasonal or other periodic control. More likely they represent random density underflows from delta slopes or other unstable surfaces. The random intrabeds of gravelly sand are stratified to graded, occasionally with erosive lower contact. I interpret them as lag deposits caused by bottom currents. The tidal amplitude in Børgefjord today is about 4 m, generating strong tidal currents.

Palaeoecological interpretation of the fossil fauna assemblage puts it with the Macoma calcarea community, a boreal to arctic mollusc community described in East Greenland by Thorson (1933) and Ockelmann (1958) and from Vestspitsbergen by Feyling-Hanssen (1955). Most individuals of Mya truncata belong to forma uddevallensis, which is a thick-shelled, panarctic, circumpolar form, e.g., described from Late Weichselian sediments on Vestspitsbergen (Feyling-Hanssen 1955) and Upper Pleistocene sediments on West Greenland (Simonarson 1981). The Macoma calcarea community prefers silty and sandy-silty fjord bottoms with low salinity, water temperatures below +5°C and water depths less than 45-50 m (Thorson 1953, 1957). Spjælkesnes (1978) pointed out that the Macoma community prefers low salinity “fjord water” conditions, and thus can be found at greater water depths than 50 m if the local fjord topography and sufficient input of freshwater allow it.

There is no conclusive evidence of a nearby glacier during the deposition of facies Dms, and I interpret this as a ice-distal to ice-intermediate facies (Fig. 5). The occasional granule and pebble clasts are probably ice rafted, either as dropstones from icebergs or rafted from winter ice.

Powell (1981, 1983b) and Molnia (1983) have described distal glaciomarine sediments off the Alaskan coast as bimodal due to a combination of sedimentation from suspension, underflows and ice rafting. Domack (1984) and Stevens (1985) described rhythmically bedded glaciomarine sediments of late Pleistocene age, where fluctuations of meltwater discharge and sediment load into a density stratified nearshore marine environment are called upon to explain the stratification. Stevens (1985) pointed out that more distally within the glaciomarine environment the rhythmic character probably becomes less distinct due to weaker and more irregular density stratification, lower and more homogeneous sediment supply and increased bioturbation.

**Facies Dm**

**Description:**
Facies Dms grades into facies Dmu, a sandy-silty, massive diamict, with relatively fewer fossils but with an increased number of gravel and boulder clasts (Fig. 6A). The increased ratio of sand and gravel in facies Dmu compared to facies Dms is reflected in samples 3, 4 and 5 in Fig. 4. Upwards in the facies the fossil molluscs gradually disappear, and intrabedded units of stratified and massive diamictons (Dms, Dmu) and stratified sand (Ss, Ss) occur frequently. The gravel and boulder clasts are angular to subrounded, and on one occasion a faceted and striated boulder was recognized. The clast distribution varies both laterally and vertically, from isolated clasts to clusters with grain-to-grain contacts. No preferred clast orientation was observed, but on a few occasions the stratum below a clast was bent downwards (Fig. 7A).

**Interpretation:**
I interpret the transition from facies Dms to Dmu, to reflect increasing proximity of the depositional basin to the sediment source, an advancing ice front. Increase both in the rate of sedimentation and brackishness of the

![Fig. 7. Structures from the Melabakkar–Ashakkar sediments, drawn after field sketches and photographs: (a) downbended strata below outsized clasts in the Ashakkar diamicton, (b) convolute structures of stratified diamictons and sands in the Ashakkar diamicton at 4750 m, (c) "roll-up" structures in the Látrar glaciomarine facies. Palaeocurrent from right. 7 mynd. Dæmi um byggisingarlag sets i bókkum.](image)
water could explain the disappearance of molluscs from the sediments. I interpret the sandy facies of facies Dmu to have accumulated through a combination of settling of suspended material from turbid overflows (the silt fraction), iceberg rafting (the sand and outsized clast fraction) and possible density flow input of sand. The interbedded units will be treated separately below.

There is some controversy in the scientific literature as to the proximity of ice-rafted glacimarine facies to a glacier margin (Boulton and Dreyfous 1981, Molnia 1983, Powell 1983a, 1984, Mackiewich et al. 1984). Though iceberg dropped coarse detritus enters the proximal glacimarine environment, it can be masked when incorporated in the fjord floor sediments due to the dilution effect of the much greater volume of finer grain sizes. The relative magnitude of iceberg dropped material, compared to other genetic components in the iceproximal environment, is a function of calving activity, meltwater activity and debris content of the ice, i.e. it varies in time and space for individual depositional basins, and given favourable conditions should be recognizable very close to the ice front. In the case of Borgarfjörður, the high and steep mountains on the fjord/valley eastern flank, and their easily weathered volcanic rocks, could have introduced large quantities of debris onto the surface of a passing valley glacier. In a few instances in the cliffs, isolated mounds, pods or lenses of material, on the whole much coarser than the surrounding sediments, were observed. These fit well to descriptions given by Thomas and Connell (1985) and Domack and Lawson (1985) of dump structures resulting from release of debris aggregates from overturning icebergs. Powell (1983b, 1984), Domack (1983) and Domack and Lawson (1985) have modelled ice-rafted diamict deposition in a proglacial marine environment. I suggest that facies Dmu, with a peak in dropped detritus, was deposited in an environment similar to Powell's (1983b) glacimarine environment in front of a slowly advancing, actively calving tidewater glacier, and corresponds to the dispersed meltwater and ice-rafted facies of Domack (1983). I interpret this environment as an ice-intermediate (molluscs disappear) to ice-proximal depositional environment (Fig. 5).

The intrabedded units

Description:
Intrabedded in the Åshakkari diamicton are units of intrabedded sand (Ss, Si) and diamictons (Dms, Dmu). These are most conspicuous in the southernmost part of the section (4900-5250 m in Fig. 2). They usually occur in poorly defined lenses or tongues, randomly stacked or superimposed on each other, often with a lamina or thin bed of silt on the bounding surfaces (Fig. 8). Occasionally, the intrabedded units have a lobate-like appearance, with sharp to erosive base and slightly convex upper contacts (Fig. 6B). There is a tendency towards concentration of coarser clasts at the base of some of the units.

The diamicton lenses (Dms, Dmu) differ from the surrounding Åshakkari diamicton in having a coarser texture, with subangular to rounded gravel clasts, floating in a sandy-silty matrix. The stratified diamicton lenses have weakly stratified silt, sand and gravel in the outer parts, and a core of either silty diamicton or massive silty sand. The stratification is an expression of intraformational discontinuous sand and silt bandings and lami-

Interpretation and discussion:
The Åshakkari diamicton is glaciectonically deformed (see later) and the intrabedded units are often displaced so that it is difficult to reconstruct their primary sedimentary geometry. A glaciectonic origin of some of the structures observed cannot be ruled out. I propose that the intrabedded sand and diamicton facies are formed due to resedimentation processes and meltwater influx, where semi-plastic to liquefied glaciogenic sedi-

Fig. 8. A close up of an interbedded diamicton and sand body in the Åshakkari diamicton at 5100 m: (1) silty-sandy, stratified diamicton, (2) pebbly, massive diamicton. Black arrows point at the sharp but conformable contact with the Åshakkari diamicton. White arrow points at an intraformational silt lamina. 8. mynd. Seteining í Åshakkum.
ment debris flows or slumps off an ice front and/or submarine morainal bank were deposited as vaguely defined lobes or lenses together with stratified sands from meltwater streams.

