

The Quaternary Alpine Glaciation and marine Erosion in Iceland

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ABSTRACT

Geomorphological studies of the coastal areas of South-eastern and Eastern Iceland show the main topographical landforms eroded by alpine glaciation and marine abrasion. Those areas of Iceland which show predominantly alpine landscape are presented on a map as well as the largest ones of the coastal cliffs. Attention is drawn to the difference in the development of the strandflat and coastal scenery in the northern and southern parts of Iceland. This evaluation leads to that conclusion that the thickness of the Pleistocene glaciers has been much less in the Southeastern Iceland than in the North and that there have always been some ice-free areas during the glacials.

INTRODUCTION

The paper presented here is intended as a small contribution to the Quaternary geomorphology of Iceland. It is not a complete account, nor does it reach any definite scientific conclusions, but rather considers and discusses two important aspects i. e. the importance of alpine glaciers and of marine erosion in the formation of the landscape. The work is particularly based on observations on the coastlines and coastal areas of southeastern and eastern Iceland from Fljótsdalshérað to Eyjafjöll, although other areas are of course considered. In the light of these observations it is attempted to build up a picture of the thickness and extent of glaciers in previous glacial periods in this area, and indeed for the country as a whole, although it is as yet imperfect.

GEOMORPHOLOGY OF ICELAND IN QUATERNARY TIME

Few earth scientists will doubt that many of the more important features in the Icelandic landscape bear witness to Quaternary glaciation, such as

fjords, valleys, corries and serrated edges (arêtes). Many authors have discussed or pointed at these in their work. Mention can be made of *Thorvaldur Thoroddsen* (1905-06, 1908-1911), *Helgi Pjetursson* (1905, 1906, 1908), *Trausti Einarsson* (1959, 1961, 1962, 1972, 1977), *Gudmundur Kjartansson* (1943, 1955, 1961, 1962, 1966), *Sigurður Thórarinnsson* (1937, 1951, 1956, 1960), *Thorleifur Einarsson* (1961, 1968, 1969, 1976), *Kristján Sæmundsson* (1979), and *Thórdís Ólafsdóttir* (1975) as well as various other papers by these authors not mentioned here. In addition a large number of other earth scientists both from Iceland and abroad have mentioned these features, it being sufficient to refer here to *Arthur Holmes* (1965), *Arne Noe-Nygaard* (1962), *Gunnar Hoppe* (1968) and *Hubertus Preusser* (1976). No discussion will here be made on the theories of individual authors or their separate topics but reference is made to their work where relevant.

There are different opinions amongst these authors as regards the possible thickness and extent of glaciers during glacial periods and whether certain areas have been ice-free and even vegetated throughout the Quaternary Era. In the last few decades the opinion has become rapidly popular that Iceland has been covered by a very thick ice sheet, even 2000-3000 m, in previous glaciations and that it has calved off the edge of the continental shelf at depths of at least 200 m or more so that the country was completely covered by ice. This view is very similar to that held for the ice sheets of Scandinavia and Canada. According to this view the formation of the Icelandic landscape and its continental shelf should be foremost due to erosion by a thick ice sheet with an ice centre and main divide somewhere in the central highlands.

In my opinion many geomorphological and glaciological arguments are decidedly against this theory. In the discussion that follows I shall try to



Fig. 1. Alpine landscape south of Reyðarfjörður from Oddskard. The picture shows the mountain ridge between Reyðarfjörður and Fáskrúðsfjörður from Godaborg to beyond Studla. Eyrardalur, Jökulbotnar and Hrutadalur are all hanging valleys in Reyðarfjörður while the valley spurs between Berutindur, Eyrarfjall, Kambsfjall and Hádegisfjall are serrated edges (arêtes). Glacial cols can be seen at 350-400 m.a.s.l. on valley spurs. cf. Fig. 9.
— Photo G. Sigbj.

Mynd 1. Alpalandslag sunnan Reyðarfjarðar frá Oddskarði. Á myndinni sést fjallshryggurinn milli Reyðarfjarðar og Fáskrúðsfjarðar frá Godaborg inn fyrir Studla. Eyrardalur, Jökulbotnar og Hrutadalur eru allt hangandi dalir við Reyðarfjörð á meðan dal-múlarnir á milli þeirra Berutindur, Eyrarfjall, Kambsfjall og Hádegisfjall eru jökuleggjar (arête). Greina má jökulaxlir í 350-400 m y.s. utan í dalmúlunum sbr. 9. mynd. — Ljós. G. Sigbj.

assemble some of the most compelling factors to support this view.

