Glacial history of the lower Borgarfjördur area, western Iceland

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The glacial development of the lower Borgarfjördur region, western Iceland, was investigated with regard to morphology, lithostratigraphy and chronology of glacial events. The maximum glacial situation is outlined, and a synthesis of all available evidence on the deglaciation is proposed. It is concluded that after an initial deglaciation of the coastal lowlands, some time prior to 12,500 BP, glaciers again advanced to the outer coastal areas between 12,000 and 11,700 BP, and, after a minor retreat between 11,700 and 11,000 BP, retained nearly their former positions between 11,000 and 10,300 BP. The marine maximum limit, at 80–90 m a.s.l., was reached in connection with the former advance, and the regional marine limit, at 60–70 m, at the end of the latter advance. A raised beach at 40 m a.s.l. possibly relates to an Early Flandrian glacial episode. These results imply a more extensive glaciation in coastal western Iceland at the end of the Late Weichselian than hitherto assumed. □ *Glacial geology, chronology, radiocarbon dates, lithostratigraphy, Late Weichselian, deglaciation, sea level changes, Borgarfjördur, Hvalfjördur, Iceland.*

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The lower Borgarfjördur area, western Iceland, lies between two large fjords, Borgarfjördur and Hvalfjördur (Fig. 1). The Hafnarfjall–Skardsheidi massif (1053 m) and Mount Akrafjall (643 m) are covered with a scree of colluvium, alluvial cones and rockfall debris. At higher levels, large and small pinnacles of bedrock protrude. The local bedrock is mostly basalts of Late Pliocene age. The coastal and valley lowlands are blanketed by extensive bogs, and meadows and heaths with occasional brush. Outcrops of basaltic ridges and dykes are frequent. Natural exposures of sediments are found in riverbanks and along the coast. The coastal erosion rate in the area is among the highest in Iceland, at places along the Melabakkar-Asbakkar coastal cliffs up to 1.5 m/yr.

In a review of the history of Quaternary research in the lower Borgarfjördur region (Ingólfsson 1984), I concluded that there are controversial interpretations of its glacial history, and in two recent papers (Ingólfsson 1985, 1988) I proposed that western Iceland was subject to an extensive glaciation during the last stages of the Late Weichselian. The present paper presents a summary of morphological, stratigraphical and chronological data on the Weichselian glacial development, from Ingólfsson (1987, 1988). A new synthesis of the Late Weichselian glacial development and sea level changes is discussed in the light of recent data from Iceland and western Norway.

Glacial geomorphology

Landscape and bedrock

The landscape of the region has been shaped by glaciers that have been constrained by topography (Fig. 2). The large fjords/valleys of Borgarfjördur, Hvalfjördur and Svinadalur are glacial troughs, eroded by large outlet glaciers. Hvalfjördur (35 km long) is an overdeepened trough, barred at the mouth by a bedrock threshold with present waterdepth of 20 m, but with a waterdepth of >80 m at the head. The Borgarfjördur fjord is very shallow due to infilling of sediments. According to data from seismic soundings and boreholes on a transsect across the fjord between Seleyri and Borgarnes (Figs. 1 and 3), the fjord is an up to 100 m deep rock trough, almost completely filled with sediments (Hreinn Haraldsson, Reykjavik, pers. comm. 1986).

The Hafnarfjall-Skardsheidi scenery is characterized by glacial cirques, horns and arrêtes, created by interaction of glacial and periglacial activity. The dimensions of the Hafnarfjall-Skardsheidi cirques vary considerably, and fluv-

