WEICHSELIAN GLACIAL EXTENT IN MOUNTAIN AREA IN CENTRAL NORTH ICELAND

Shuji IWATA*

Abstract Glaciers during the Last Glacial Maximum sculptured many troughs and cirques in the core area of the lava plateau, including Hörgardalur, in the mountain area between Eyjafjördur and Skagafjördur, North Iceland. Data obtained from geomorphological mapping and field measurements of weathering characteristics on glacial troughs and plateau surfaces fail to confirm that the area was covered with the thick ice sheet which flowed out from the central Iceland in the Last Glacial. Rather, thin and inactive-ice fields which connected with the valley glaciers covered the plateau surfaces. The connected glaciers form an ice field. The ice field joined with the outlet glaciers from the main ice sheet of the island.

Key words: extent of the last glaciation, glacier-erosional landforms, ice-free areas, basalt plateau, weathering of tertiary lava

1. Introduction

Two different opinions exist on the glacial extent of the Last Glacial age in Iceland. Some Scandinavian investigators such as Andersen (1981) and Hoppé (1968, 1982) concluded that a large ice sheet occupied the whole island in the Weichselian Glacial Maximum. But Icelandic geologists insisted that the glaciers in Iceland were only jointed ice fields or aggregated local ice caps, and considerable ice-free areas resulted (Thorarinsson, 1937; Sigbjarnarson, 1983; Hjort *et al.,* 1985). One of these ice-free areas is the peninsula between Eyjafjördur and Skagafjördur in central North Iceland (Fig. 1). The peninsula which is a lava plateau represents a glaciated mountain-landscape. Sugden and John (1976, p. 195) regard the landscape as a typical example of selective linear erosion. Such erosion, however, fails to confirm the existence of a thick ice sheet because such landscape often develops even beneath an ice sheet (Sugden and John, 1976). Norddahl (1983) who studied the Quaternary geology of the paleo ice-lake in Fnjoskadalur, east of Eyjafjördur, mapped the extent of the ice-free areas along both sides of the mountains in the Eyjafjördur area. His map projects the ice-free areas that protrude from the

* Department of Geography, Mie University

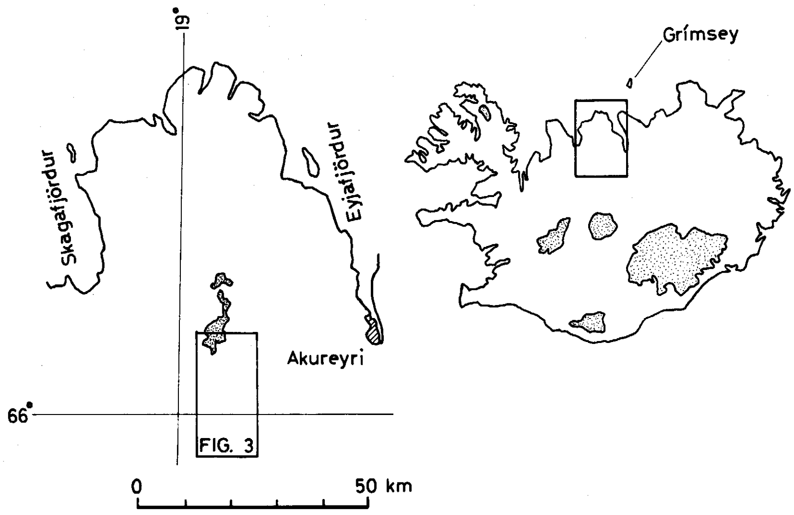

Fig. 1 Maps of the study area showing existing glacier distribution

glaciers. He determined the ice thickness at Eyjafjördur, based on a theory derived from glacier studies in the Arctic and Antarctic regions (Norddahl, 1983). The results from this model resembles to the Einarsson's profile of the paleo Eyjafjördur glacier obtained from the morphological and geological field research on valley walls (Tr. Einarsson, 1959).

As even Norddahl (1983, p. 9) suggested, the upper limits of glaciation on the mountain slopes should be determined in the field by topographic and geologic evidence. Little has been known, however, about the geomorphology and the Quaternary geology in the mountain areas in central North Iceland. This study illustrates the features of the glaciers in the Last Glacial time in the core areas of the mountains in the region based on field evidence.

2. Study Area

As shown in Figs. 1 and 3, the study area is located in the dissected basalt plateau composed of horizontally stratified Tertiary lava layers, piled one on the top of the other. Since the lava erupted at least 7 million years ago (Saemundsson, 1979), the plateau has been gradually uplifted throughout the Tertiary and Quaternary periods as Walker (1982) illustrated in eastern Iceland. Accordingly, the flat plateau surfaces, lying between 1,000 m and 1,300 m a.s.l., have planation-surface remnants that were uplifted considerably. Many typical U-shaped glacial-troughs and cirques were sculptured in the original plateau surface (Fig. 2) and show a complex dendritic network. The planation remnants among the troughs are fragmentary in the central and north parts of the peninsula. This dissected plateau in the north part of the study area connects with the central highlands of the island at Öxnadalsheidi where the circumferential motor road (Route 1) passes.