The deposition by flow mechanisms of glaciogenic debris in the ice-proximal glaciomarine and glacilacustrine environments has been discussed by various authors during the past few years, and the existence of subaqueous deposits of an origin similar to Boult's (1968) "flow tills" and Lawson's (1979) "sediment flows" is well established (May 1977, Evenson et al. 1977, Dreimanis 1979). Hicock et al. 1981, Cheel and Rusi 1982, Powell 1983a, 1983b, Domark 1983, Gravenor et al. 1984, Broster and Hicock 1985, Eyles et al. 1985). The characteristics of glaciogenic subaqueous debris flow deposits include unit geometries, deformation structures resulting from penecontemporaneous slumping and liquefaction, flow structures formed during deposition, and content of glacially abraded clasts. Gravenor et al. (1984) stated that in most cases it is difficult to determine if a debris flow originated directly from ice surface or from a break in the paleoslope or an unstable pile-up of debris in the proglacial environment. They suggested that such flows should be called "glaciogenic subaqueous debris flows", indiscriminately of flow origin.

The Åsbakkar diamict, a discussion:
The maximum thickness of the Åsbakkar diamicton is 35-40 m. Radiocarbon dated shells place its deposition between about 12,500 and 12,000 14C years BP (Table III, samples R1 to R6). The radiocarbon dated shells give decreasing ages upwards in the sequence, and from them sedimentation rates of 0.54 × 10⁻² m · yr⁻¹ to 3.6 × 10⁻² m · yr⁻¹ can be calculated for the lower, fossiliferous part of the sequence. This can be compared to average Holocene glaciomarine sedimentation rates for the Gulf of Alaska shelf, 0.45 × 10⁻² m · yr⁻¹ (Mollus 1983), and 5 × 10⁻² m · yr⁻¹ to 1 × 10⁻² m · yr⁻¹ for the inner basin of Kongsfjorden, W-Spitsbergen (Elverhøi et al. 1983). The Åsbakkar diamicton is bounded upwards by a glacial unconformity except in the southern part of the cliffs, from ca. 3650 m, where it is partly conformably overlain by the Áls beds (see later). The thickness of the Åsbakkar diamicton in the section ranges from a few cm to about 25 m. It is compact and sometimes lithified. A thin section study showed a tendency of sideromelane

**TABLE III.**
Radiocarbon dates of subfossil marine shells collected from the Melabakkar-Åsbakk sequence.

<table>
<thead>
<tr>
<th>Location no. (Fig. 2)</th>
<th>Sample name</th>
<th>m above sea level</th>
<th>14C date, years BP</th>
<th>Species</th>
<th>Reference no of date</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Melabakkar-Melaleiti</td>
<td>2</td>
<td>12.465±110</td>
<td><em>Chlamys islandica</em> (Muller)</td>
<td>Lu-2193</td>
</tr>
<tr>
<td>R2</td>
<td>Melabakkar-Melaleiti 2</td>
<td>4</td>
<td>12.095±120</td>
<td><em>Chlamys islandica</em> (Muller), <em>Mya truncata</em> (Linneé)</td>
<td>Lu-2192</td>
</tr>
<tr>
<td>R3</td>
<td>Åsbakkar 1</td>
<td>2-3</td>
<td>12.505±110</td>
<td><em>Chlamys islandica</em> (Muller)</td>
<td>Lu-2195</td>
</tr>
<tr>
<td>R4</td>
<td>Ås</td>
<td>23-25</td>
<td>12.015±110</td>
<td><em>Chlamys islandica</em></td>
<td>Lu-2379</td>
</tr>
<tr>
<td>R5</td>
<td>Åsbakkar 3</td>
<td>3-4</td>
<td>11.945±110</td>
<td><em>Chlamys islandica</em> (Muller), <em>Hiatella arctica</em> (Linneé), <em>Balanus</em> spp.</td>
<td>Lu-2377</td>
</tr>
<tr>
<td>R6</td>
<td>Åsbakkar-Ásgil 1</td>
<td>2-3</td>
<td>11.615±130</td>
<td><em>Chlamys islandica</em> (Muller), <em>Mya truncata</em> (Linneé), <em>Buccinum</em> spp., <em>Balanus</em> spp.</td>
<td>Lu-2196</td>
</tr>
<tr>
<td>R7</td>
<td>Åsbakkar-Ásgil 2</td>
<td>3-4</td>
<td>11.715±120</td>
<td><em>Chlamys islandica</em> (Muller), <em>Mya truncata</em> (Linneé), <em>Hiatella arctica</em> (Linneé), <em>Asterina elliptica</em> (Brown)</td>
<td>Lu-2372</td>
</tr>
<tr>
<td>R8</td>
<td>Åsbakkar-Ásgil 3</td>
<td>3-4</td>
<td>11.545±140</td>
<td><em>Chlamys islandica</em> spp., <em>Balanus</em> spp.</td>
<td>Lu-2373</td>
</tr>
<tr>
<td>R9</td>
<td>Ásbakkar 2</td>
<td>6-8</td>
<td>11.465±100</td>
<td><em>Mya truncata</em> (Linneé), <em>Hiatella arctica</em> (Linneé)</td>
<td>Lu-2376</td>
</tr>
<tr>
<td>R10</td>
<td>Melabakkar-Melar 1</td>
<td>3-20</td>
<td>11.985±120</td>
<td><em>Chlamys islandica</em> (Muller), <em>Mya truncata</em> (Linneé), <em>Balanus balanus</em> (Linneé), + unidentified fragments.</td>
<td>Lu-2375</td>
</tr>
</tbody>
</table>

(Scattered fragments)

All samples are referred to 0.95 NBS oxalic acid standard, using the value of 5568 for the half life of 14C. The base year is 1950. Corrections for 14C/13C ratios and apparent age of living marine organisms have been made for all samples, using the reservoir age 565 ± 20 years (Håkansson 1983). Samples R1, R2, R3, and R4 were described and discussed by Håkansson (1984).
grains in the matrix to be altered into palagonite, which then can be seen as a cementing substance. The sediments lack other diagnostic characteristics of palagonite, such as a brownish color or precipitation of opal and zeolites.

The relative sea level was high during the deposition of the Ás bakkar diamicton, possibly at the marine maximum limit at 80-90 m some time during its deposition. A shell sample from the Skorradalur valley, dated to about 12,500 BP (Aashwell 1975), implies that at that time the relative sea level was above 62 m a.s.l., which is the elevation of the valley threshold.

THE ÁS BEDS: A MORAINAL BANK FACIES ASSOCIATION

The Ás bakkar diamicton is over lain by a sequence of gravels, sands and diamictons, the Ás beds. They are exposed in the cliffs below the Ás farm (Fig. 1), between 3550 m and about 4700 m in the section (Fig. 2 and Figs. 4 and G in Fig. 3). The Ás beds have four major characteristics: (1) Their lower contact with the Ás bakkar diamicton is locally gradational and conformable, indicating continued submarine deposition, and locally a glaciotectonic thrust plane. (2) Except for the lowest part of the strata, beds are discontinuous and laterally variable in thickness. (3) There is a clear coarsening upwards trend in the unit from silty sands to coarse gravel. (4) The unit is bounded upwards by a surface of glacial erosion and shear. Its uppermost part is at places so sheared and mixed that it is difficult to recognize primary textures, fabrics and geometries.

The Ás beds gravel facies
Description:
The gravel facies are most conspicuous in the Ás beds sequence, especially in its upper part between 3550 m and 3900 m in the cliffs, and constitute about half its total thickness. Four major lithofacies of gravel were recognized: normally graded gravel (Gg), reverse graded gravel (Gsr), massive to weakly stratified gravel (Gu) and planar cross-stratified gravel (Gp). The gravel facies are interbedded with units of sands and diamictons described below. The gravel facies are discontinuous and laterally variable in thickness. Typical dimensions for individual units are thicknesses of less than 1 m and a lateral extent of less than 40 m. Unit contacts are sharp and sometimes erosional. The gravel is unconsolidated and poorly sorted, and the graded facies show variations from pebble-cobble gravels to sandy pebble gravels or vice versa. Lenses of sorted grain-to-grain contact pebbles, sometimes showing imbrication, occur in all gravel facies. The imbricated fabrics indicate a depositing stream or current from a northerly direction. Laminae and lenses of silt, thin beds of crudely stratified to laminated sand and massive to stratified diamicton occur in all gravel units, except in facies Gp. Facies Gp is a 2-3 m thick isolated set of planar, tangential-bedded cross-stratified sandy gravel with foreset bed thicknesses of 10-30 cm. Individual beds extend over the full thickness of the unit and dip at an angle of 8-17° towards SW.