Two types of landform have mainly aroused my interest in field trips to the coastal areas of the country. On the one hand there is the factor of how extensive areas exclusively or predominantly display characteristics of alpine glaciation. The highland in Tröllaskagi, Snæfellsnes and the eastern fjord mountains (Fig. 1) are clear examples of this. These landforms are widespread elsewhere if one looks closely for example in the western fjord mountains, in southeast Iceland and the Skaftafell mountains in the Örfæli district. On the other hand there are highly developed wave-cut cliffs and promontories (Fig. 2) which not only extend seawards from various headlands, exposed to wave attack at the present sea level, but also for a considerable distance landwards, requiring a sea level 20-40 m higher

than today for their formation, and even as high as 100-120 m a.s.l. Látrabjarg, Hornbjarg and Gerpir are examples of promontories which extend seawards today, while Lómagnúpur, Eyjafjöll, the western slopes of Esja and Hafnarfjall are examples of promontories having well developed strandflats beneath.

Fig. 3 is a map of Iceland showing promontories and definite wave-cut cliffs, which reach more than 60 to 80 m above their present base, whether it is sea level, strandflat or sedimentary infill. On Fig. 3 are also shown all those areas where the glacial geomorphology shows predominantly alpine landscape characteristics. Various other areas should also be considered, where certain mountainous areas have a composite form. The map as a whole can neither be considered as complete nor exact. Time neither permits description of individual features of the map nor explanation of those features which appear doubtful but I have based it on various definitions of Sugden and John (1976) and Krüger (1974).

FORMATION OF THE ALPINE LANDSCAPE

The main characteristic of alpine glaciers is that their location depends almost exclusively on the



Fig. 2. Finnurinn (foreground) and Hvannadalabjörg (distance) are typical fjord promontories as they occur in the western fjords, northern Iceland and eastern fjords north of Gerpir. The picture is taken from Ólafsfjardarmúli at the mouth of Ólafsfjörður. — Photo G. Sigbj.

Mynd 2. Finnurinn (nær) og Hvannadalabjörg (fjar) eru dæmigerðir fjardarmúlar eins og þeir gerast um Vestfirði, Norðurland og Austfirði norðan Gerpis. Myndin er tekin í Ólafsfjardarmúla fyrir mynni Ólafsfjarðar. — Ljós. G. Sigbj.