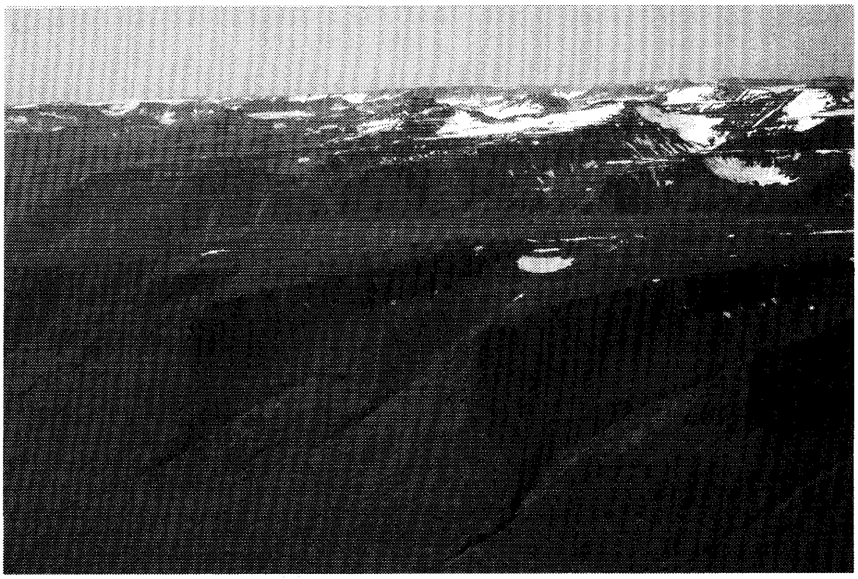

Fig. 2 Aerial view of the dissected lava plateau from the northeast
Cirques and glacial troughs were sculptured in the flat topped plateau.

The area south of Öxnadalsheidi is referred to as the south part.

Intensive study areas involving two glacial troughs, Kaldbaksdalur and Hörgardalur, were chosen for field work (Fig. 3). The Kaldbaksdalur is located at the northern margin of the central highlands of the island, while the Hörgardalur is located just south of the highest core area of the peninsula. One of the highest points of the peninsula (1,399 m a.s.l.) is located to the northwest of the valley. The area belongs to periglacial zone so that various kinds of patterned ground are common (Kanzawa, 1987).

Deglaciation of the area has been traced on lowlands in the fjords on both sides of the peninsula. In the Weichselian Glacial Maximum, glaciers which flowed out from the central ice sheet attached to Grímsey Island, 40 km north from the main island (Norddahl, 1983). In the Late Glacial stage (the Alftanes stage: 12,400 yr.B.P.) outlet glaciers occupied both Skagafjördur and Eyjafjördur (Vikingsson, 1978; Andersen, 1981; Th. Einarsson, 1985). Glaciers retreated largely after the Alftanes stage, and subsequently, the valley glaciers in the peninsula re-advanced far down to the mouths of the troughs in the Budi stage (10,000-11,000 yr.B.P.) (Hallsdőttir, 1973; Hjartarson, 1973). The rapid retreat of the valley glaciers after the Budi stage has been supported by the occurrence of a peat layer on the trough bottom at Heidara to the south of Hörgardalur (Fig. 4), dated by ^{14}C to 7920±140 yr.B.P. Small glaciers survive in cirques and in trough heads in the central part of the peninsula.