The Ás beds sand and silt facies
Description:
The lowest part of the Ás beds, which can be seen at intervals between 3650 m and 4700 m, is up to about 8 m thick unit of stratified sand (Ss). Its lower part is poorly sorted and pebbly (samples 14 and 15, Fig. 4), with stratification due to normal grading of individual 5-40 cm thick beds from gravelly sand to poorly sorted sand. Upwards the unit grades to stratified silty sand, with laminae and thin intra beds of sandy silt (Fs) and coarse to fine sand (S1 Sa Su Ss). Random rippled bedding surfaces and isolated structures such as sand lags and rip-ups of sandy silt laminae also occur. The unit is heavily sheared, and its lower gravelly part is partly incorporated in a large fold (Fig. 12). The silty upper part is lithified, at least partly due to palagonitization (precipitates of opal present). The contact with the underlying Ás bakkar diamicton is of two types: between about 3560 m and 4000 m it is obscure due to glaciotectonic shear, but beyond 4000 m the contact is gradual. Incorporated in the lowest gravelly sand are pitted and worn shell fragments, probably derived from the Ás bakkar diamicton.

The lowest stratified sand facies is conformably overlain by the only major silt facies in the Ás beds sequence, a laminated sandy silt (Fs), deformed due to loading. The thickness of facies Fs ranges from a few cm to about 30 cm. Silt laminae and thin silt beds were also found coating bounding surfaces of many of the overlying lithofacies in the sequence.

Fig. 9. The Látrar beds stratified diamicton: The contact (broken line) between the cross-stratified esker fan sediments (Sp) and the stratified undermelt/ice-rafted diamicton (Dms). Here, the diamicton is very rich in outsized clasts.
There are three major facies of sand in the sequence overlying the silt facies (logs F and G, Fig. 3), divided into a number of beds: Massive to crudely bedded, moderately sorted to silty sand (Su) stratified sand (Ss) and laminated silty sand (Ss). The sand units range in thickness from about 0.2 m to about 1.2 m, with conformable and loaded or erosional lower contacts, and stratification due to normal to reversed grading in the individual beds. Random intraformational lags of coarse sand to pebbly sand occur in most units. In facies Su, intralaminae of silt, resembling dish structures, were observed. Facies Ss is a succession of thin, silt coated sand beds.

The Ås beds diamicton

Description:
Interbedded with the sand- and gravel facies in the sequence are discontinuous sheets or lenses of massive and stratified diamictons (Dmu, Dms, logs F and G, Fig. 3). Their matrix is sandy-silty, but they display considerable variability in both texture and clast content. Individual units range in thickness from a few centimetres to about one m, and, where occurring isolated, have sharp or erosive bases and a tendency towards convex upper contacts. On one occasion a 3 m thick diamicton succession was observed (Log F). Facies Dms has intraformational bands of silt and thin sand beds. Both facies Dms and Dmu show a tendency towards concentration of gravels at the base. The diamicton units appear to be randomly interbedded with the lithofacies of sand and gravel, suggesting penecontemporaneous deposition.

Interpretation of the Ås beds
The transition from the Åskaaker diamicton to the generally coarser overlying sequence indicates an increased energy input into the depositional basin. In the subpolar glaciomarine environment, proximity to both the ice margin and to the source of meltwater plays a key role in determining the lithofacies distribution (e.g. Molnia 1983, Powell 1984). Powell (1983b) pointed out that supraglacial streams are absent and englacial streams rarely flow from tidewater glaciers, due to their highly crevassed nature. The meltwater discharge from such glaciers is almost entirely subglacial, and results in a proglacial submarine outwash deposit, composed of several lithofacies reflecting discharge, sediment load and the proximity of the deposit to the glacier margin.

The lithologies and structures of the Ås beds are best explained as being a result of a combination of sedimentation from subaqueous ice-marginal outwash streams and glaciogenic subaqueous debris flows. I suggest that the sand and gravel facies are ice-proximal meltwater fan sediments, where the gravel facies represent
deposition from bedloads of meltwater streams at a submarine fan apex, the gravelly and stratified sand facies represent deposition in a meltwater channel, and the silty sand and the massive to crudely bedded sand facies represent proximal interchannel deposition. Rust and Romanelli (1975), Cheel and Rust (1982) and Domack (1983) described similar facies distribution from ice-marginal subaqueous meltwater fans. The coarse gravels and the tangential foresets of facies Gp indicate a relatively fast flowing depositing stream. I interpret the diamicton facies as glaciogenic subaqueous debris flows, representing a proximal facies to the intrabedded diamicton units found in the Ásbakkars diamicton.

Processes affecting the sandfacies deposition could include bottom current or traction load deposition, resulting in relatively well sorted sand, rippled bed surfaces and sand/gravel lags, and high concentration underflow turbidity currents, resulting in relatively poorly sorted silty sand and graded bedding. Massive to crudely bedded sands in the ice proximal glaciomarine environment have been attributed to a deposition from high concentration sediment flows during periods of high meltwater discharge from a glacier (Cheel and Rust 1982, Powell 1984, Eyles et al. 1985). The laminated silt and silt coatings on unit contacts could be due to fluctuations of meltwater and its sedimentary load and/or shifts in the concentration of glaciofluvial activity along the ice margin. Mackiewich et al. (1984) pointed out that interaction of stream discharge with tidewater also causes fluctuations in particle sizes, and that tidal currents can produce thin, discontinuous silt laminae. The loaded structures and the dish structures indicate rapid deposition (Collinson and Thompson 1982), and by analogy to present day sub-polar ice-proximal glaciomarine environments (e.g. Powell 1981, Gilbert 1982, Molnia 1983) a very rapid deposition can be suggested for these sediments.

The abrupt lateral and vertical facies changes in an overall coarsening upwards sequence, leads me to conclude that the facies association was deposited close to the grounding line of the glacier. I interpret it as a stratified ice proximal/ice marginal deposit (Fig. 5) built up as a shoal or bank in front of a slowly advancing glacier. Powell (1984) described glaciomarine processes related to morainal bank construction in front of a warm based tidewater outlet glacier, and modelled the inductive lithofacies. He modelled a lithofacies association related to a morainal bank deposition similar to the one described above.

The contact between the Ás beds and the Ásbakkars diamicton is transgressive, i.e. while the the morainal bank built up at the glacier margin, glaciomarine sediments with interbedded diamictons and sands were being deposited beyond the bank. The relative sea level during the deposition of the Ás beds was as high as during the deposition of the Dmu facies of the Ásbakkars diamicton.