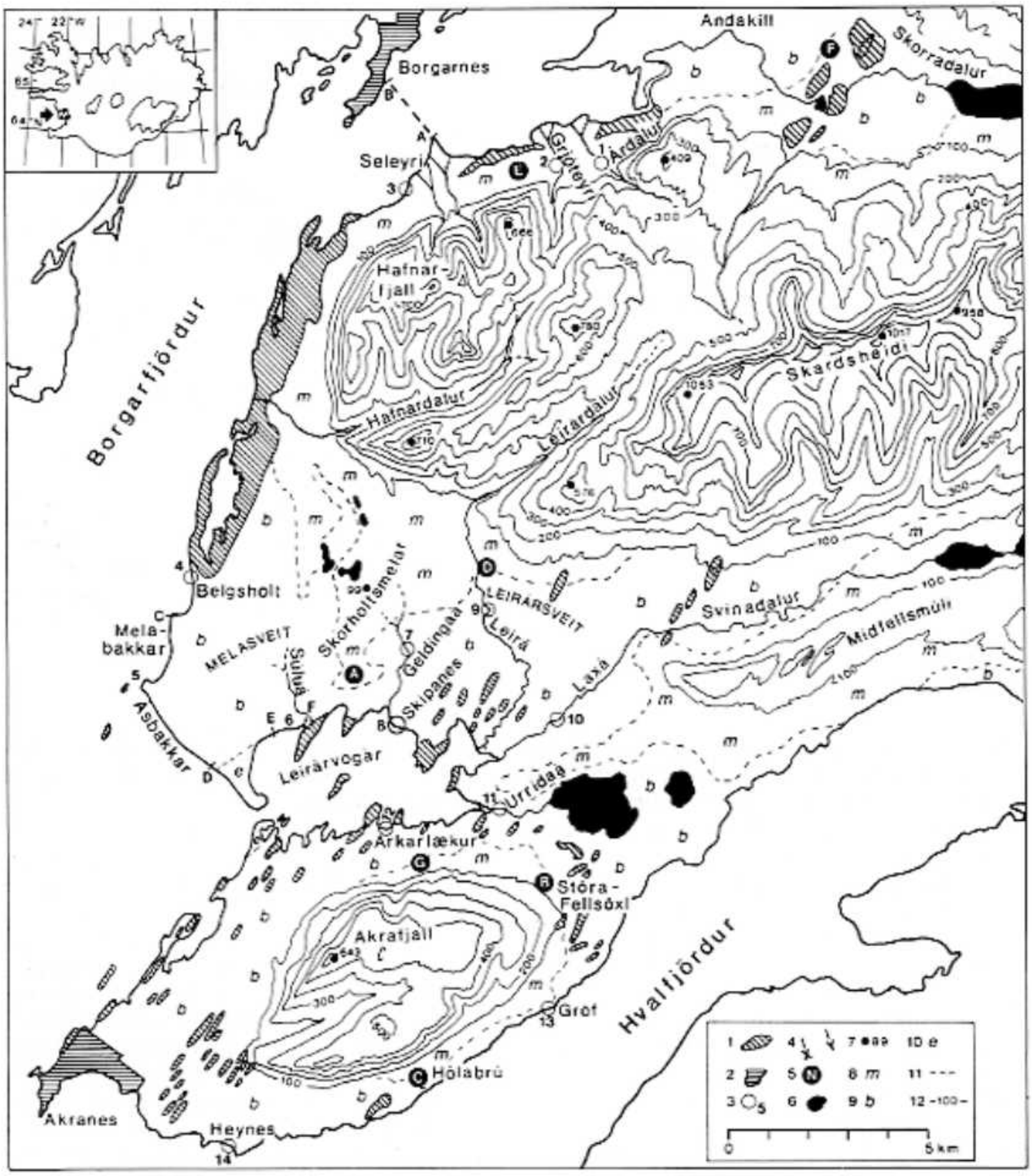

Fig. 1. Location and general physiography of the lower Borgarfjördur region. 1: outcrops of bedrock, 2: town, 3: section described, 4: location of profiles, 5: locality discussed in text, 6: lake, 7: elevation above sea level, 8: meadows and heaths, 9: bogs, 10: eolian dunes, 11: approximate meadow/bog boundaries, 12: contour lines, 100 m interval.

ial erosion, landslides and colluvial deposits have influenced their form in various degrees. Most cirques have floors around 400 m a.s.l. and headwalls going up to 700–900 m a.s.l. A distinct basin threshold is usually absent. This can indicate that the cirque glaciers fed and merged with outlet glaciers during the glaciation, as cirque glaciers confined to hollows are more likely to erode a rock basin than those flowing out of a corrie (Evans 1969).