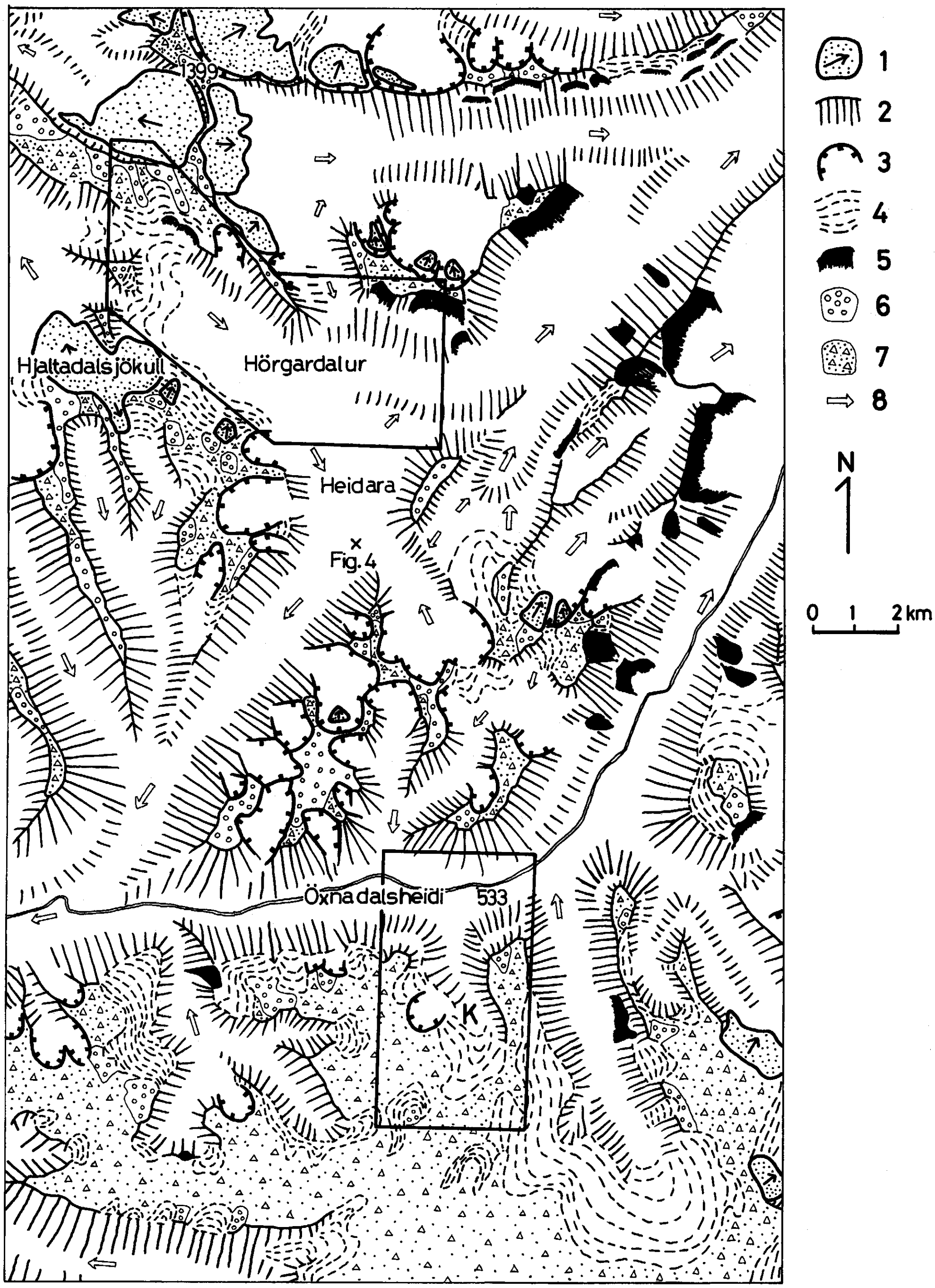

Fig. 3 Distribution of the plateau surfaces and valley walls based on aerial photograph interpretation. The location of the area is shown in Fig. 1. 1: Existing glacier; 2: Trough wall; 3: Cirque edge; 4: Gently glaciated slope; 5: Landslide scarp; 6: Flat and unmodified surface; 7: Uneven or sloping surface; 8: Flow direction of the past glacier. K and Fig. 4 on the map refer to Kaldbaksdalur and the location of Fig. 4 respectively

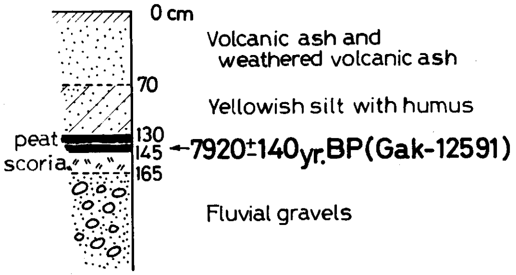

Fig. 4 Section of the glaciated-valley bottom in Heidara, central North Iceland
The location is shown in Fig. 3.

3. Research Methods

It is not easy to define the limit of glaciation in erosional landscapes where glacial deposits are scarce. Generally speaking, glacial deposits and landforms are regarded as the most useful clues in order to understand the past glaciers. In this context, deposits and landforms in the study area were intensively investigated in the field with help of aerial photographs (1:40,000 scale, taken in 1960). In addition, a chartered cessna flight enabled extensive observation of planation surface remnants on the mountain tops.

However, Hoppe (1982), for instance asserts that the absence of glacial traces does not necessarily prove ice-free conditions. He mentioned that the Pleistocene ice sheet failed to mark enough evidence of glaciation in the higher parts of the Scandinavian mountains. It is known that landscapes with no sign of glacial erosion emerged after disappearance of cold-based ice sheets during the Pleistocene period (Sugden and John, 1976).

Boyer and Pheasant (1974) delimited three weathering zones in a glaciated upland area in Baffin Island, Arctic Canada, by using detail measurements of weathering characteristics of debris and bedrock. Using several useful features of weathering, they confirmed that the boundaries of weathering zones reflected the former margins of fjord glaciers. They concluded that the weathering zone provides solid clues for the chronological study of the glacial geomorphology.

In present study, besides observing of the landforms, weathering features on the

Table 1 Weathering characteristics and research method used in central North Iceland

Weathering index (W.I.): descriptive terms for weathering grade[1](6 classes): By naked eyes observation and test by rock-hammer blow
Pitting of bedrock surface (4 classes)
Edge modification (angularity of corner) of splitting bedrock (4 classes)
Maximum joint density per unit length (per 1 m)
Thickness of weathering rinds
P-wave velocity. By seismo counter (Oyo Ps-1); line length is 1 m

[1]Gardiner and Dackombe (1983) p. 86

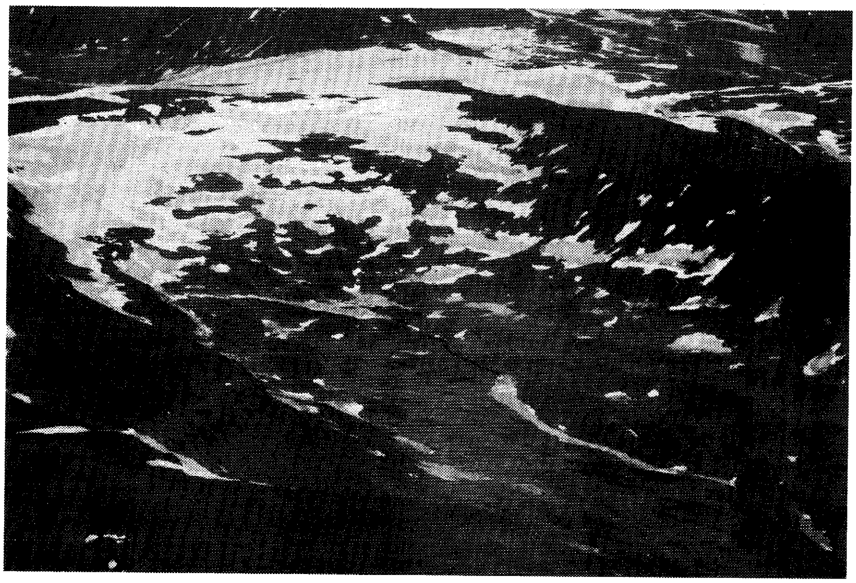

Fig. 5 Aerial view of the gently glaciated slope located at the head of the glaciated trough

bedrock were analyzed. Table 1 shows the weathering characteristics analyzed in this study. Measurements based on longitudinal wave velocity (the P-wave velocity: Vp) enables to estimate size and prevarence of joints and cracks in the weathered bedrock.

4. Results

Geomorphological features

Plateau surfaces and valley walls

Aerial photograph interpretation helped ascertain the distribution of plateau surfaces and valley walls in the study area (Fig. 3). Only fragmentary patches of the plateau surfaces remained to the north of Öxnadalsheidi, while wide plateau surfaces extended southward in the south part. Plateau surface is subdivided into two categories: 1) flat and unmodified surfaces and 2) uneven or sloping surfaces.

