The Late Weichselian glacial geology of the Melabakkar-Ásbakkar 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 ^{14}C 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 glaciotectonic 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 Melabakkar-Ásbakkar 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 Skorholtsmelar moraines (Fig. 1). A survey of the geological literature (*Ingólfsson* 1984) showed that opinions on the Late Weichselian geology and glacial history

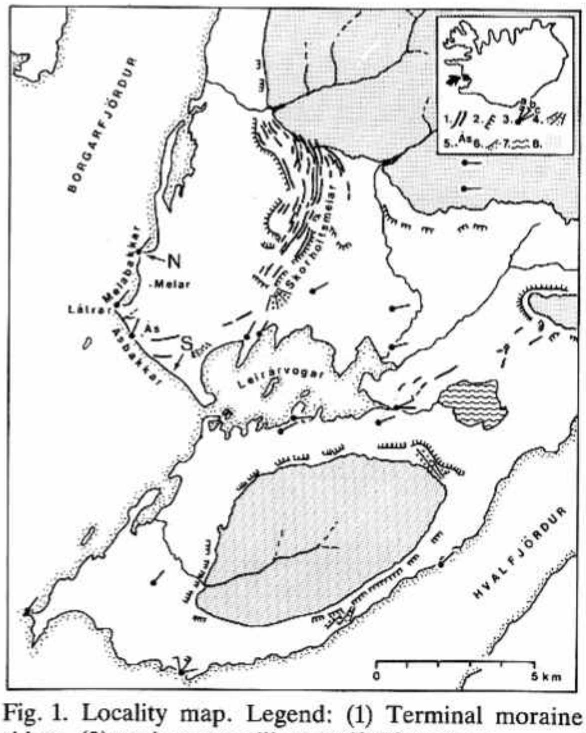

Fig. 1. Locality map. Legend: (1) Terminal moraine ridges, (2) ancient strandlines at 60–70 m above present sea level, (3) glacial striae: a: oldest, b: younger, c: youngest, (4) ice-marginal delta, (5) farm, (6) present coastline, (7) lake, (8) areas above 100 m a.s.l. The coastal profile in Fig. 2 runs between points N and S.
1. mynd. Staðsetningarkort

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) Álftanes Stadial, correlated with the Older Dryas of Scandinavia (*Einarsson* 1979) as the Álftanes glacial advance was radiocarbon dated by a mollusc 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 molluscs 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 *Ingólfsson* (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