THE LÁTRAR BEDS: AN ESKER FAN FACIES AND GLACIOMARINE FACIES ASSOCIATION

The Ás beds are discordantly overlain by the Látrar beds, a major sequence of gravelly sands (Sp, Sr), and diamictons (Dms), and laminated silts and sands (Fl, SI) (Fig. 3, logs C, D, F), exposed between about 1650 m and 3650 m in the cliffs (Fig. 2). All lithofacies belonging to the unit can be observed at Látrar, around 2100 m.
The gravelly sands and diamictons

Description:
At the base of the sequence, between 2175 m and 2400 m and between 2575 m and 2710 m, there are two occurrences of low (up to 5 m), broad, mound-like deposits of sands and gravels. Their major lithofacies are planar cross stratified pebbly sand (Sp) and trough cross stratified pebbly sand (St), but minor lithofacies of pebble-cobble gravels (Gc, Ggn) and poorly sorted sand (Ss) also occur. The trough sets are large scale, with a maximum thickness of roughly one m and a maximum width of four m, though thicknesses of 30-50 cm and widths of 1.5 to 2 m are most common. The angles of plunge in both planar- and trough cross stratified sets vary between 20° and 37°, and common foreset bed thickness is around 20 cm. The lower sets strike 205°-285° and dip towards SSW, but upwards in the unit the sets strike 160°-340° and dip towards WSW. There is a rough grading upwards in texture: The lower sets tend to be more pebbly with more frequent pebble-cobble trains while the upper sets tend to be more silty. Some of the pebble-cobble trains show imbricated fabrics. A palaeocurrent estimation from the imbricated structures gave flow direction towards SSE.

The cross bedded pebbly sand unit is capped by 15-100 cm thick lenses of silty-sandy diamicton (Dms) containing angular gravel- and boulder clasts. The cross-stratification of the diamicton is due to laminae of silt and sand. Sometimes the diamicton interfingers with the uppermost sets of cross bedded pebbly sand, suggesting simultaneous deposition. The clasts do not show any preferred orientation. Downbedding of silt and sand laminae was observed below some of the clasts.

The laminated silts and sands

Description:
The stratified diamicton grades upwards into a unit of laminated to thinly bedded sandy silt (F) and silty sand (Ss) containing subfossil molluscs and numerous gravel to boulder clasts (Fig. 6C). The unit is a rhythmic deposit, where 5-40 cm thick beds of laminated sandy silt (samples 7 and 8, Fig. 4) alternate with 1-4 cm thick beds of laminated silty sand (sample 9, Fig. 4). The unit is up to 20 m thick, and two counts of a number of silt-sand couplets give 145 and 160 sets. The average couplet thickness for 305 sets was 17 cm, where the silt- and sand beds were on the average 15 cm and 2 cm thick, respectively. Each set begins with a silty sand bed with sharp lower contact, which then grades into laminated silt.

The unit smooths out all undulations in the underlying strata until it reaches planar parallel stratification. Structures observed within the unit include small scale folds near the base where deposition has taken place on a sloping surface, convolute bedding structures and "roll-up" structures (Fig. 7C).

The fossil molluscs in the interbedded silt and sand unit belong to the same faunal assemblage as the fossils in the Ásbakkur diamicton (Table II) but there are fewer species and individuals. No fossils were found in situ nor as paired bivalves, the finds being mostly fragments bearing evidence of transport. Some of the fossils sampled may be derived from older sediments, and therefore the radiocarbon dates (samples R, - R, Table III) should be considered as maximum ages for the sediments. All radiocarbon dated samples were collected from the lowest part of the interbedded silt and sand unit (location in Fig. 2). Their radiocarbon ages range from 11,715±120 BP to 11,465±100 BP.

Interpretation of the Látrar beds

I suggest that the Látrar beds were deposited during a transition from an ice-marginal environment to an ice-proximal glaciomarine environment (Fig. 5) with the following sequence of events: The glacier retreated after having overran the Ás beds and the Ásbakkur diamicton in the southern part of the cliffs. It left an erosional hollow which could function as a sediment trap for glaciogenic sediments carried into the basin by subglacial meltwater streams. I interpret the cross stratified pebbly sand facies as esker fan sediments, deposited at the ice margin.

Fig. 12. Stratigraphy and structural features at 3700 m, drawn from photographs. In the center, a large isocinal fold affecting the lowest lithofacies of the Ás beds and the Ásbakkur diamicton. 12.1: (A) Ásbakkur diamicton, (B) lowest sandy part of the Ás beds. Zone of maximum shear shaded in gray. (C) upper gravelly part of the Ás beds. 12.2: Sheared and folded structures within the lowest silty-sandy Ás beds lithofacies. 12.3 Boudins developed in facies Ss at the contact with the Ásbakkur diamicton.

12. mynd. Jarolagaskipan og dæmi um höggun og hnik við 3700 m. Fyrir midju er stór felling.
margin where meltwater entered the sea from subglacial tunnels. The change in texture and fabric, upwards within the esker sediments, could reflect a change from a fast flowing stream in a tunnel to a more deflecting stream in front of the tunnel. On top of the esker sediments and partly interlingering with them, a cap of diamicton was deposited. The diamicton contains outsized clasts, interpreted as dropstones, and I conclude that it was produced by undermelt and/or slumping of debris from the glacier or from collapsing ice bergs. The silt and sand laminae and thin beds within the diamicton could have been produced by current reworking and/or turbidite deposition from underflows.

As the ice margin retreated, the deposition gradually changed from diamicton to interbedded, rhythmic silt and sand with iceberg dropped debris. Sedimentary structures in the rhythmic unit, such as "roll-up" structures and convolute bedding indicate strong current activity and rapid sedimentation (Gustavson and Ashley 1975, Collinson and Thompson 1982). The environment was marine, but the small number of molluscs may indicate rapid sedimentation or brackish water. If the rhythmic control has been seasonal, a mean sedimentation rate of 0.17 m \( \cdot \) y\(^{-1}\) for at least 160 years can be inferred for the sediments. This is a sedimentation rate at least fifty times faster than the one inferred for the fossiliferous Åshbakkar diamicton, but it is similar to sedimentation rates in present day glaciomarine fjord environments on Svalbard (Elverhøi et al. 1983) and on Baffin Island (Gilbert 1982). The relative sea level during the deposition of the glaciomarine facies was higher than 23 m above the present level, which is the highest occurrence of undisturbed rhythmic silt and sand in the cliffs, probably considerably higher.

THE LANDHÓLMI SANDS, MELAR DIAMICTON AND ÅSGIL GRAVELS: ICE PROXIMAL, ICE CONTACT AND ICE-MARGINAL FACIES ASSOCIATIONS

There are indications in the cliffs of a glacial advance after the deposition of the Látrar beds glaciomarine facies. Three major stratigraphic units resulted from this advance: The Landhólmi sands, Mælar diamicton and the Åsgil gravels.

The Landhólmi sands: an ice proximal delta facies association

**Description:**

Between 200 m and 2400 m, landwards of the Landhólmi skerry in the Látrar parts of the cliffs (Fig. 1), a unit of predominantly sand lies on top of the Látrar beds (Fig. 3, log D). There, the interbedded silt and sand facies of the Látrar beds become increasingly sandy upwards, and are overlain by a 1.2-1.6 m thick sequence of massive pebble gravel (Gu), stratified silty sand (Sm) with discontinuous parallel laminations of sandy silt, and poorly sorted sand (Su). The gravelly-tandy sequence is conformably overlain by a 4-6 m thick single set of planar cross stratified, pebbly sand (Sp). Its foresets are angular to tangential based, 4-15 cm thick, with internal fining upwards from pebbly sand to coarse sand. The foresets dip towards SE-SW at angles between 10\(^{\circ}\) and 20\(^{\circ}\). Interbedded in the cross stratified sand are up to 20 cm thick units of clast supported pebble to cobble gravels (Gu) and, in the upper part of the set, a number of 0-15 cm thick sandy-silty stratified diamicton lenses with pebble-cobble clasts (Dms). The interbedded units have erosive bases.

The upper parts of the Landhólmi sands are tectonically disturbed, but the disturbance is complex and the exposure poor so that structural analysis was not attempted. The deposits are at places capped by lenses of boulder-rich diamicton and lag concentrations of boulders (Fig. 10C).