The flat and unmodified surfaces represent flat and smooth features covered with weathered debris. They are located in the highest places or peripheral parts of the plateau surfaces. They seem to be remnants of the original plateau surface. To the south of Öxnadalsheidi, they occur sparsely in marginal parts of the plateau.

The uneven or sloping surfaces have small knobs and shallow furrows and/or step-like features. The unevenness is controlled by the horizontal lava structures and has been emphasized by snowpatch erosion. Almost all the plateau surfaces in the southern part of the study area are classified into the second category. Apparently, glaciers eroded portions of these surfaces, while snowpatch erosion modified the remainder.

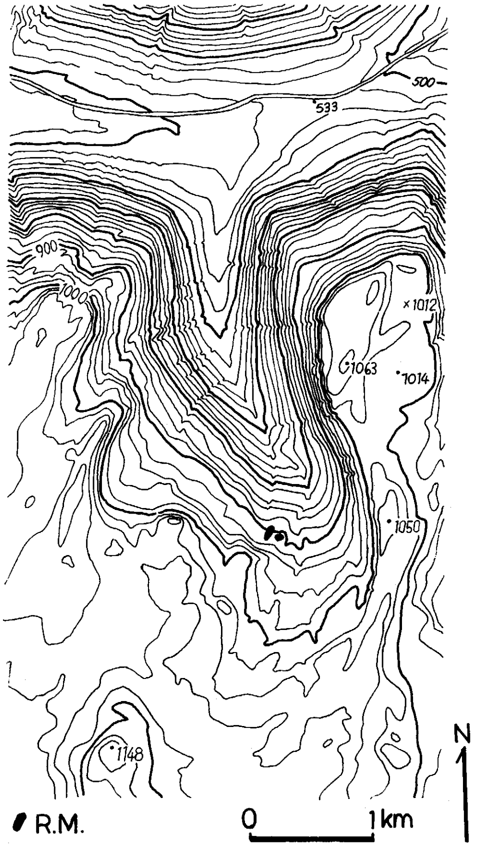

Fig. 6 Topographical features of the Kaldbaksdalur area

A gently glaciated slope with roche moutonnées (R.M.) connects the trough to the plateau surface. Based on the Geodetic Survey of Iceland 1:50,000 topo-sheet. The location is shown in Fig. 3.

The valley walls encompassed distinctly the outer fringe of these plateaus. The valley walls are classified into the following: trough walls, cirque walls, and landslide scarps. In the north part of the area, these valley walls form a network of typical glacial troughs.

On the other hand, some plateau surfaces failed to connect directly with the valley slopes. In these cases the side slopes gently form the top of each plateau surface. Some of them are situated at the heads of the glacial troughs (Fig. 5) while the others between the plateau surfaces and the steep trough walls. The boundaries between these gentle slopes and the plateau surfaces are not well-defined: The former gradually changes to the latter. These gentle slopes represent apparent glaciated features with various glacier-erosional forms referred to as "gently glaciated slopes".

Landforms in Kaldbaksdalur

The topographical map shows the Kaldbaksdalur (Fig. 6). This valley is one of the typical glaciated troughs sculptured on the northern margin of the main highland. The plateau surface features low and gentle hills, covered with rock fragments consisting of intermittent patches of local bedrock. No macro weathering features, such as tors and large-scale cavernous weathering, occurred on the plateau. Although no erratic boulder and no striated bedrock were found, an ice field or an ice sheet covered most of the

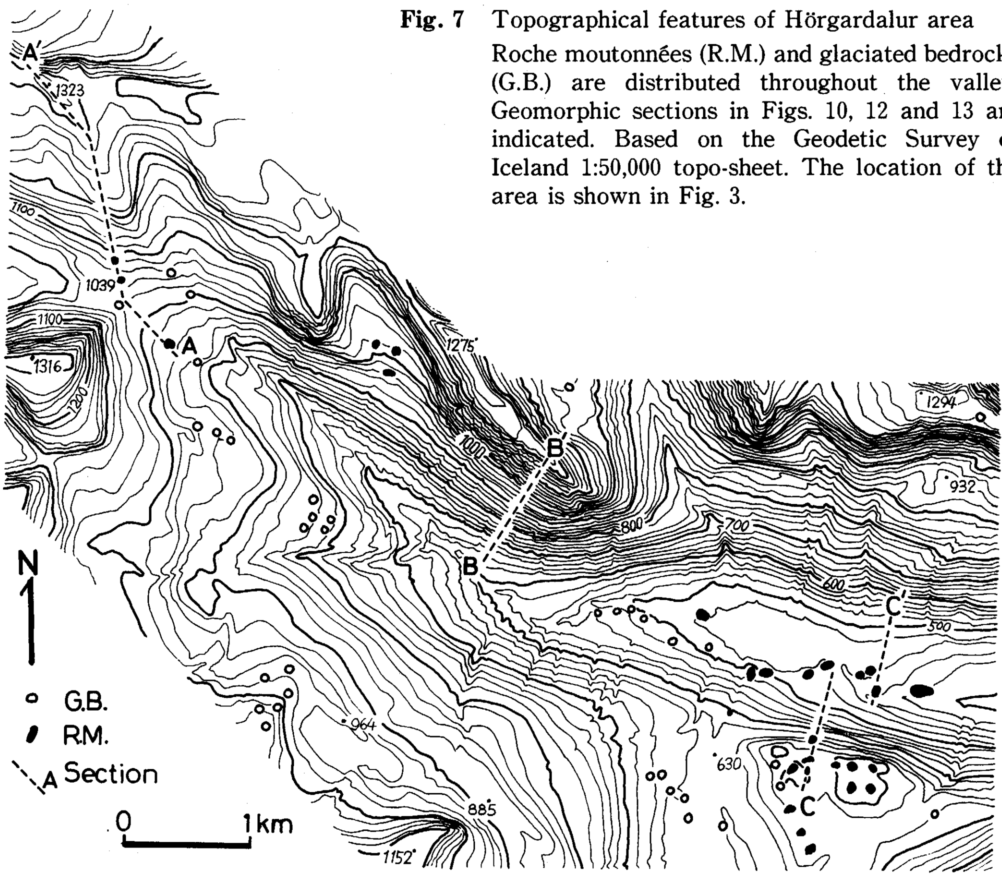

Fig. 7 Topographical features of Hörgardalur area
Roche moutonnées (R.M.) and glaciated bedrocks (G.B.) are distributed throughout the valley. Geomorphic sections in Figs. 10, 12 and 13 are indicated. Based on the Geodetic Survey of Iceland 1:50,000 topo-sheet. The location of the area is shown in Fig. 3.