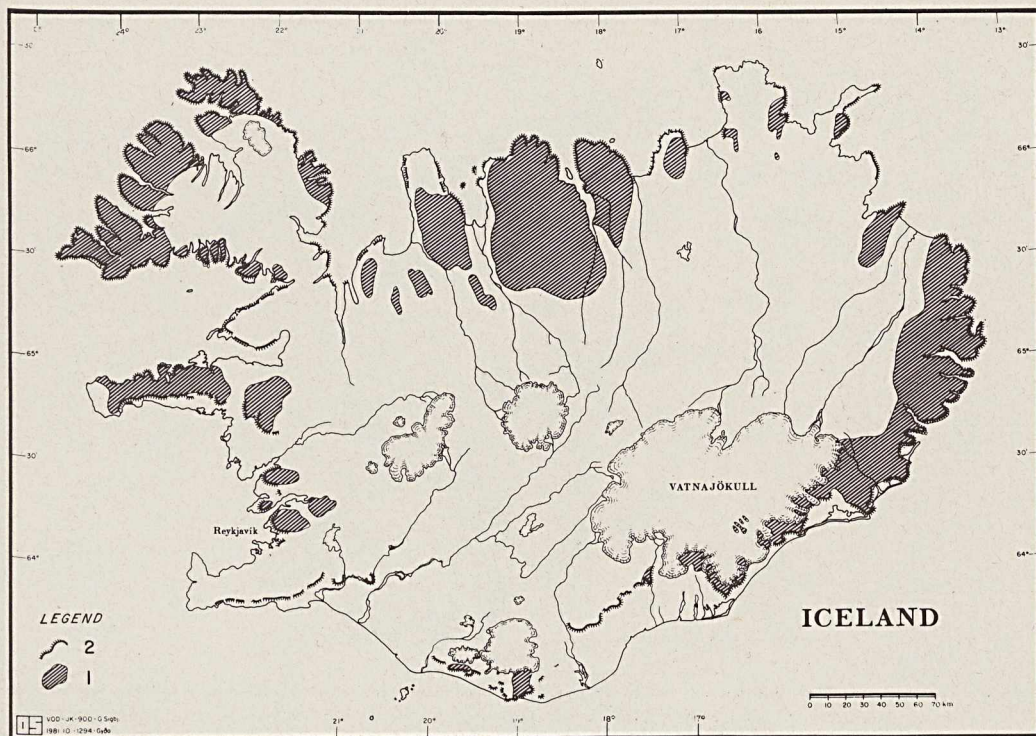


Fig. 3. Alpine landscape and coastal cliffs in Iceland. 1. Cross hatched areas show the part of the country where erosional forms of alpine glaciers predominate, or approximately 26,000 km². 2. Marine eroded fjord promontories and wave cut cliffs higher than 60 to 80 m are shown with broad, broken lines.

Mynd 3. Alpalandslag og sjávarhamrar á Íslandi. Skástrikuðu svæðin sýna þá hluta landslagsins, þar sem rofform alpjökla eru ríkjandi, en það eru um 26.000 km². Sjávarrofnir fjarðarmúlar og brimklif hærri en 60 til 80 m eru sýnd með breiðum, hökuðum línum.

mountain landscape which existed before their formation. Above the glaciation limit snow and ice collect on top of the mountain peaks and on their flanks, and collapse as avalanches and ice-falls to the corries and valleys, where the ice and snow are welded together as an homogeneous mass, which creeps downslope. The valley glaciers flow along the main valleys and are constantly added to by tributary glaciers and overfull corries in the valley sides continuing until ablation equilibrium is reached. If the ablation is insufficient to melt the ice before the snout has emerged from the valleys (fjords), it extends in all directions forming a piedmont glacier, such as Múlajökull in Hofsjökull does today, and this rapidly increases the ablation area.

The geomorphology due to alpine glaciation (Fig. 1) is predominantly a sharpening and enlarging of the fluviially eroded landforms which preexisted at

each glaciation, rather than the creation of a new landscape. It is characterised therefore by serrated ridges, horns, corries, throughs or fjords which are often excavated more deeply than the land in front of them. The formation of a piedmont glacier has only a minor effect on this development, since the erosional capability of a glacier decreases very rapidly as it spreads outwards.

Those areas in Iceland, where alpine landforms are predominant, are shown in Fig. 3. Glacier formation there has thus been the result of the pre-glacial landscape. There is no reason to suppose that these areas have at any time been covered by very thick ice sheets, because they would be bound to have left very distinct erosional traces, since the erosional capability of glaciers increases very quickly with increasing ice thickness. Many of the alpine areas shown on Fig. 3 have been located inbetween two