**Interpretation of the Landhólmi sands**

Thick single set cross stratified sands and gravels can form where a glaciofluvial stream carries bedload into quieter water and deposits it via grainflow avalanches down a foreset delta slope (e.g. Gustavson and Ashley 1975, Edwards 1978, Clemmensen and Houmark-Nielsen 1980). I suggest that the Landhólmi sands were deposited as a fan delta in an ice proximal glaciomarine environment. The contact with the Látrar beds glaciomarine facies is non-crosional, and possibly the uppermost part of the Látrar beds are bottomsets of the delta, deposited beyond its cross stratified seaward face. The thin, graded foreset beds indicate deposition during a period of reducing flow strength. The interbedded gravels and stratified diamictons could have been deposited from periodic strong current induced avalanches or grainflows and subaqueous slumps off an unstable delta front. Some of the gravel trains could be lag deposits. Thomas (1984a) described thin diamicton units, interbedded with foresets in an ancient glaciofluvial fan delta, as subaqueous slumps. The relative sea level during the deposition of the delta sediments was at least 30 m above the present level.

**The Mælar diamicton: a lodgement till facies**

**Description:**

Beneath the farm of Mælar (Fig. 1), a 1-2 m thick diamicton sheet is exposed (Fig. 3, log C). It has an erosive base, and can be followed from the base of the sequence at 1500 m, where it disconformably overlies the Åshbakkar diamicton, concavely upwards across the glaciomarine unit boundaries to the top of the sequence at 1700 m (Fig. 2). The diamicton is matrix supported and massive (Dms), with clasts of all sizes from pebbles to large boulders embedded in a silt- or sand-matrix (Fig. 10B), but clusters of boulders also occur (Dcu). The clasts are subrounded to
angular, and serveral striated and faceted clasts with double stoss-lee sides, characteristic for lodgment till (Kräger 1984) were recognized. Some of the elongated clasts show an apparent imbricated fabric in the exposure, with a dip towards north. The diamicton is lithified and very difficult to sample or check for preferred orientation fabric. Where the diamicton sheet climbs the cliffs, clasts can be seen thrust or lodged into the substratum (Fig. 10A) and silt clasts from the substratum are incorporated into the diamicton. Neither joints nor folds were observed within the diamicton, but both occur in its substratum (see later). At some places the upper contact is coated by a thin (1-5 cm) sheared silbend. Concentrations of large boulders on top of the strata between 1700 and 2500 m and large, striated erratics on the lowland surface above Látrar (Fig. 10D), could be lag deposits from the Melar diamicton.

Interpretation of the Melar diamicton
The Melar diamicton has many of the properties commonly used for recognizing lodgement tills (for reviews see Boulton 1976, Dreimanis and Schlueter 1985): It is a non-sorted, massive sediment, containing large, striated and faceted clasts. Elongated clasts show imbricated fabric. Its lower contact is erosional and it has a sheet-like depositional geometry. Its surface is sheared at places, and glaciectonic deformations occur in its substratum. On this basis I interpret the Melar diamicton as lodgement till. Apparent fabric and direction of the glaciectonically deformations in its substratum (see later) indicate a deposition beneath a glacier coming from a northerly direction, out of the Borgarfjördur main valley.

The Ásgil gravels: an ice-marginal outwash facies association

Description:
A deposit of coarse gravels, trending NE-SW, is buried in the sediments south of the Ásgil ravine, between 2725 m and 2875 m (Fig. 2, Fig. 3, log E). It has a ridge-like morphology: It is about 150 m wide and 5-12 m high, and can be followed in exposures some 300 m inland from the coast. The deposit is composed of four major gravel facies (Gu, Gp, Gs, Ggn) and three major sand facies (Ss, St, Sp). Most conspicuous are the facies of massive to weakly stratified gravel (Gu, Fig. 11A), often with well developed imbricate fabrics, arranged together with facies Gs in poorly defined multistory sets (Fig. 11B). Set thicknesses are 1-2 m, set contacts are erosional or gradational, and individual sets can be traced laterally for up to 45 m. Boulders are abundant in the gravels, and the largest one encountered had a diameter of 60 cm. The gravel and boulder clasts are sub-rounded to well rounded. Some of the clasts derive from the Asbakkar diamicton and contain subfossil molluscs. Facies Gs (sample 16, Fig. 4) is sandy, planar stratified, with imbricated gravel train and minor intrabeds of gravelly sand. The graded facies (Ggn) grades upwards from clast supported gravel to sandy, matrix-supported pebble gravel.

The Gp facies consists of large-scale isolated sets of planar cross-stratified gravels, occurring within and below the multistory sequence of Gu and Gs facies. Set thicknesses observed were around 1 m, with foreset thicknesses of 20-30 cm, dipping around 20° towards SE. The foresets are angular based to slightly concave.

Facies Ss is a roughly planar parallel stratified poorly sorted sand, with occasional pebbles (Fig. 11C). It occurs both as about 1 m thick single units, and as thin and discontinuous lenses within the multistory sequence. The stratification is due to normal grading from pebbly to poorly sorted sand within the individual 4-10 cm thick sandbeds.

Facies St is gravelly sand (Fig. 4, sample 17) in grouped trough sets, with onset thickness of about 1.5 m. Set thicknesses are 20-30 cm and set widths about 1 m.

Planar cross stratified sand (Sp) occurs in large scale isolated sets at the base of the sequence (Fig. 11D). Set thicknesses are up to 1.5 m, with foreset dip angles up to 26° towards SE and foreset thicknesses of 10-20 cm. The foresets are angular based and consist of alternating layers of coarse, pebbly sand and somewhat better sorted sand.

Interpretation of the Ásgil gravels
I interpret the Ásgil gravels to be ice-marginal glaciofluvial outwash deposits. Their sedimentology fits descriptions of proximal glaciofluvial deposits by e.g. Boothroyd and Ashley (1975), Frazer (1982) and Miall (1983). Large boulders in glaciofluvial deposits have been used by e.g. Thomas (1984a) to infer ice-contact depositional environment, as the stream capacity to carry large boulders downstream is limited. Haraldsson (1981), who studied the recent Markarfljótssandur in S-Iceland, rarely found boulders with diameters larger than 40 cm outside its very proximal part.

The deposit is buried under glaciomarine sediments (Fig. 2) belonging to the Melabakkar silts and sands described below. Paleocurrent measurements from imbricated fabrics and foreset dips (Fig. 2) indicate a depositing stream direction from NW. The glaciofluvial deposits interfinger as gravel trains with the Melabakkar silts and sands glaciomarine facies. That, along with the lack of faults or other tectonic features supports the assumption that the broad ridge form is the syndepositional geometry of the deposits. I suggest that the Ásgil gravels were deposited as an ice-marginal transverse ridge where fast flowing subglacial streams entered the marine environment. The waterdepth during the ridge deposition was more than 25 m.

THE MELABAKKAR SILTS AND SANDS:
A GLACIOMARINE FACIES ASSOCIATION AND SUBLITTORAL FACIES
A third major sequence of silty-sandy sediments, with a
maximum thickness of about 25 m, is exposed between 0 and 1670 m and 2720 m and 3400 m (Fig. 2, Fig. 3: logs B, C and E). It differs from the underlying glacimarine sequences in containing almost no fossils or dropstones, being neither fractured nor sheared, and being lithified to soft.

Description:
The Melabakkir silts and sands consist of four major lithofacies (Fig. 6D): (1) the lowest, a massive to weakly stratified sandy silt (Fs), which grades upwards over (2) sandy laminated silt (F1) to (3) interbedded laminated silt (F1) and stratified sand (Ss). Stratified sand (Ss) (4), containing numerous burrows, tops the sequence.

The lowest facies, Fs, is compact to lithified due to palagonitization. A grain size analysis (sample 12, Fig. 4) and a thin section study showed it to be poorly sorted, silt (75%), sand (15-20%), and granules (5-10%). The weak stratification is due to occasional discontinuous interlaminae of fine to medium sand, spaced at 20-30 cm intervals. The Fs facies is dark grey in color, sometimes with a slight brownish shade due to palagonitization. Its thickness varies between 0.5 m and 5 m.