plateau during the Last Glacial period. Gentle glaciated slopes occurring at the heads of all the glaciated valleys supports this glacial situation (Fig. 3). The gently glaciated slopes, with its step-like rugged forms with round edges, suggests glacial erosion. At the head of Kaldbaksdalur, roche moutonnées rest on the upper part of the slopes just below the plateau surface. These features suggest that an outlet glacier or ice stream from the ice sheet or ice field invaded the valley in the last glaciation and it joined the transection glacier at Öxnadalsheidi.

Landforms in Hörgardalur

An upper part of Hörgardalur has a considerably wide and gentle valley-head area which was entirely glaciated (Fig. 7). Roche moutonnées are distributed in various places through the valley, but concentrate down to middle course below 700 m in altitude. Roche moutonnées are distributed on both the east and west sides of the pass through the valley located on the west. The pass is a glaciated col and the Pleistocene glacier of the Hörgardalur was a transect glacier. Indistinct roche moutonnées or glacier-smoothed bedrocks the south-facing slope above the pass; the highest one is located at 1,170 m in altitude. These features indicate that the past glacier occupied the pass and extended nearly to the edge of the plateau surfaces.

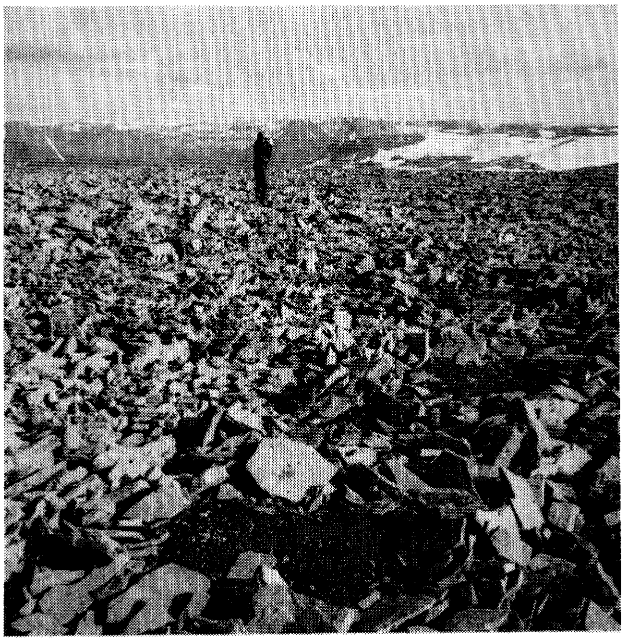

Fig. 8 Debris field on the plateau surface 2 km northwest of the pass of the Hörgardalur valley-head The altitude is about 1,300 m. In the background a flat plateau surface can be seen.

The plateau surface above 1,200 m on the northwest of the valley head is almost flat. Neither hillock nor prominence, such as roche moutonnée, whaleback, and tor exists (Fig. 8). The flat surfaces are covered with in situ debris which form various types of patterned ground. Surprisingly, neither erratic boulders nor ice-smoothed and striated