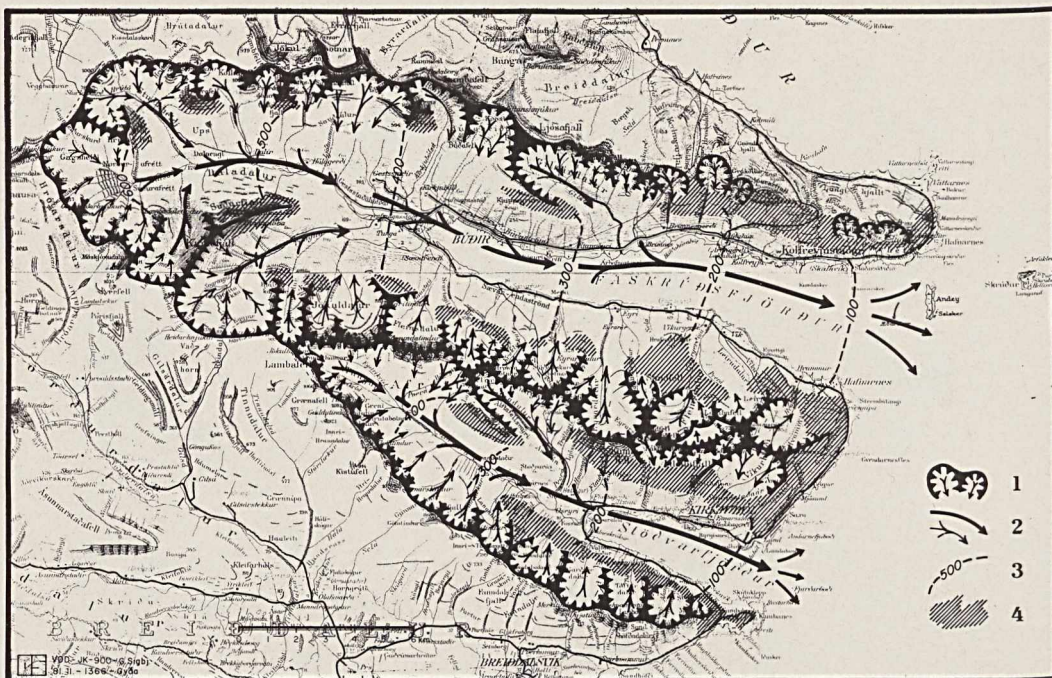


Fig. 4. Glacial geomorphology in Fáskrúðsfjörður and Stöðvarfjörður. 1. Accumulation zone: mountain slopes, hanging valleys, corries and depressions are shown with broad broken lines, while 2. arrows show direction of flow of glaciers from them and along the fjords. 3. Contour lines show probable thickness of the main glacier. 4. In cross hatched areas it is likely that there have always been some ice free areas.

Mynd 4. Jöklalandmótun í Fáskrúðsfirði og Stöðvarfirði. Jökulsafnsvæðin: 1. Fjallshlíðar, hangandi dalir, botnar og skálar eru sýnd með breiðum hökuðum línum. 2. Örvarnar sýna skriðstefnu jöklanna út frá heim og út firðina. 3. Jafnhæðarlínurnar sýna líklega þykkt aðaljöklans. 4. Á skástrikuðu svæðunum er líklegt, að alltaf hafi verið einhver ísvana svæði.

large valley glaciers flowing out of valleys or fjords on either side of them. *Sudgen and John* (1976) cite the promontories of the western fjords as being typical for this development (p. 207). It is likely that the proportion of alpine glacier areas has increased throughout Quaternary time, glacial periods have become more frequent and glacial erosion has increased.

According to Fig. 3 one quarter of the country, just over 26000 km², is eroded by alpine glaciers. Normally there are some ice free areas in alpine glaciers. They appear as horns, serrated ridges, steep slopes or promontories. Even so it cannot be discounted that some of those alpine areas shown on Fig. 3, have at times been completely covered by ice, and then as independent ice centres. On the other hand it is equally possible that there have always

been some nunataks and ice free patches in large alpine glaciers, such as in the eastern fjords, south-east Iceland, Snæfellsnes, the western fjords and Tröllaskagi.

Figure 4 is a map of Fáskrúðsfjörður and Stöðvarfjörður. They are taken as being typical of those landforms formed by alpine glaciers. The accumulation zones of the glaciers, hanging valleys, corries and depressions in the mountain slopes are specially indicated on the map as well as the direction of flow of the glaciers from them. There is no evidence in the landforms that glaciers from the central highland have flowed in these fjords, so that they have been independent accumulation zones of alpine glaciers which have produced valley or fjord glaciers as shown in Fig. 4. It can be judged with some certainty, how far the accumulation glaciers flowed

down the slopes, before they joined the main valley glacier. On this basis I have therefore estimated the mean thickness of the main valley glaciers, which have formed the fjords and the valleys inland of them, as well as showing their main direction of flow. It should be pointed out that by the estimated mean thickness I do not refer to any particular time, but rather the mean thickness of glaciers responsible for erosional forms. It is estimated by many factors, such as the erosional forms of the main fjords and valleys glacial cols the height of hanging valley and corries and the spurs between them.

With the formation of the fjords the mean thickness of the glaciers was 100 m above present sea level at their mouth and increased slightly inland up to 500-600 m a. s. l. farthest up the valleys. Observations on the level of corries farthest out on the fjords and promontories suggest that the glaciation limit has been 350-450 m a. s. l. facing the sun on the northern side of the fjords, but about 100 m lower in the shaded southern side of the fjords. The glaciation limit and therefore the corries level has then

usually increased gradually inland, but here it is more difficult to estimate because of the added factor of the increasing thickness of the main valley glacier.