Facies Fs grades into facies F1, a fine, well sorted (sample 13, Fig. 4) and very tightly, laminated silt. The palagonitization decreases upwards, and facies F1 is soft when wet. A thin section study showed the fine laminations to be due to bandings of grain-to-grain contact coarse silt and fine sand sized fragments in a finer matrix. The laminae are spaced at one to a few mm intervals and can be difficult to see in the field without the help of a loupe. Facies F1 is so impervious that groundwater can not percolate through it, but is conducted on its upper surface to the cliffs. The thickness of facies F1 is 2-5 m. It is gray to bluish in color when dry.

Upwards in the sequence, thin interbeds of well sorted fine to silty sand (Ss, sample 11, Fig. 4) appear. The sand beds have sharp lower contacts, but grade upwards into silt with thin intralaminae of fine sand. The total thickness of the planar parallel interbedded sand and silt is about 4 m, and two counts of a number of couplets gave 33 and 41 couplets. Upwards the facies grades into a 3-7 m thick unit of planar parallel stratified, well sorted fine to medium sand (Ss, sample 10, Fig. 4). I counted 60 beds of sand, 8-18 cm thick (mean: 12 cm). Bed contacts are sharp, and going down from the upper bounding surfaces are numerous burrows (Arenicolites). The sand is truncated by sharp to erosional contact with the Melagil gravels and sands described below.

Interpretation of the Melabakkir silts and sands:
I interpret the Melabakkir silts and sands to be a distal glacimarine facies association and sublittoral facies, deposited after the second glacial advance registered in the cliffs. I interpret the facies changes from facies Fs to facies F1 to reflect an increasing distance of the basin to the sediment input, i.e. glacial meltwater streams entering the marine environment during a rapid retreat of the glacial front to a position within the present coast. The massive appearance of the lowest facies could be due to rapid sediment accumulation due to flocculation, only occasionally disturbed by underflows during periods of high meltwater discharge. The better sorting upwards could also reflect increasing waterdepths due to a marine transgression in connection with the deglaciation. I interpret the well sorted facies F1 to indicate a change from dispersed meltwater and underflow sedimentation to sedimentation mainly from overflows. At this stage, perhaps, the glaciers had retreated to a position within the present coast, so that the meltwater streams reached the depositional basin via coastal deltas. The very fine

Fig. 13. An overturned anticlinal, folded and sheared structure, developed in interbedded gravels and diamictons of the Ås beds at ca. 3750 m. The deforming push has been from left to right. Photographed with a 400 mm telelens from the beach.

Is. mynd. Andhverfa við 3750 m.
laminae could reflect tidewater current activity or fluctuations in the meltwater input.

I interpret the transition upwards in the sequence, over interbedded silt and sand to stratified sand with burrows, to reflect the growing proximity of the basin to a beach environment due to isostatic uplift and marine regression, after the glaciers had retreated from the coastal areas. The relative sea level during the deposition of the lower-middle part of the Melabakkur silts and sands was at the regional marine limit at 60-70 m above the present sea level. Only a few broken and pitted shell fragments were found in the Melabakkur silts, and three field seasons yielded 23 gr. of dateable material. Radiocarbon dating of this sample gave the age of 11,985 ± 120 BP (Table II; sample 10). There are indications that this dating value is too high for the sediments, and that the shell fragments derive from older sediments: Firstly, it predates the Melabakkur silts and sands to the glaciomarine facies of the Látrar beds, which is inconsistent with the stratigraphical and other dating evidence. Secondly, radiocarbon dated fossiliferous marine and sublittoral sediments in a similar stratigraphic position as the Melabakkur silts and sands, found in Leirárvogar, some 4-5 km east of the Melabakkur-Ásbakkur cliffs, date around 10,000 BP (Ingólfsson 1985).

THE MELAGIL GRAVELS AND SANDS: EMERGENCE FACIES ASSOCIATION OF BEACH GRAVELS AND EOLIAN SANDS

The Melabakkur-Ásbakkur section is truncated by a gravel lag horizon, G(I). The unconformity is very distinct and can be mapped in sections throughout the region. Above the lag horizon there are four major facies of gravels and sands, up to 15 m thick, below recent soils (Fig. 3, all logs), which can be observed in the vicinity of the Melagil ravine: (1) a planar parallel stratified sandy pebble-gravel (Gs, sample 20, Fig. 4), (2) planar cross stratified gravel (Gp), (3) planar parallel stratified pebbly sand (Sp, sample 19, Fig. 4) and (4) planar cross stratified silty sand (Sp, sample 18, Fig. 4). I interpret facies Gs, Gp and Sp as littoral deposits, and facies Sp as eolian deposits. The littoral and eolian sediments are found regionally and below 60 m a.s.l., and have been deposited during and after the marine regression that resulted from the isostatic rebound of the depositional basin after the glaciers had retreated from the lowlands.

GLACIOTECTONIC STRUCTURES

A number of tectonic structures, ranging from small scale fracturing and shearing to large scale overfolding and thrusting, are found in the cliffs. If considered as isolated phenomena, many of the structures could be interpreted as disturbances caused by local sliding or slumping of sediments down a slope, or as load-cast structures. But the consistent dislocation direction (Fig. 2) as well as the pattern of overthrusts and overfolding makes glaciotectonism the most plausible explanation for the deformations. The deformations occur at two stratigraphic levels: a lower level with extensive deformations affecting the Ásbakkur diamicton and the Æs beds, and a upper level with less intense deformations, mainly affecting the glaciomarine facies of the Látrar beds and the Landhólmi sands. The following is a brief description of deformation features, with emphasis on good structural indicators of glacial push and its direction, such as large-scale structures (>10 m), overfolds and low angled thrusts.

Folds

Descriptions of folds were done in two steps in the field: (1) fold appearance in profile was determined, and (2) orientations of its axial plane and fold axis were estimated from dip and strike measurements.

At around 3700 m (Figs. 2 and 12) a large scale isoclinal fold, affecting the Ásbakkur diamicton and the lowest lithofacies of the Ás beds, is truncated by a rising thrust plane that carries the bulk of the Ás beds across the axis of the fold. The thrust plane can be followed about 450 m to the SE. The lowest lithofacies of the Ás beds is thickest forward of the fold. Beyond the hinge

Fig. 14. An overturned, isoclinal folded structure, developed in the mid-section of the Ás beds. A core of silty sand penetrates the overlying sandy-gravelly strata which constitute the limbs. Deforming push obliquely upwards and out of the photograph from left to right. Photographed with a 400 mm telephoto from the beach.

14. mynd. Andhverfa víð 3850 m.
zone of the fold, wing shaped, drawn-out boudins (Fig. 12–3) have developed on the boundary between the Ås beds and the Åsbakkar diamicton. The boudins are 0.3–1.0 m long, 0.2–0.4 m thick, separated by a distance of approximately half their width. The isoclinal fold is a 8–10 m high anticline. Its limbs consist of the lowest lithofacies of the Ås beds, while the core is of Åsbakkar diamicton. The fold axis trends 75°–255° and the axial plane dips 28° towards 345°, indicating a glacial push from NW.

The Ås beds above the fold are also sheared and folded. Immediately above the fold, in facies Ss, there are boudins and small-scale overturned to recumbent folds (Fig. 12–2). Higher up in the interbedded gravel- and diamicton facies, larger overturned sheared folds occur (Fig. 13). At 3850 m, a overturned folded structure has developed in the mid-section of the Ås beds, at the junction between the lowest sandy lithofacies and the gravelly upper part (Fig. 14). Its fold axis trends 90°–270°, and the axial plane dips 20° towards 360°, indicating a deforming push from approximately north. The uppermost part of the Ås beds is so heavily sheared and mixed that it is often difficult to recognize primary textures, fabrics and geometries. Boulton and Deynoux (1981) suggested that such non-tilt glacially deformed sediments should be called “deformation till”.