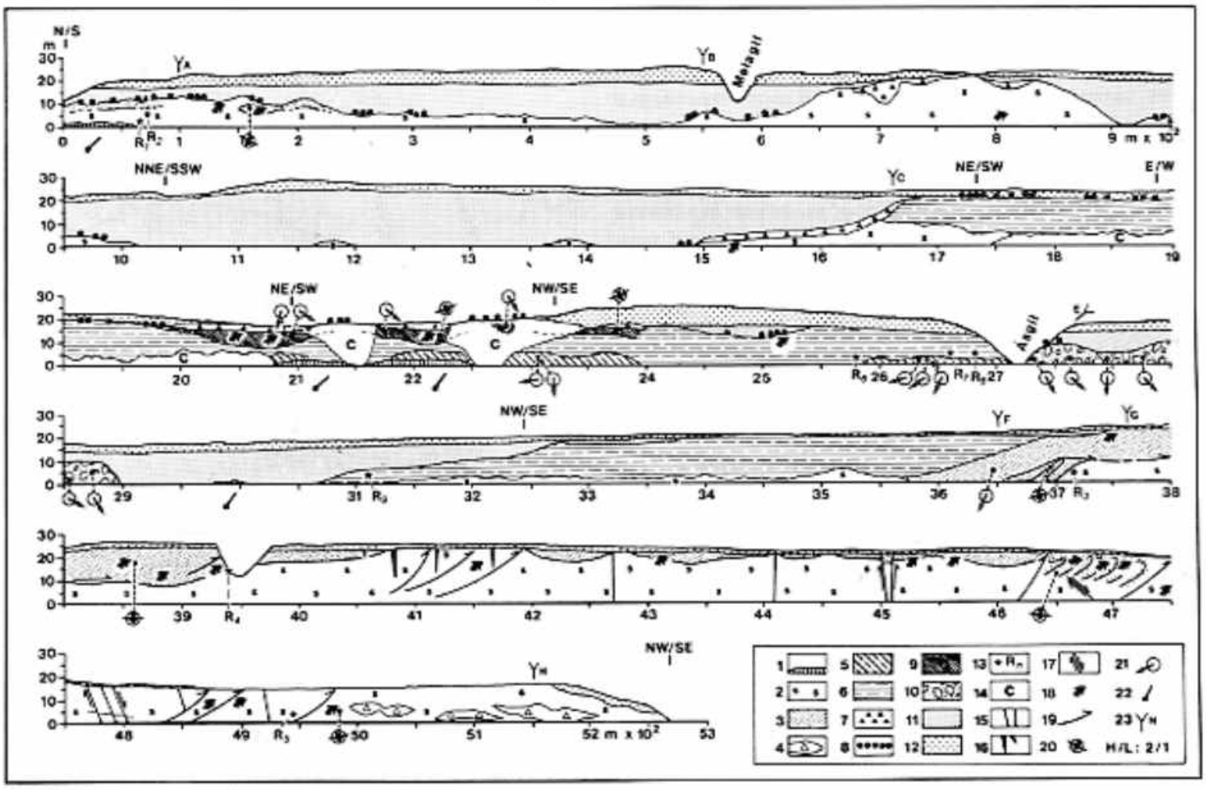

Fig. 2. Melabakkar-Ásbakkar coastal profile. Legend: (1) bedrock, (2) Ásbakkar diamicton, (3) Ás beds, (4) units of interbedded sands and diamictons, intrabedded in the Ásbakkar diamicton, (5) the Látrar beds cross stratified sand facies, (6) the Látrar beds interbedded silt and sand facies, (7) Melar diamicton, (8) boulders, (9) Landhólmi 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) clastic 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. Strandsnið Mela- og Ásbakka.

TABLE I.
Lithofacies code and descriptions of lithofacies in the Melabakkar-Ásbakkar sediments
Tafla 1: Setlykill og lýsingar seteininga

Facies code	Lithofacies	Comments
Dmu	Diamicton, matrix-supported, unstratified	Massive to weakly stratified (stratification less than 10% of unit thickness), silt-sand-gravel-boulder admixture
Dms	Diamicton, matrix-supported, stratified	Clear textural differentiation or structure within a diamiction
Dcu	Diamicton, clast-supported, unstratified	Massive silt-sand-gravel-boulder admixture with clast-to-clast contact gravel and boulder clasts
Gu	Gravel, massive to crudely stratified	Crude horizontal stratification, imbrication, minor sand and silt lenses may occur
Gs	Gravel, stratified	Clear stratification, often alternating openwork and matrix-rich gravels, normal grading, imbrication, minor silt- and sand-lenses
Ggn/Ggr	Gravel, normal/reversed grading	
Gp	Gravel, stratified	Planar cross-stratification, angular to tangential based foresets, alternating clast- and matrix supported foresets, reactivation surfaces
G(l)	Gravel	Lag deposits
B	Boulders	Lag deposits
Su	Sand, massive to weakly stratified	Poorly sorted, may be silty or gravelly, minor intrabeds of sorted sand and silt, dish structures
Ss	Sand, stratified	Planar-parallel bedding, clear stratification, fine to coarse sand, normal grading, occasional rippled surfaces, intralaminae of silt, occasional gravel trains
Sp	Sand, stratified	Planar cross-stratification, angular to tangential based, normal graded foresets, poorly sorted, may be silty, sometimes interbedded gravel trains or diamicton lenses, reactivation surfaces
St	Sand, stratified	Trough cross-stratification, poorly sorted, pebbly
Sl	Sand, laminated	Fine sand to poorly sorted sand, laminated to thin-bedded, usually interbedded with silt. Soft sediment deformations, paleocurrent indication structures
Fu	Fines (silt, clay), unstratified	Massive to weakly stratified, usually sandy. Discontinuous intralaminae of sand
Fl	Fines (silt, clay),	planar parallel lamination, laminated sometimes sandy, usually interbedded with sorted sand, occasional rippled surfaces, soft sediment deformations

in greater details. Bedding type, thickness, contacts, sedimentary structures, texture, deformational 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 "gravel", if not specified, includes granules, pebbles and cobbles. For documentation and interpretation of the sedimentological data a modified version of the lithologic code of *Miall* (1977) and *Eyles et al.* (1983) was used (Table I). I omit the interpretative parenthized last letter of the *Eyles et al.* (1983) code, except when describing regionally extensive lag concentration deposits (G(l)). Chronostratigraphical terminology used is in accordance with *Mangerud and Berglund* (1978).