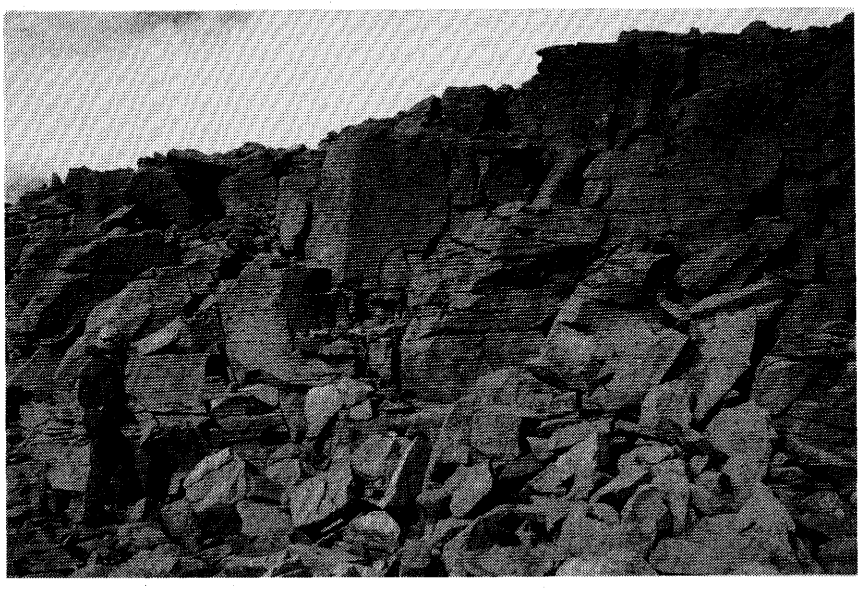

Fig. 9 Joints in basalt exposed at the head of Hörgardalur, 1,150 m in altitude

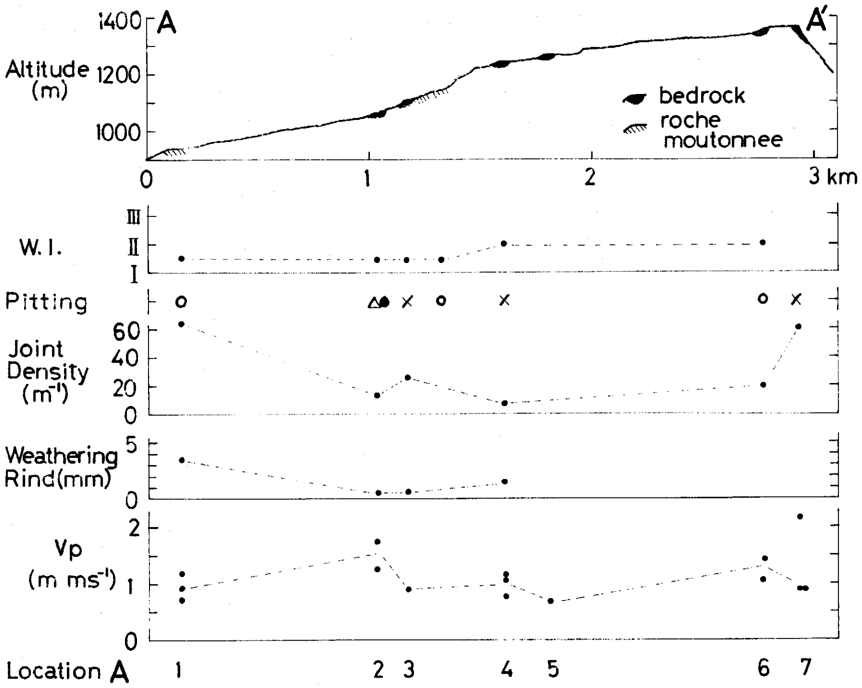

Fig. 10 Results of the measured weathering characteristics in the section (A) from the head of the Hörgardalur area to the plateau
The location is shown in Fig. 3.

bedrock could be found, but gentle step-like slopes, influenced by glacial erosion and/or by snowpatch erosion, constitute the southern margin of the plateau surface. This suggests that some kind of ice mass, causing impotent or very weak erosion, covered the plateau surface. To the south of the pass small existing glaciers, named Hjaltadalsjökull, cover parts of the plateau surfaces, saddles, and heads of valleys (Fig. 3). Scattered around Hjaltadalsjökull, gently glaciated slopes surround most of these plateaus. These gently glaciated slopes indicate that past glaciers covered the plateau surface around Hörgardalur.

Weathering features

Weathering index, pit weathering, joint density, thickness of weathering rinds, and P-wave velocity were measured from the head of Hörgardalur to the top of plateau surface. Weathered debris cover so many parts of the slopes in the study area that the bedrock exposes in limited places, such as roche moutonnees, and step and cliff edges. Measuring points are accordingly scarce. In the bedrock horizontal joints occur intensively, while vertical joints are sparse (Fig. 9). The results are illustrated in Fig. 10. The measured values do not vary widely with the locality except for the values of the joint density. Relatively high joint density and thick weathering-rind in location no. 1 indicates that intensive weathering occurred. Snow action causes this weathering due to the existence of a snowpatch at the head of the valley. The intensive joint-density and the

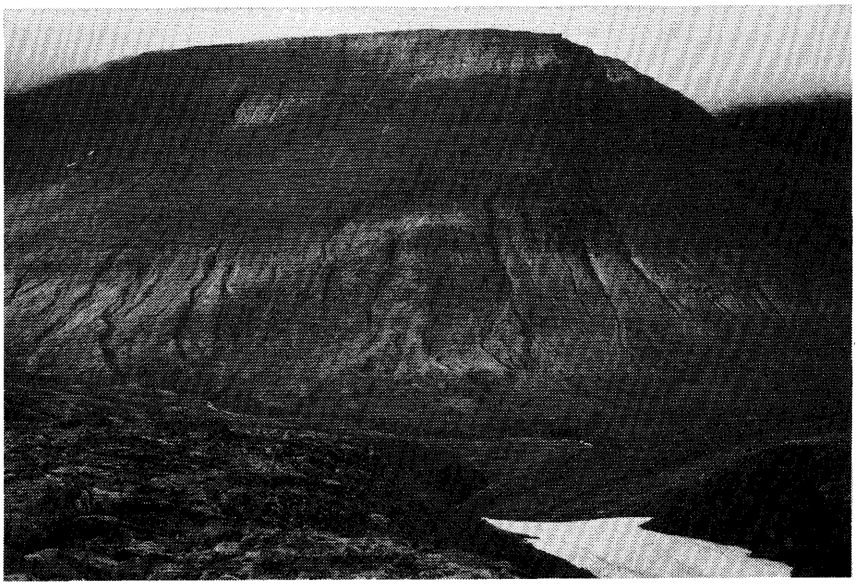

Fig. 11 Trough wall at the middle course of the Hörgardalur
Weathering characteristics in section B, measured along the slope to the left of center, appear in Fig. 12.

very-fast P-wave velocity in location no. 7, produces contradictory results which defy explanation. Locations no. 2 and no. 3 were apparently glaciated because of the existence of roche moutonnées, while locations nos. 4 to 7 on the plateau surface represent no concrete evidence of glaciation. In these latter two locations, however, similar weathering occurred. The almost same weathering intensity suggests that these locations share a relatively same exposed conditions to the atmosphere. The relatively moderate weathering indicates that the plateau surface have not been exposed for long period.