Cirque recession has resulted in the formation of horns and arrêtes where headwalls converge and intersect. The central part of Skardsheidi is a series of horns, at four places reaching above

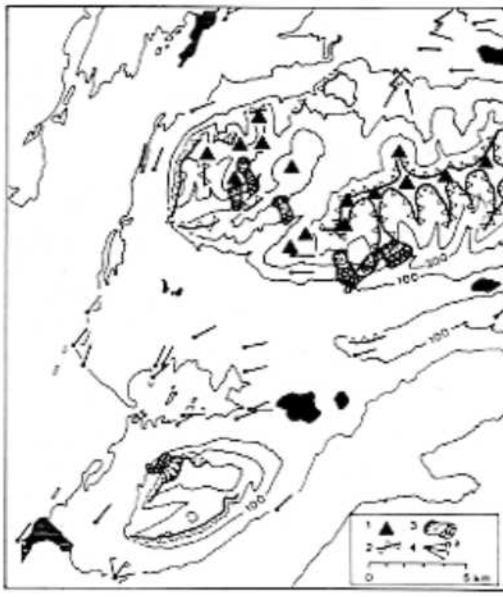

Fig. 2. Glacial landscape and striae. 1: horn, 2: glacially formed, sharp edge, 3: rockslide, 4: glacial striae, a: oldest.

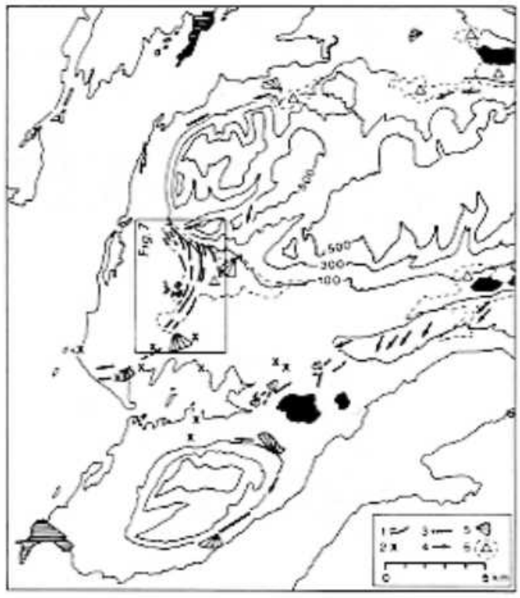

Fig. 4. Glacial landforms and deposits. 1: morainal ridges, 2: large erratics, 3: kame deposits, 4: glaciofluvial channels in bedrock, 5: ice marginal outwash deposits, 6: glacial drift cover.

1000 m a.s.l. The Leirárdalur valley, separating the Hafnarfjall mountain from the Skardsheidi massif, probably developed into a col when cirques from north and south coalesced. Glacial striae in Skorradalur indicates that Leirárdalur has at some time conducted a major glacial stream towards the south.

Large rockslides are characteristic for glacial landscapes in Tertiary basalt plateau areas of Iceland. They occur where glacial erosion has undercut valley slopes and cliffs (Thorarinsson 1954). Conditions for rockslides are favorable due to a combination of a dipping lava pile intersecting valley profiles and interbasaltic clastic beds which can serve as slip surfaces.

The pattern of glacial striae (Fig. 2) suggests a situation where glaciers from Borgarfjördur,

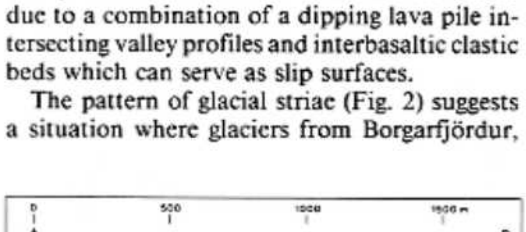

Fig. 3. Transect across the Borgarfjördur fjord, from Seleyri to Borgarnes (location A–B, Fig. 1). Infilling of silts, sands and gravels shaded gray. After Haraldsson (pers. comm. 1986).