Piedmont glaciers have spread out considerably from the fjord mouths as the arrows in Fig. 4 show. It is difficult to estimate their size. The accuracy of marine charts is not sufficient to enable the determination of smaller landforms on the seafloor. The ablation zone of the glaciers extended fairly far up the fjords, and that makes it possible to conclude that piedmont glaciers have never extended more than a short distance outwards on the continental shelf (5-10 km). This all suggests that there have always been some ice free areas on the spurs and farther out on the fjord slopes, as well as nunataks on steep slopes, serrated edges and horns above the firm limit. On Fig. 4 those areas are marked where it is very probable that there were always some ice free areas.

In comparison with the alpine landscape of the eastern fjords (Fig. 4), Fig. 5 shows the geomorpho-

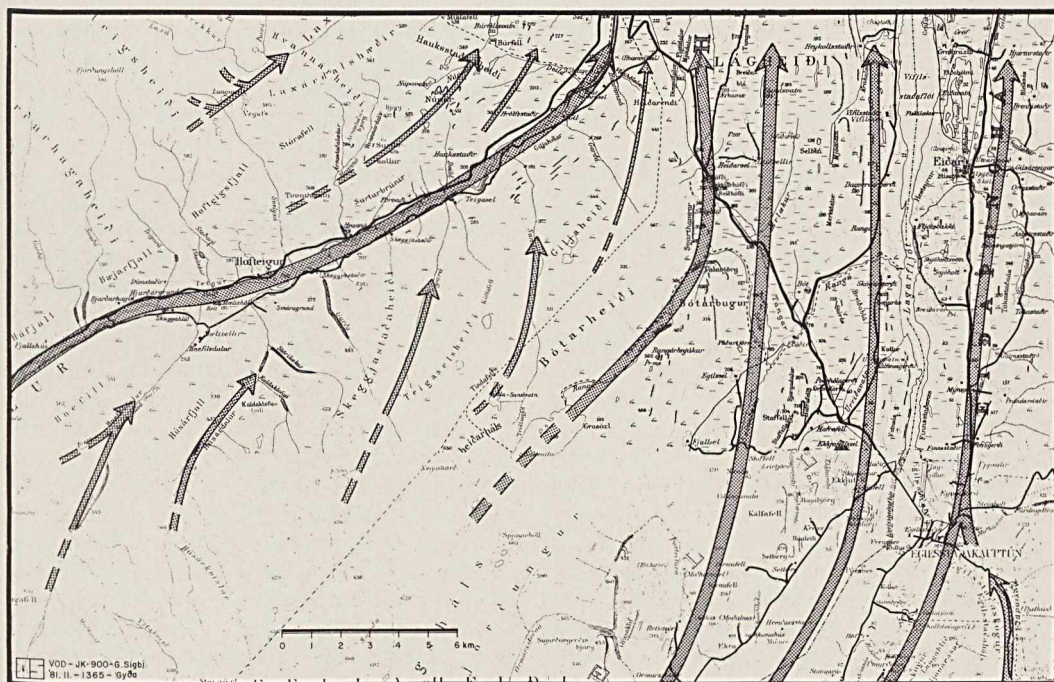


Fig. 5. Glacial geomorphology in Mid-Hérað and Jökuldalur. Arrows show the main direction of flow of glaciers which produced the landforms. Fellaheidi has probably been a glacier accumulation area.

Mynd 5. Jöklalandsmótun á Mið-Héraði og Jökuldal. Örvonar sýna megin skriðstefnu þeirra jökla er mótuðu jöklalandsformin. Fellaheidið hefur líklega verið jökulsafnsvæði.

logy of ice sheets from the central highlands, showing Mid-Hérad, Fellaheidi, and the mouth of Jökuldalur. The landscape forms are rather different from those shown on Fig. 4. The arrows show the main direction of flow of those glaciers responsible for the formation of the landscape. From them it can be seen that these glaciers have moved over an undulating surface and eroded it according to their direction of flow. On the other hand it can also be seen that the main direction of flow has adapted itself somewhat to the larger landforms such as Fljótsdalshérad and Jökuldalur where glacial erosion has been very active. Fellaheidi displays considerably less of the characteristics of glacial erosion so that the glaciers there have been considerably less active, and in all probability it was an accumulation zone, so that it was completely ice covered, although it can be considered likely that Rangárhjúkur and Sigurdargerdishjarg where nunataks for long periods of time (Fig. 5).