In the middle course of the Hörgardalur the existence of many roche moutonnées indicates that the valley bottom was apparently occupied by an active glacier. A boundary between severe and moderate weathering which may reflect the upper limit of the glacial erosion was examined on the left bank of the trough wall. Horizontally stratified basalt layers outcropping on the thin-debris mantled slope were observed and measured. Well-eroded rugged features were observed on the upper slope above 1,000 m in altitude (Fig. 11). Scoria layers intercalated in the basalt layers were excluded for the measurements. Figure 12 indicates that fresh rocks appear on the valley slopes except for the location no. 8. The highly weathered features of location no. 8 imply a possibility that the glaciation limit existed between locations no. 7 and no. 8. This boundary seems to coincide with the morphological boundary at 1,000 m in the altitude mentioned above. There is no large difference, however, between the measured values at location no. 8 and those in the apparently glaciated locations in the valley bottom shown in Fig. 13. Measurements of intensity of pitting and of thickness of the weathering rind in no. 8 of

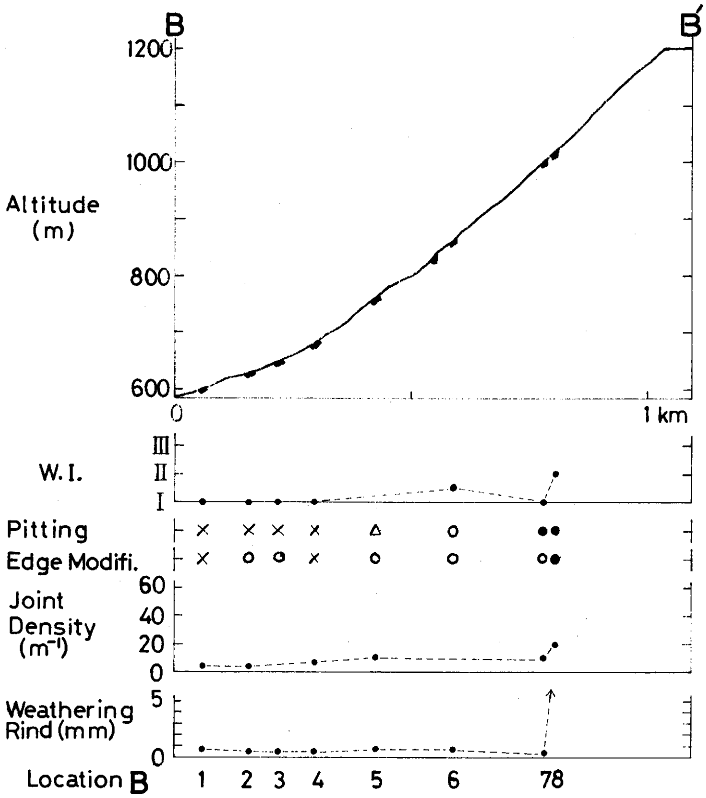

Fig. 12 Results of the measured weathering characteristics at site (B) in the mid section of Hörgardalur
The location is shown in Fig. 3.

section B slightly exceed those in section C. This fact suggests the following two possibilities: (1) the ice-free condition of the upper trough wall lasted for only a short period; and (2) the glacier occupied the entire trough wall but some specific petrological characteristics at location no. 8 caused the intensive weathering.

5. Discussion

The well-developed trough network in the study area indicates that selective linear erosion surely occurred. However, if glaciers occupied the currently ice-free plateau surfaces during the Last Glacial remains uncertain. A sharp contrast between intervening upland surfaces and trough walls typically suggests selective linear erosion (Sugden and John, 1976). This contrast reflects that erosion on the valley walls exceeds that on the plateau surface. Moreover, this feature more typically appears on the horizontally stratified bedrock like that in this study area than on the non-stratified bedrock, like

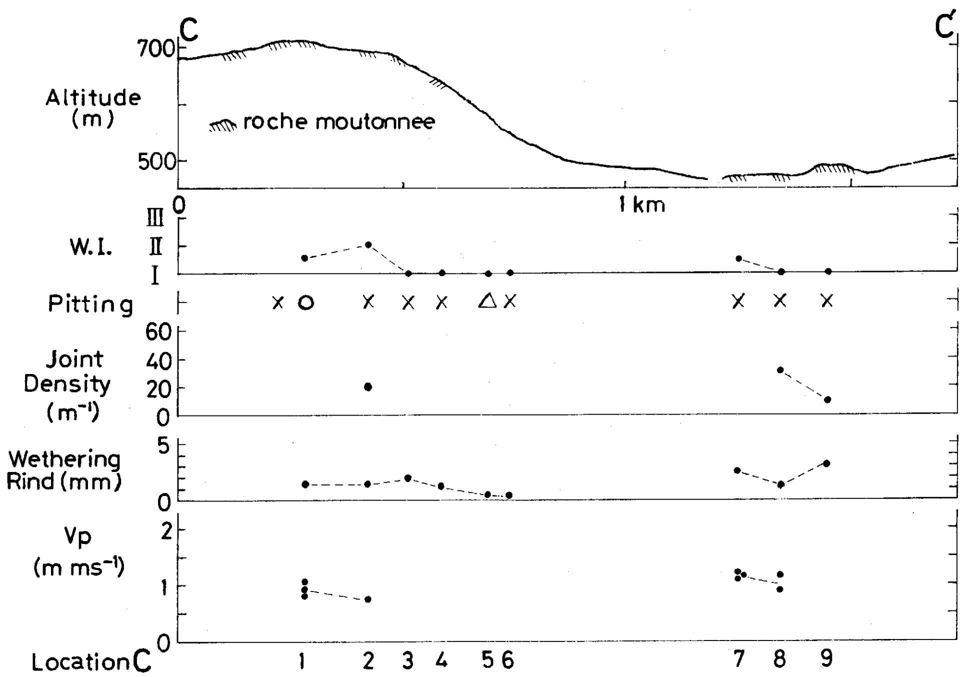

Fig. 13 Results of the measured weathering characteristics at site (C) in the mid section of Hörgardalur
The location is shown in Fig. 3.

massive granitic rocks. This dillerence of lithology suggests that the sharp contrast does not always indicate the past existence of the ice-free area. Conceivably, table-shaped landforms sustained while occupied by the glaciers. The distinct plateau edges at the margins of the present ice fields at Vatnajökull and Hofsjökull supports such a scenario.