Svinadalur and Hvalfjördur coalesced. The only indications of glacial activity above 400–600 m a.s.l. are in the glacial cirques. On the eastern slopes of Akrafjall, in a zone between c. 300 and 450 m a.s.l., there are many large, subrounded to angular erratics. Kjartansson (1955) suggested that Akrafjall divided the Hvalfjördur ice stream during the last glaciation, and that the zone of erratics marks the thickness of the ice as it passed the mountain. Thorarinsson (1937) estimated the upper limit of glacial grinding along the northern side of the Skardsheidi massif at 400-500 m a.s.l. I estimated the boundary zone between glacially abraded and striated bedrock and periglacially sculptured terrain along the southern side of Skardsheidi to be at about 500 m a.s.l. Glacial drift was not found above 200 m a.s.l. and meltwater channels were not recognized above 500 m (Fig. 4). The glacial landscape reflects a full glacial situation, with an extensive ice cover. My reconstruction of the Weichselian maximum ice cover, based on the morphological evidence, is outlined in Fig. 5.

Glacial and marine landforms and sediments

The distribution and pattern of glacial and marine landforms and surface sediments is outlined in Figs. 4 and 6, with a close-up of the

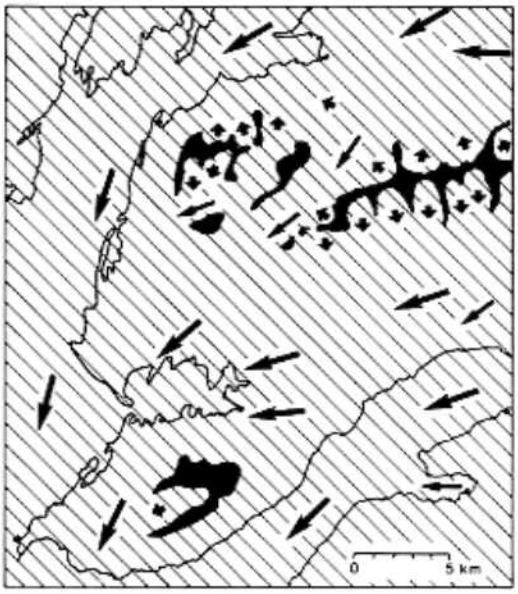

Fig. 5. Reconstruction of the Weichselian maximum situation. Black areas were ice free. Large arrows indicate major ice streams, small arrows contributing cirque glaciers.

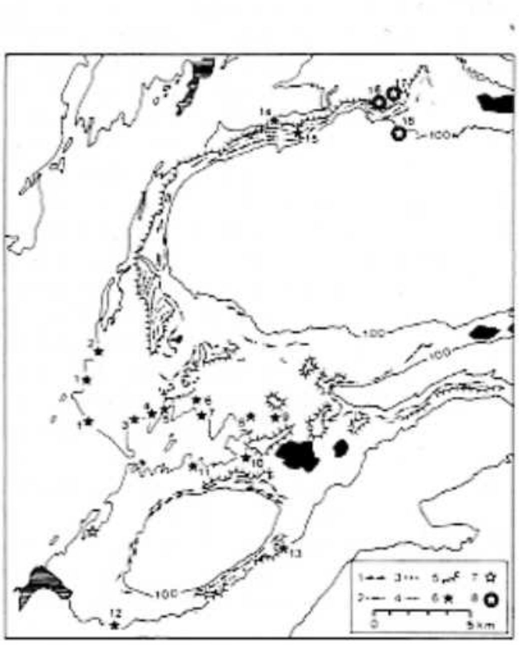

Fig. 6. Raised marine features and occurrences of fossil molluscs. 1: marine maximum limit at 80–90 m a.s.l., 2: regional marine limit at 60–70 m a.s.l., 3: strandline at 40 m a.s.l., 4: beach ridges, 5: edges of marine terraces, 6: location of fossil shells. The numbers refer to columns in Fig. 14. 7: submerged peat, 8: location of fossil shells, sampled and discussed by Ashwell (1975).