MARINE EROSION

As to be expected in an oceanic island the coast of Iceland is much eroded by the sea i.e. wave-cut cliffs, sea crags and fjord promontories. The more outstanding examples of such formations are shown on the map of Iceland in Fig. 3. There it can be seen that they surround the land almost completely except in the geologically youngest parts and farthest inland in the fjords and inlets. Their development is at various stages, depending on situation and part of the country. It is noteworthy that highly developed marine erosion is associated with the alpine geomorphology in all headlands and fjord promontories, where coastal cliffs rising several hundred meters directly out of the sea are widespread or have a low coastal rim beneath them.

Relative to the present day strandline the strandflats appear to be higher in the south and west of the country than in the north. From Gerpir southwards and westwards as far as Stálfall and Látrabjarg there are strandflats in front of almost all headlands, but hardly at all underneath headlands in the western fjords, northern Iceland or the eastern fjords north of Gerpir. I have not seen or found any satisfactory explanation for this phenomenon, but the strandflat is of great importance to the road system. Where the marine terrace is available the mountain roads are both few and low.

The Norwegian *Reusch* (1901) introduced the

term *strandflat* in 1894, and he believed it to be the result of marine erosion. Since then various theories have been put forward as to its formation, for instance *Nansen* (1922) and *Holtedahl* (1960), the former rather favouring marine erosion with a mixture of glacial erosion, and the latter favouring nearly entirely glacial erosion. As regards strandflats in Iceland, I lean towards the opinion that marine erosion in collaboration with piedmont glaciers and sea ice are responsible for their formation. It is also advisable to keep in mind that when marine erosion at the coastline of an ice covered land, in the Quaternary Era, is compared to the coast of an ice free land then relative strandline changes are very unlike because of the interplay of land submergence caused by ice pressure and a fall of sea level due to glacier formation. Marine erosion could have been more effective on a glacially eroded land, especially since erosion by fjord glaciers helped to keep the coast open for attack by the sea.

It is clear that most of the more important wave-cut cliffs and promontories in the south and west of the country have been eroded and have acquired their present appearance at a higher strandline than that of today. Widespread erosional forms suggest a strandline 20-40 m higher and even higher, for instance in the inner part of Faxaflói, where marine erosional forms appear to extend upwards to over 100 m a.s.l. It is now known that the strandline in Iceland reached from 40 m and up to as high as 100 m in different areas, at the close of the last glaciation. On the other hand I consider it out of the question to attribute to such a sea level rise of short duration, the formation of wave-cut cliffs and promontories such as Gvendarnes, Austurhorn and Vesturhorn, Lómagnúpur, Eyjafjöll, Esjuhlíðar at Kjalarnes, or Hafnarfjall, to name a few examples. In fact nearly all the coasts of Iceland display evidence of severe marine erosion in Quaternary time (Fig. 3). In my opinion another explanation must be sought for this, rather than the short-term, relative rise in sea level, at the end of each glaciation.

Because of the storage of water in Pleistocene glaciers the surface of the world's oceans fell about 100-125 m during the last glaciation and even as much as 160 m when the ice age glaciers reached their greatest extent in the Quaternary Era (*Seibold* 1974), but in addition Iceland was submerged to some extent due to the weight of ice. Most authors have however tended to the opinion that the strandline in Iceland has been somewhat lower than today, even to the extent of several tens of meters. I

don't believe there is any reason to question the fact that the strandline in Iceland has been somewhat lower than today in former glaciations. However I consider that there is no reason to assume a large fall in sea level, since it is fairly certain that the Icelandic crust is so weak and flexible, that its isostatic sinking under ice pressure takes a very short time compared with the continents. It is even possible that at certain times isostatic sinking has been so much in certain areas, that the sea level has been higher than it is today. On the other hand it would hardly be likely, that the extensive marine erosion along the coast of the country has occurred during glacial periods themselves, except to a small degree.

It is considered well proven that sea level was considerably higher during interglacial periods of the Quaternary Era than it is today, and still more so towards the beginning of the Quaternary Era. Holmes (1965) believes sea level to have fallen nearly 200 m in the last 2 million years (p. 713), and Woldstedt (1961) reaches a similar conclusion (p. 374). He believes that sea level has been almost 20 m higher during the last interglacial and 30 m higher in the second last interglacial.

When it is borne in mind that the majority of promontories and wave-cut cliffs belong to the alp-



Fig. 6. Hvalsnesskridur are wave cut cliffs with a strandflat beneath such as is most common on coastal promontories in western Iceland, southern Iceland and the eastern fjords south of Gerpir. In the distance the promontories of Streitishvarf and Kambanes can be seen. — Photo G. Sigbj.