No sign of glacial erosion on the flat plateau surfaces suggests that the surfaces were not covered with a wet-based ice sheet. On the other hand, each area reveals no intensive weathering feature and/or no macro weathering form, both on the plateau surfaces and on the most valley slopes. This fact suggests that the area was not free from glaciers. A probable solution is that the surfaces were covered with glaciers during the Last Glacial, but these glaciers froze to the ground. The occupying glaciers were too thin to cause pressure melting for basal sliding and plastic deformation necessary for forming the stream-lined erosional bedrocks. Therefore, the glaciers on the plateau surfaces were thin inactive and/or cold-based ice fields and mountain glaciers. The thin glaciers on the plateau concentrated and thickened at the heads of the troughs or margins of the plateau, and could sculptured the bedrocks into gently glaciated slopes.

The extensive distribution of the gently glaciated slopes indicated that the ice-covers on the plateaus flowed into the valleys and nourished trough glaciers. The glaciers probably filled the troughs and cirques nearly up to their upper walls.

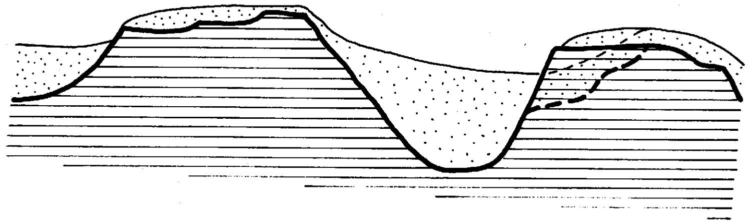

Fig. 14 Schematic cross section of the plateau area of the central North Iceland during the Last Glacial
Trough glaciers connected with thin plateau glaciers, and formed an ice field.

These glaciers in the Last Glacial Maximum formed a nearly continuous ice field and the surface altitude was about 1,100-1,200 m in the central part of the peninsula. Ice free areas (dry land) in the mountains were limited to small areas such as along steep walls between the trough and cirque glaciers and along the plateau edges (Fig. 14).

The same glacial environment in the Last Glacial Maximum was elucidated in Vestfirdir, northwestern Iceland (Hjort *et al.,* 1985). The maximum extent of the ice age glaciers in Vestfirdir was smaller than previously thought.

The features of the glaciers during the Last Glacial time in the core area of the mountains, central North Iceland, are as follows: The area was probably not covered with a thick ice sheet which flowed out from the central highland. Thin inactive ice fields covered the plateau surfaces and connected glaciers that flowed into the troughs. Accordingly, the glacial condition in the central part of the peninsula was classified as an ice field. The ice field joined with the outlet glaciers from the main ice sheet of the island.

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References Cited

Andersen, B.G. (1981): Late Weichselian Ice Sheets in Eurasia and Greenland. In Denton, G.H. and Hughes, T.J. (eds.) *"The Last Great Ice Sheets"*, John Wiley & Sons, New York, 3-65.

Boyer, S.J. and Pheasant, D.R. (1974): Delimitation of weathering zones in the fiord area of eastern Baffin Island, Canada. *Geol. Society Amer. Bull.*, **85**, 805-810.

Einarsson, Thorleifur (1985): *Jardfraedi,* Mâl og menning, Reykjavîk, 233p.

Einarsson, Trausti (1959): Studies of the Pleistocene in Eyjafjördur, Middle Northern Iceland. *Vîsindafêlagîslendinga (Societas Scientiarum Islandica),* **33**, 62p.

Gardiner, V. and Dackombe, R. (1983): *Geomorphological Field Manual,* George Allen & Unwin, London, 254p.

Hallsdôttir, M. (1973): *Um isaldarlok â Glerârdal og î nâgrenni Akureyrar.* Unpublished B.S. dissertation, University of Iceland, 39p.*

Hjartarson, Â. (1973): *Rof jardlagastaflans milli Eyjaffardar og Skagaffjardar og îsaldarmenjar vid utanverdan Eyjafjörd.* Unpublished B.S. dissertation, University of Iceland, 36p.*

Hjort, C., Ingolfsson, O., and Norddahl, H. (1985): Late Quaternary geology and glacial history of Hornstrandir, northwest Iceland: a reconnaissance study. *Jökull,* **35**, 9-29.

Hoppe, G. (1968): Grîmsey and the maximum extent of the last glaciation of Iceland. *Geogr. Ann.*, **50A**, 16-24.

——— (1982): The extent of the last inland ice sheet of Iceland. *Jökull,* **32**, 3-11.

Kanzawa, K. (1987): *The distribution and altitudinal zonation of periglacial landforms, in Hörgardalur, Iceland.* Unpublished M.A. dissertation, University of Hokkaido.**

Norddahl, H. (1983): Late Quaternary stratigraphy of Fnjôskadalur central North Iceland, A study of sediments, ice-lake strandlines, glacial isostasy and ice-free areas. *Lundqua Thesis (Lund Univ.),* **12**, 78p.

Saemundsson, K. (1979): Outline of the geology of Iceland. *Jökull,* **29**, 7-28.

Sigbjarnarson, G. (1983): The Quaternary alpine glaciation and marine erosion in Iceland. *Jökull,* **33**, 87-98.

Sugden, D.E. and John, B.S. (1976): *Glaciers and Landscape,* Edward Arnold, London, 376p.

Thorarinsson, S. (1937): The main geological and topographical features of Iceland. *Geogr. Ann.*, **19**, 161-175.

Vikingsson, S. (1978): The deglaciation of the southern part of the Skagafjördur district, northern Iceland. *Jökull,* **28**, 1-17.

Walker, G.P.L. (1982): Topographic evolution of Iceland. *Jökull,* **32**, 13-20.

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