Skorholtsmelar area in Fig. 7. The glacial deposits are mainly ice marginal sediments of tills and glaciofluvial outwash. The marine landforms and sediments are abrasion cliffs and raised beaches and terraces with littoral sands and gravels.

The Skorholtsmelar area is a c. 5 km long and up to c. 2.5 km wide terminal moraine complex, of arcuate ridges traversing across the Leirársveit lowland (Fig. 7). The ridge-trough amplitude is usually 15–20 m, with the largest ridge rising c. 40 m above the surroundings. Maximum drift thickness of about 60 m have been reported from seismic soundings on a traverse across the ridge zone (Gíslason 1973). Large erratics are common, some of which are of granophyre. The only known occurrence of granophyre in the region is in the central western slopes of Hafnarfjall. Proximally to the ridges the terrain is hummocky, with large, water-filled kettle holes.

There are no natural exposures in the moraine complex. In two small gravel pits, superimposed sequences of crudely bedded sandy gravels were exposed. Thin lenses of stratified silty-sandy diamicton and sand occur within the gravel sequences. I interpret the gravels as glaciofluvial outwash, and the interbedded diamicton as flow-till. A major component of the Skorholtsmelar complex are glaciofluvial delta sediments. In a gravel pit on the southern margin of the arc (Fig. 1A), a 20 m thick planar cross-stratified foreset delta sequence is exposed. The foreset beds are 20–100 cm thick and dip towards SE. The material is sandy-pebbly with frequent cobble trains, and occasional lenses of stratified to massive sandy-silty diamictons. The foresets are truncated by a gravel lag horizon of wave erosion at 52 m a.s.l.

The morphology of the Skorholtsmelar complex suggests a deposition in front of a lobate glacier tongue extending from the Borgarfjördur valley onto the lowland. The granophyre erratics also suggest debris transport down the Borgarfjördur valley. The arcuate ridges probably formed due to a combination of glacier push on ice marginal outwash deposits and supraglacial melt out of debris. Boulton (1986) has pointed out that the development of large push-moraines is promoted by the presence of large accumulations of ice marginal outwash deposits. The delta deposits on the distal side of the complex indicate a sea level of at least 52 m above the present at some time during its formation.

Another ridge zone extends from the Midfellsmúli ridge towards Akrafjall (Fig. 4). The