STRATIGRAPHY AND FACIES RELATIONSHIPS

A profile section of the Melabakkar-Ásbakkar 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

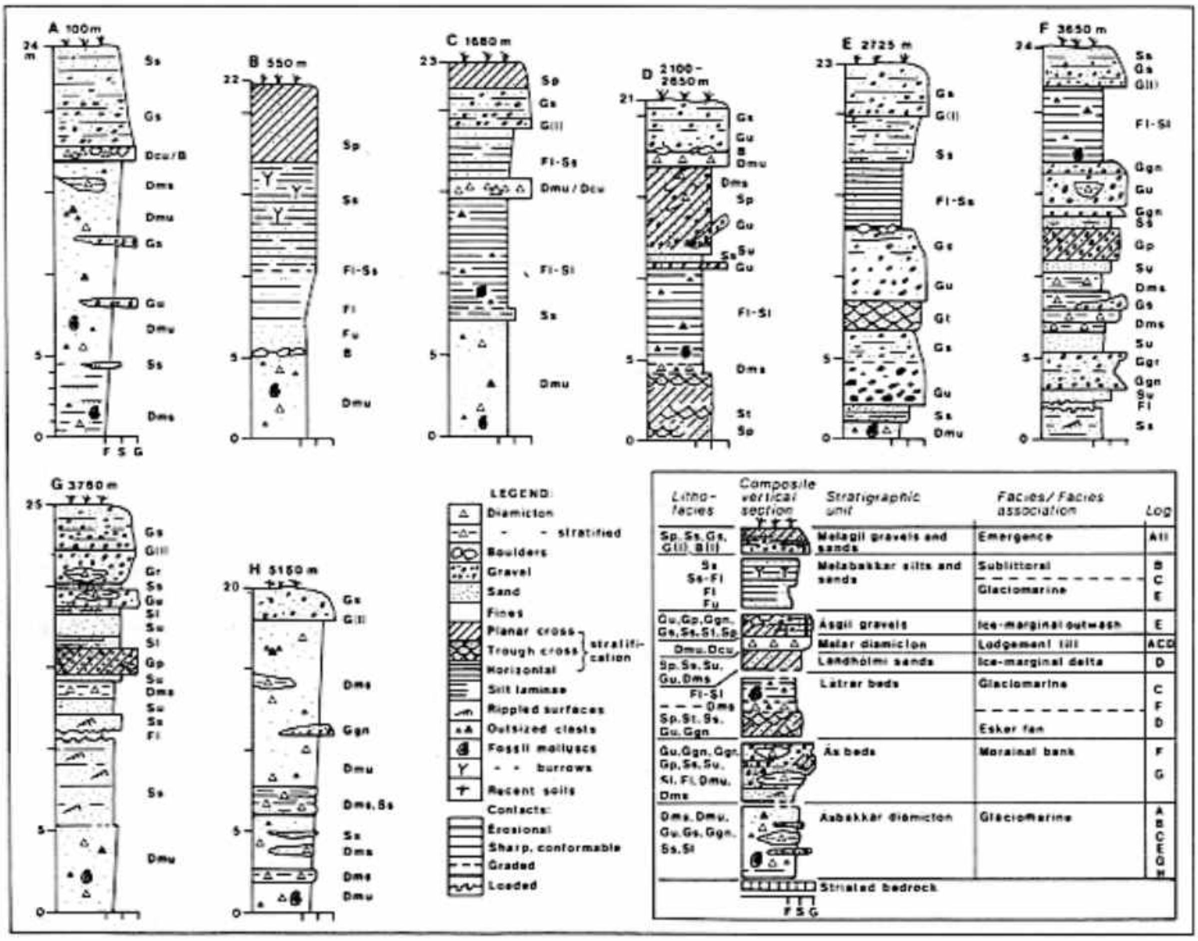

Fig. 3. Lithologic logs from the cliffs. For locations and correlations see Fig. 2. Lithologic code in Table I. Inserted figure: A composite vertical section (not to scale) showing lithofacies, stratigraphy and facies interpretations.
3. mynd. Jarðlagasnið frá bökkunum. Staðsetning sniða í 2. mynd. Setlykill í töflu I. Innskotsmynd: samsett snið.