A large-scale (> 50 m long) recumbent structure of concentric folded strata, with almost horizontal axial plane, is exposed at around 4700 m in the cliffs, affecting the Åsbakkar diamicton (Fig. 15). The inverted strata and part of the anticlinal hinge zone are exposed in the section. The upper part of the structure has been removed by erosion along a horizon approximately coinciding with the axial plane. The fold axis appears to trend 100°–280°. As the exposure trends 135°–315°, the SSW facing hinge strata appear as a succession of concave clastic dykes, stacked sub-parallel to the exposure. The folded strata are transected by normal- and reverse faults as well as overthrusts who converge towards north. The dislocating force has operated from a northerly direction. The folded structure is discordantly overlain by heavily sheared gravel-diamicton admixture (“deformation till”).

At 1525 m, in the immediate substratum of the Melar diamicton there is an example of a small scale, symmetrical, angular fold which has been transformed into a thrust fault (Fig. 16A). The sharp trough hinge has fractured and the inverted limb has been replaced by a slide plane with an apparent dip of 26° towards NNE.

At 2400 m there is a folded structure affecting the glacimarine facies of the Látrar beds (Fig. 16B). It is a 5–6 m high structure of open (interlimb angle: 115°), asymmetrical anticlinal strata. The fold axis trends 80°–260° and the axial plane dips 50° towards 350°, indicating a push from approximately NNW.

At 160 m, a synclinal part of a large overturned fold.

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Fig. 15. Structural outline of heavily sheared and folded strata of the Åsbakkar diamicton at 4650–4700 m, drawn from photographs. The deformed strata are truncated by a glacial discordance, approximately coinciding with the axial plane of the folded structure. They are overlain by a heavily sheared gravel-diamicton admixture (“deformation till”), probably belonging to the Ås beds. The deforming shear has been from left to right. Height of section about 20 m.

15. mynd. Óþyrmilega haggðar jardlagabunki við 4650–4700 m.

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affecting the Ásbakkar diamicton, is exposed (Fig. 17),
showing the lower uninveted limb, a streaked out
trough hinge zone and part of the inverted limb. The
exposure trends N-S, and as the fold axis trends 105°–
285° with an axial plane dipping about 18° towards 15°.
the exposure cuts the fold sub-perpendicular to the
fold axis. Therefore, folded surfaces sub-parallel to the
axial plane are exposed, and examples of “slaty cleav-
age-like” axial plane foliations can be seen above the
streaked out trough hinge zone. The fold geometry
indicates a deforming push from approximately NNE.

Fauls and joints
The Ásbakkar diamicton, south of about 3700 m, is
transected by a number of major normal and low angled
reverse (thrust) faults (Fig. 2). The thrust fault planes
are usually slightly concave upwards. Measurements of
10 fault planes revealed apparent dips between 28° and
42° towards NW-N. At 4975 m the Ásbakkar diamicton
is transected by a thrust fault, running slightly concavely
upwards from the base of the sequence (Fig. 18). Immedi-
ately below the thrust plane there is a body of stratified
sand, which has been subject to fault drag. The drag has
overturned the sand with a minimum displacement of
about 5 m along the thrust plane. The displacement
strike of the sand body measured 80°-260°, which is
perpendicular to the direction of the section and indi-
cates a displacement approximately normal to the out-
cropping trace of the fault, towards SSE-S. The thrust
faults belong to the same dislocation pattern as the
large-scale folds, showing a direction of maximal stress
from north.

The Ásbakkar diamicton and the glacimarine facies
of the Látrar beds are at places heavily jointed. The
most apparent joints are sub-vertical to vertical joints,
usually spaced at 10-25 cm intervals. Sometimes the
joints can be traced over entire unit thicknesses, giving
the cliff face a columnar-like appearance. In connection
with folds and faults, straight to undulating, sub-parallel
fractures occur (Fig. 6A). They appear to strike parallel
to the associated sheared structure, and dip in opposite
directions to shear planes and axial planes. Similar joints
in sub-till sediments have been described as tension
fractures by Hicock and Dreimanis (1985).

Glaciodynamic deformations: a discussion
Although the study of glaciotectonic structures has a
long tradition (for short reviews, see Berthelsen 1978,
Aber 1982, Hicock and Dreimanis 1985), many funda-
mental problems of their development still remain to be
satisfactorily explained. There are two schools of
thought as to whether large scale dislocations take place
mainly in front of advancing glaciers (e.g. Berthelsen
1979), or beneath advancing glaciers via compressive
flow in the basal zone (e.g. Moran 1971). Another funda-
mental problem with regard to the conditions at the base
of the ice is whether glaciotectonic deformations de-
velop in frozen or unfrozen sediments, and conse-
quently the role of basal meltwater, pore-water pressure
and permeability of the substratum. Two basic concepts
have been presented regarding the connection between
the basal/fractured situation and the development of
glaciotectonic structures: A “permafrost concept” which
assumes that the effect of differential glacier load and
shearing stress is transmitted from the moving glacier to
its frozen pro- and substratum, causing the formation
of glaciotectonic structures (e.g. Moran et al. 1980, Aber
1982). The other concept calls upon the combined effect
of differential ice loading and hydrodynamic mechani-
isms to account for the development of glaciotectonic
structures, and points out the potential importance of

Fig. 16. Deformation structures. (A) A thrust fault de-
veloped from an angular fold in the Ásbakkar diamicton
below the Mælar diamicton at 1525 m. The inverted limb
of the fold has been replaced by a slide plane. Drawn
from a photograph; (B) A schematic field sketch of an
open, asymmetrical anticlinal structure, developed in the
Látrar glacimarine facies beneath the Mælar dia-
micton at 2400 m.

water in reducing shear strength of pro- and subglacial sediments (e.g. Banham 1975; Sharp 1985). But sequences also exist where a combination of high porewater pressure and differential permafrost in the strata subject to glacial pressure are invoked to explain large-scale deformations (e.g. Thomas 1984b). Recently Aber (1985, p. 389) stated that "glaciotectonic features may ... affect materials that were either frozen or thawed at the time of deformation".

There are no structural methods available yet with which to get objective information from deformed sediments on the basal conditions of a glacier at the time of glaciotectonic deformation. The information is sparse from recent glaciers on the effects of different combinations of basal temperature, different substratum, hydrodynamic situation, differential loading, compressive ice flow etc. on the development of glaciotectonic deformation. Thus at this stage, the models are somewhat circumstantial and should be used carefully. In the case of the Melabakkark-Ásbakkak glaciotectonics, the combined effect of frontal push, differential ice loading and hydrodynamic mechanisms is to me the most attractive explanation. The two ice advances occurred into a submarine fjord basin, where the presence of any permafrost is very unlikely. There is also evidence of abundant meltwater in connection with the glacial events.

SUMMARY AND DISCUSSION

It is my conclusion, that the Melabakkark-Ásbakkark sequence, bounded by a lower surface of glacial erosion and by an upper surface of wave erosion, contains a fairly continuous record of glacial episodes in the lower Borgarfjörður region for the later part of the Late Weichselian, after ca. 12,500 BP. The sequence was deposited in a glacio-isostatically depressed fjord basin, where the major controls of lithofacies distribution and stratigraphical associations were water depth and the proximity to an ice margin and a source of meltwater input. The total thickness of the exposed strata is about 145 m. of which the glaciomarine sequences constitute about 85 m. ice-proximalic contact outwash sediments, debris flows and tills 40-45 m., and an emergence facies of sand and gravel about 15 m. A composite vertical section is shown in Fig. 3.