Mynd 6. Hvalsnesskridur eru brimklif með strandfleti fyrir framan eins og algengast er með sjávarmúla á Vesturlandi, Suðurlandi og Austfjörðum sunnan Gerpis. Í fjarrika sjást múlarnir Streitishvarf og Kambanes. — Ljós. G. Sigbj.

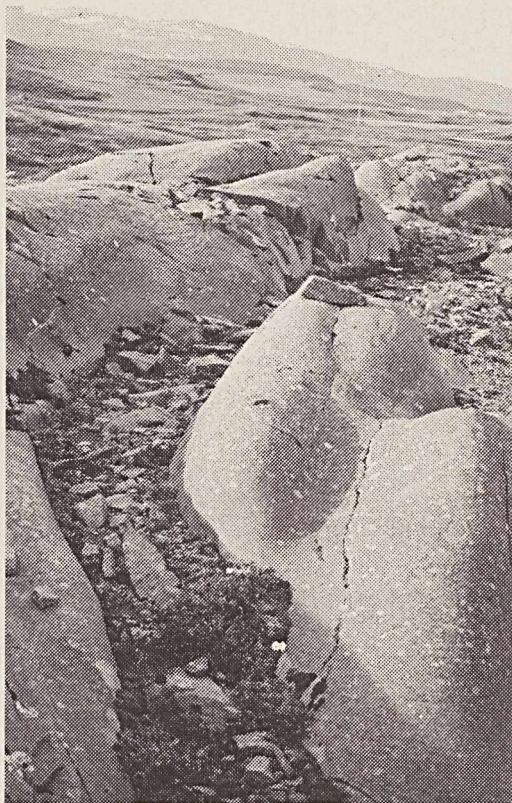


Fig. 7. Glacially grooved outcrop south of the farm Sledbrjótur in Jökulsárhlíð. Sinous glacial grooves are called "cavettos" and together with smoothed outcrops they are indications of erosion by a thick glacier.

Mynd 7. Jökulgrópuð klöpp sunnan við bæinn Sledbrjót í Jökulsárhlíð. Bugðóttar jökulgrópir eru nefndar „cavetto“ og eru ásamt mjög ávöluðum klöppum merki um rof eftir þykkan jökul. — Ljós. G. Sigbj.

ine landscape and that it is likely that glacial erosion at the coast was limited during the last glaciation, it seems obvious to conclude that the fjords promontories and wave-cut cliffs have been formed largely during the interglacial periods of the Quaternary Era.

GLACIAL EROSION AND FLUVIAL EROSION

By comparing Figs. 2 and 3 the enormous difference in the large scale landforms of the landscape formed by alpine glaciers on the one hand and by

the ice sheet of the central highland on the other can be clearly seen. On closer examination this difference is not only apparent in the large scale landforms but in the smaller ones too. A well developed roche-moutonnée landscape where erosion by a comparatively thick glacier has been very effective is very widespread in Scandinavia and Canada, but in Iceland it is only found in Fljótsdalshérað, in a small area in Borgarfjörður and a very few other areas. In the very same places very well developed large glacial grooves (flutations) are also found such as can be seen in Fig. 7 which shows glacial grooves in the Sledbrjótur region in Hérað. Here a sinuous groove can be seen, a so-called "cavetto", a feature believed represent "highly plastic" erosion (Gjessing 1965, 1966). This suggests that the erosive capability of glaciers has been most in these areas, since as well known it depends mainly on the glacier thickness and the rate of flow.

Widespread on the fjord promontories and mountain sides near the coast are to be found large, steep talus slopes, especially where characteristic features of marine erosion are dominant, as for example on Hvalnes (Fig. 6). Such screes are hardly found inland where glacial erosion features are dominant. Towards the top of the screes is a network of water eroded gullies, which are often tens of meters deep, so that the landscape there appears as a forest of pyramids (buttresses) uppermost in the mountain sides. (Figs. 6 and 8). A number of water eroded gullies can be seen in Fig. 8, which extend side by side downslope from the corrie landscape farthest up the mountain. The talus, gullies and pyramids bear witness to very active water erosion and frost weathering of long duration. The position of these strongly water eroded areas on peninsulas and farther out the fjords slopes decidedly suggest that they have been subjected to little or no glacial erosion during the last glaciation and possibly others, since their position agrees with probable ice free areas, as they are shown in Fig. 4.