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

THE ÁSBAKKAR 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 Ásbakkar diamicton makes up the bulk of the cliffs over long stretches (Fig. 2). All its lithofacies can be seen in the Ásbakkar-part of the section.

Facies Dms

Description:

The lowest lithofacies is a fossiliferous, matrix supported, vaguely to clearly stratified silty diamicton with occasional granule 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.

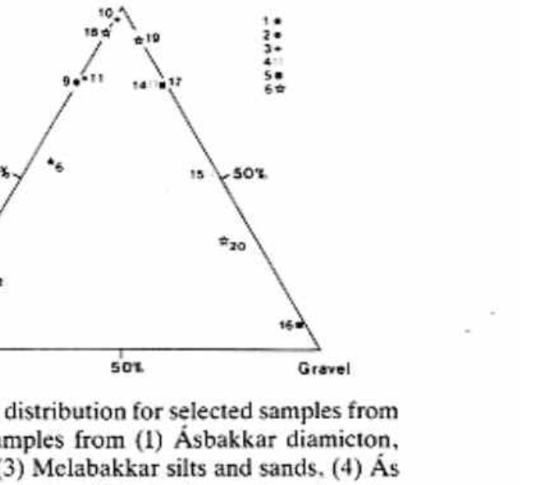

Fig. 4. Grain size distribution for selected samples from the sequence. Samples from (1) Ásbakkar diamicton, (2) Látrar beds, (3) Melabakkar silts and sands, (4) Ás beds, (5) Ásgil gravels, (6) Melagil gravels and sands. Samples described in the text refer to figures within the triangle.

4. mynd. Kornastærðardreifing nokkurra sýna frá bökkunum.

The shells are evenly distributed in the sediments, except in the random beds of gravelly 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-

SPECIES	GLACIOMARINE UNIT 1	GLACIOMARINE UNIT 2	GLACIOMARINE UNIT 3	RECENT DISTRIBUTION Lusitanian	Boreal Low	Boreal Mid	Boreal High	Arctic Low	Arctic Mid	Arctic High
Natica (Tectonatica) affinis	••		•							
Trophon (Boreotrophon) truncatus	••	•								
Colus fusiformis	•									
Buccinum undatum	•••	•								
Nucula (Leionucula) tenuis	•••		•							
Chlamys (Chlamys) islandica	••••	•	•							
Tridonta (Tridonta) elliptica	••••	••								
Tridonta (Nicania) montagui	•••									
Macoma (Macoma) calcarea	•••		•							
Hiatella (Hiatella) arctica	••••	••	•							
Mya (Mya) truncata	••••	••	•							
Balanus (Balanus) balanus	•••	••	•							
Balanus sp.	•••	•	•							

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

REGIONAL DIVISION OF THE EUROPEAN SEAS

TABLE II.

Molluscs and barnacles collected from the Melabakkar-Ásbakkar glaciomarine sediments. Stratigraphical position and Recent geographical distribution. Glaciomarine units: 1: Ásbakkar diamiction, 2: Látrar beds, 3: Melabakkar silts and sands. Location of samples in the cliffs: see Fig 2. Regional division of the European seas from Feyling-Hansen (1955). Taxonomical nomenclature and recent geographical distribution of species from Simonarson (1981).

TAFLA II: Fornskeljar úr mela- og Ásbökkum: Tegund, staðsetning, landfræðileg dreifing í dag.