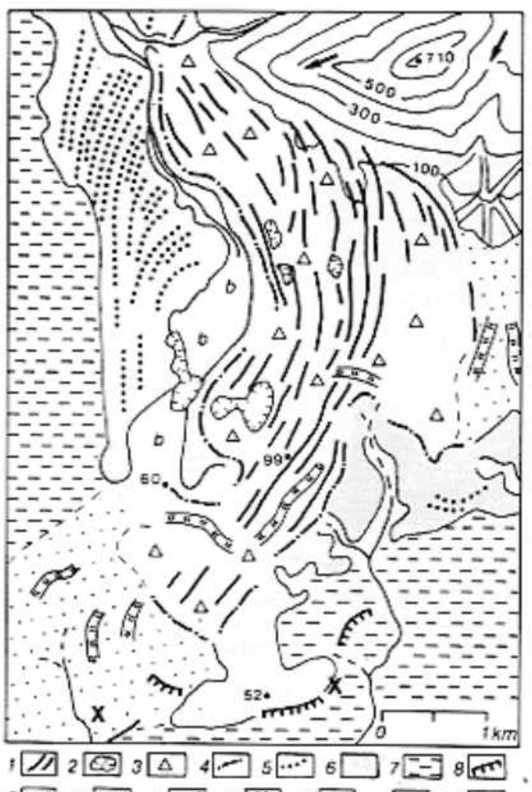

Fig. 7. The Skorholtsmelar area. 1: morainal ridges, 2: kettle hole, 3: glacial drift cover, 4: strandline at 60 m a.s.l., 5: beach ridges, 6: marine terrace platform, 7: sub-soil littoral sediments, 8: strandline at 40 m a.s.l., 9: glaciofluvial channel in sediment, 10: outwash sediments, 11: glaciofluvial channel in bedrock, 12: large erratics, 13: bogs, 14: approximate boundaries, 15: elevation in m a.s.l.

ridges rise to 30–40 m above the surroundings, and proximally embay a lowlying mire with two small lakes. The ridges are made up of dislocated and folded diamicton, containing abundant cobbles and larger clasts in a silty-sandy matrix. The deforming push has come from an easterly direction, and I interpret them to be terminal moraines, pushed up by a glacier tongue from a Hvalfjördur glacier.

Surface outcrops of glacial drift also occur in the Svinadalur valley and the Andakill-Skorradalur area (Figs. 1 and 4). They are diamictons of angular to subrounded gravels and boulders in sandy-silty matrix, often with intrabedded lenses and tongues of stratified diamicton, sands and gravels. Large erratics are common on the surface. I interpret the sediments mainly to derive from meltout, debris flows and meltwater reworking during ice disintegration and retreat. The drift sediments are often reworked by cryoturbation and, below the regional marine limit, abraded and modified by wave action. Large erratics occurring in trains or zones (Fig. 4) may be residuals from frontal, medial or lateral moraines.

At Stóra Fellsöxl, on the eastern flank of Akrafjall (Fig. 1B), there is a large delta deposit of single-set, planar cross-stratified glaciofluvial gravels and sands (Fig. 8). The set thickness is up to 25 m. The foresets are 0.3–1.0 m thick, angular to tangential based, and dip towards N–NE. The topset-foreset contact is at 80 m a.s.l. A delta body with a northerly foreset dip at this location requires that meltwater has been conducted by a glacier occupying the Hvalfjördur trough. I interpret the delta to be an ice lateral deposit, relating to a marine level of 80–90 m above present sea level. At Hólabrú, on the central south-eastern flank of Mount Akrafjall (Fig. 1C), there is an extremely coarse grained deposit of crudely stratified, clast supported cobble gravels and boulders. The clasts are subrounded to well rounded and often show imbricated fabrics, indicating a depositing stream direction from east. Boulders of 0.5–1.0 m in diameter are frequent, while granules and sands are almost entirely lacking. I interpret this to be an ice marginal stratified drift deposit of glaciofluvial outwash, deposited as fast flowing meltwater streams entered a marine environment during a rapid wastage of the Hvalfjördur glacier. Its surface at 58–60 m a.s.l. has been levelled by wave action and carries beach ridges.

Raised beaches are met with at three altitudes: at 80–90 m, 60–70 m and around 40 m a.s.l. (Fig. 6). The marine maximum limit at 80–90 m is marked by a raised abrasion cliff on the northern slopes of Akrafjall. The delta platform at Stóra Fellsöxl and a shoreline cut into outwash deposits in front of the Leirárdalur valley are at similar elevations. The Leirárdalur shoreline is an elongated gravel plane, bounded at about 85 m by a 3–4 m high backslope. The 80–90 m shoreline is only found in the outer coastal areas and distally of ice marginal deposits, and thus predates a later glacial event.

The 60–70 m shoreline is found as raised marine terraces throughout the region (Fig. 6), and it represents the regional marine limit. It is at 60 m a.s.l. in the southern part of the investigated area, and rises with a gradient of c. 0.9 m/km to the north. At Ardalur it is at about 70 m a.s.l, and in the mouth of the Skorradalur valley at about 80 m a.s.l. The terraces are usu-