The striated bedrock, which constitutes the lower boundary of the sequence, bears witness to a glaciation event when the ice reached beyond the present coast some time prior to about 12,500 BP. The development of the Melabakkark-Ásbakkark sequence can be divided into nine stages (Fig. 19): During the first stage (stage A), mollusc-bearing glaciomarine sediments (the Ásbakkark diamicton) accumulated from suspension, random underflows and ice-rafted debris. Around 12,300 BP, the relative sea level was at least 70 m above the present sea level, possibly reaching the marine maximum level at 80-90 m a.s.l. Around 12,000 BP a glacial advance down the Borgarfjörður valley/fjord (stage B) caused the mollusc populations to disappear, and subaqueous ice-marginal/ice-proximal stratified sediments (the Ás beds) were deposited from subglacial meltwater streams and

Fig. 17. A composite oblique photograph of a large folded structure developed in the Ásbakkak diamicton at around 160 m. The structure is truncated by a gravel lag horizon and overlain by littoral gravels. The arrow points at axial plane foliations developed close to the synclinal (tough) hinge zone. The deforming force has acted sub-parallel to the outcrop, from left to right. The section is about 50 m long.

17. mynd. Samsett lýsmýnd af höggudyrm jarðögum við 160 m.
Fig. 18. A thrust fault in the Ásbakkar diamicton at 4975 m. The arrow points at a body of sand which has been overturned by fault drag. The man pointing at the fault is 1.85 m high.

18. mynd. Prjosti-misgengi við 4975 m.

glaciogenic subaquatic debris flows, to form proglacial shoals or banks. The relative sea level was probably 80–90 m above the present level. Beyond the ice-marginal zone, glaciomarine sedimentation continued with strong influxes of meltwater underflows and subaquatic debris flows. Continued advance of the glacier (stage C) caused large-scale glaciotectonic deformations. The glacier successively overran the whole basin (stage D). Around 11,700 BP the glacier retreated to a position somewhere north of the Melabakkur-Ásbakkar section (stage E), in the course of retreat depositing the esker fan facies of the Látrar beds. The sea level was high, and the rhythmic glaciomarine facies of the Látrar beds, supporting a limited mollusc population, accumulated from suspended fines, underflows and ice rafts.

Some time after 11,400 BP the basin was re-invaded by a glacier advancing out of the Borgarfjörður main valley (stage F). In connection with this readvance, lodgement till (the Melar diamicton) and ice-proximal delta sediments (the Landhólmis sands) were deposited. The relative sea level was above 30 m above the present during the delta deposition. There is evidence in the cliffs of the glacier advancing about halfway across the section towards south, but it may have advanced further. A transverse ridge of subaquatic outwash (the Ásgil gravels) marks the position of the ice margin during some stage in its retreat (stage G).

During stage H, some time prior to 10,000 BP, the glacier retreated from the coastal areas and the sea transgressed the isostatically depressed lowlands. Re-

Fig. 19. Stages in the development of the Melabakkur-Ásbakkar coastal cliffs. Legend: (UF) underflows, (TC) tidal currents, (MS) meltwater streams, (DF) subaquatic glaciogenic debris flows, (1) bedrock, (2) Ásbakkar diamicton, (3) Ás beds, (4) Látrar esker fan facies, (5) Látrar glaciomarine silts and sands, (6) Melar diamicton, (7) Landhólmis sands, (8) Ásgil gravels, (9) Melabakkur silts and sands, (10) Melagil gravels and sands. See text for further discussion.


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regionally extensive marine terraces at 60–70 m a.s.l. relate to the relative sea level during stage H. The Melabakkar glacimarine facies was deposited primarily from suspension during this stage. The isostatic rebound is registered in the sequence as glacimarine sedimentation gives way to sublittoral sand with burrows, finally (stage I) to be truncated by an emergence facies association (the Melagil gravels and sands), of beach gravels and sands, found above a regionally extensive, time- and space transgressive gravel lag.

The glacial stratigraphy and chronology of the Melabakkar–Asbakkar cliffs presented here differ substantially from previous interpretations of the lower Borgarfjörður strata (Ingólfssson 1984). According to the deglaciation synthesis of Einarsen (1961, 1968, 1971) the Borgarfjörður main valley/fjord was not glaciated after ca. 13,000 BP. It has also been maintained that glaciers did not reach the coastal areas of W-Iceland after the Alftanes Stadial, correlated with the Older Dryas of Scandinavia, and that the region was not seriously affected by glaciation during the Buri Stadial, correlated with the Younger Dryas of Scandinavia (cf. Einarsen 1968, 1979, Andersen 1981). The evidence from the Melabakkar–Asbakkar cliffs suggests that glaciers advanced down the Borgarfjörður valley both around 12,000 BP and after 11,400 BP, indicating a more extensive glaciation than hitherto assumed for W-Iceland during the last stages of the Late Weichselian.

For explaining the development of the depositional basin with regard to lithofacies distribution and stratigraphic associations, I have applied recent models for sedimentation in a subarctic glaciated fjord environment, as outlined by e.g. Powell (1981, 1984), Molnia (1983), Mode et al. (1983), Domack (1983) and Eyles et al. (1985). These models primarily relate to glacial recession sequences, but the Melabakkar–Asbakkar example indicates that they can also be applied to ice-transgressive sequences.

The development of glaciotectonic deformations in the Melabakkar–Asbakkar strata is probably best explained by a combined effect of frontal push, differential ice loading and hydrodynamic mechanisms on pro- and subglacial unfrozen sediments.

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Ágrip
JARDFRAÐI OG JÖKLUNARSAGA MELA- OG ÁSBAKKU Í BORGARFIRÐI


Heildarpykkt járðlagastaffans er um 145 m. Mest áberandi eru þrýrar syrfur jökulsjávarsets (glaciomarine sediments). Samanlagt um 85 m í þýkkj. Þær eru aðskilda af jökulárða- og jökulútningum sem hjálpt hefur upp fram við og undir jökli sem gengið hefur fram við jökulsjávarsetið í tengslum við jökulframriðarinnar hefur stafall orðið fyrir margvisslega höggun og hniði av öldum jökulsins (glacialtectonics). Pykkkt jökulútningu og jökulsársetis í bókunum er um 45 m. Eftir í staðallunum er það hlaðað hefur upp í tengslum við aflaði sjávar í lok jökultíma er jökulsárgöngu léttir og landið reis í.


Sú mynd sem hér er dreginn af jökulansöguna Borgarfirðar í lok súdasta jökulskeiðs er um margt frábrugði fyrir því tölkuðum á járðlagaskapinn sveðisins (sja samanleikt í Jókli nr. 34, 1984, bls. 117–130). Nýstæðlegt er að (1) sjó hörfaði þeirri fram við með rannsóknunum á járðlagaskapum, setrfræði og byggingu að tveir jökulframrásir hafi átt sér stað frá Borgarfirði eftir að megjökklar súdasta jökulskeiðs hörfuðu inn fyrir núverandi strönd fyrir ú. b. 12.500–13.000 árum. (2) Jökulframrásinarnar hafa verið staeðaðar í tíma með aðstoð geislagöngu á forsøknunum, og nidurstöðurnar eru þær að í lok sjóðjökultíma hefur jökull á Borgarfirði verið mun umfangsmæli en hingað til hefur verið taldir, og (3) að úttövurðar forna strandið í 60–70 m hæð yfir sjó eru frá tímanum eftir seinni jökulframrásina, þ.e. myndar úr fyrir ú. b. 10.300–10.000 árum.

Að þöru leyti er í greininni fjallað um kenningsum um setmyndun í sjó fram við þjóku, og þegar í borg.inn um það efnar ræði í þjósi vitnisburði, liggja eftir hörfaði og hátt á byggingaður sætligi.