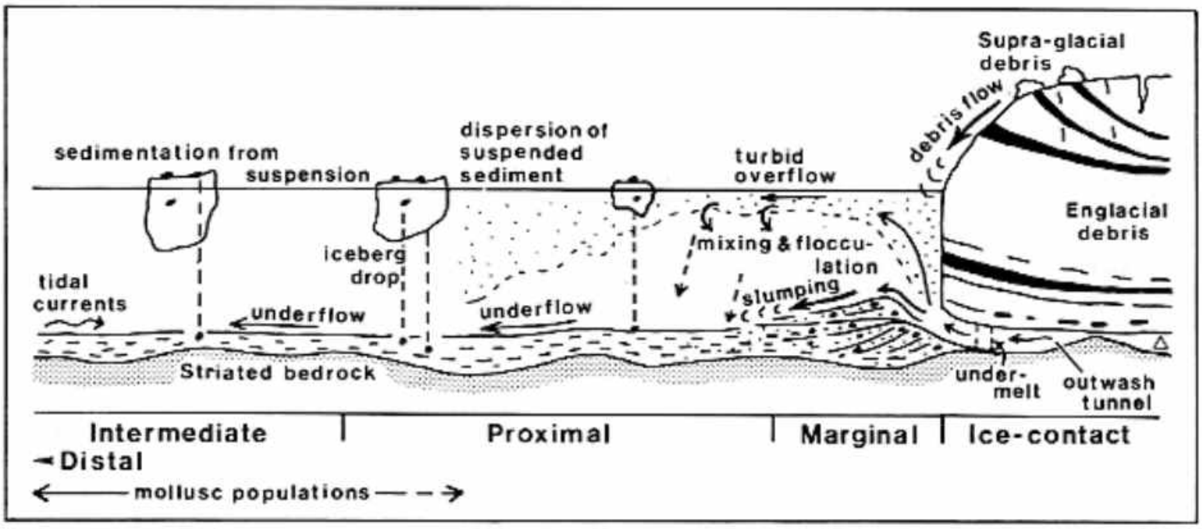

Fig. 5. Major processes operating in a fjord/bay glaciomarine environment. Compiled and modified from Boulton and Deynoux (1981), Elverhöi (1984), Powell (1984), Eyles et al. (1985), Stevens (1985).
5. mynd. Setmyndun í sjó framan við jökulsporð.

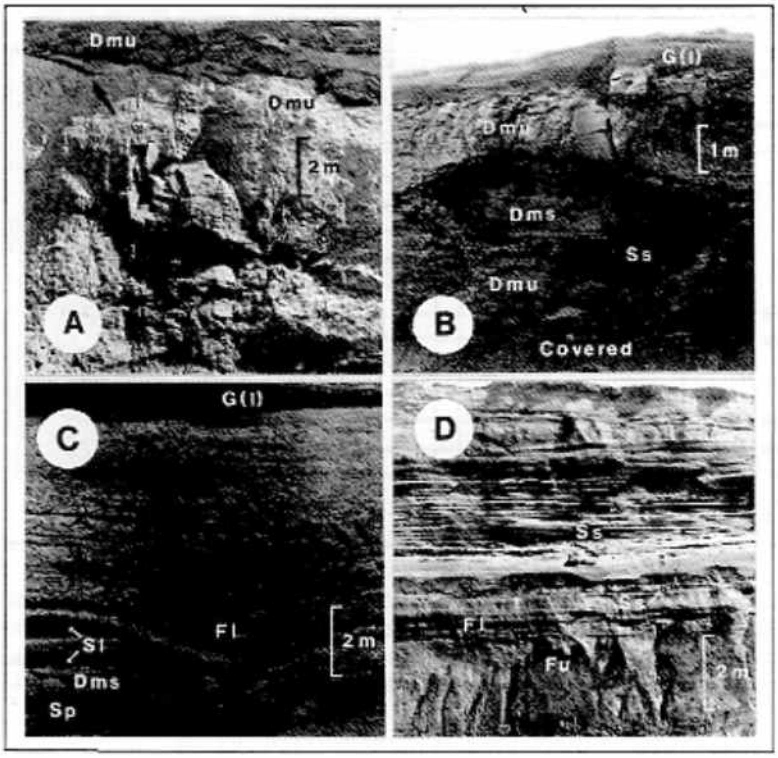

Fig. 6. Melabakkar-Ásbakkar glaciomarine lithofacies. (A) Ásbakkar diamicton at 800 m. Broken line shows contact with the overlying Melar diamicton. Arrow points at en echelon patterned joints; (B) A body of interbedded stratified diamictons and sands, intrabedded in facies Dmu of the Ásbakkar diamicton at 5000 m; (C) The Látrar beds at 2600 m: transition from planar cross stratified esker fan sediments, over stratified diamicton to interbedded laminated silts and sands. The exposure cuts facies Sp parallel to foreset strike. Note the upwards trend towards planar parallel stratification; (D) The Melabakkar silts and sands at 500 m: a transition from glaciomarine silts to sublittoral sands.
6. mynd. Ásýnd jökulsjávarsets í bökkunum.