Well developed glacial cols (Fig. 9) can be found widespread in the alpine landscape and they give an idea of the thickness of the valley or fjord glaciers at their time of formation. Helgi Pjetursson (1906) and Trausti Einarsson (1959) have treated them in their work and the latter has pointed out that in some places they are found at two or more altitude levels.

A rather thicker weathering cover is widespread above the main valley or fjord glaciation limits (Fig. 4) than below them, and all glacial erosional forms are considerably more subdued there. One of the

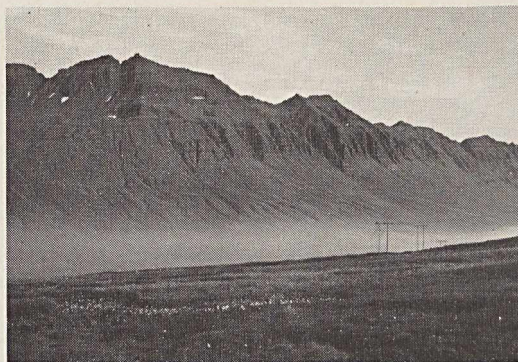


Fig. 8. Northern slope of Nordfjörður from Oddskardsvegur. At the top are horns, serrated edges and corries, which characterise the alpine landscape. Below is a greatly water eroded gully slope. To the right is the serrated edge of Bagall and beneath Bagall corrie. In front of them is landslide debris and perhaps bottom moraine. It is likely that the gully walls were ice free during the last glaciation, but the thick till cover below them represents the glacial maximum. Smoke from capelin processing plant fills the valley floor.

— Photo G. Sigbj.

Mynd 8. Norðurhlíðar Norðfjarðar frá Oddsskardsvogi. Efst eru eggjar, tindar og botnar, sem einkenna alpalandslag. Neðan við er giljött mjög vatnsrofin hlíð. Til hægri er tindurinn Bagall og undir honum Bagalsbotnar. Framan við þá er framhlaupsurð og e. t. v. botnjökulsruðningur. Líklegt er að giljahlíðin hafi verið ísvana á síðasta jökulskeiði, en þykk jökulruðningskápan neðan hennar sé jökulhámarkið. Reykur frá loðnubræðslu fyllir dalbotninn.

— Ljós. G. Sigbj.

clearest examples which I have seen of this is where the weathering cover thickness and glacially eroded forms become more subdued at 200-250 m a.s.l. at the Vatnsskard road to eastern Borgarfjörður.

THE SOUTHEASTERN COAST FROM EYJAFJÖLL TO FLJÓTSDALSHÉRAÐ

On Fig. 3 it can be seen that the coastal mountains are almost everywhere formed by alpine glaciers and marine erosion is also well developed there. A survey of the glacially eroded landforms from Breidalsvík to Eyjafjöll reveals that glacially eroded valleys and fjords are very poorly developed compared with Fljótsdalshérað and mid northern Iceland in



Fig. 9. Glacial cols at just over 400 m.a.s.l. on Hádegisfjall (right) and Skessa (left) opposite the town of Búdareyri in Reyðarfjörður. (cf. Fig. 1). — Photo G. Sigbj.

Mynd 9. Jökulaxlir í rúmlega 400 m y.s. í Hádegisfjalli (t.h.) og Skessu (t.v.) á móti Búdareyrarkauptúni við Reyðarfjörð. (Sbr. 1. mynd) —Ljós. G. Sigbj.

spite of the fact that the coast there is directly connected to the central highlands. This feature is especially poorly developed west of Hornafjörður, where it is hardly possible to talk about well developed glacially eroded valleys, except where the present glaciers, Hoffellsjökull, Breidamerkurjökull and Skeidarárjökull flow today. On the other hand marine eroded features, wave cut cliffs and promontories are very well developed and little eroded by encroaching glaciers. The age of strata does not seem to really matter, except for the very youngest. This points without doubt, to the fact that in previous glaciations the glaciers here have not attained great thickness or extent. The glaciation limits have hardly been lower than 400-600 m a. s. l. and glaciers have either melted on the slopes beneath the mountains or in the case of piedmont glaciers at the valley or fjord mouths, where calving could also have played a part in the ablation. The eastern fjords and southeastern Iceland have therefore not been unlike the coast of Spitsbergen and many other arctic islands today. I consider that a greatly reduced precipitation from that of the present could be a satisfactory explanation for this.

Observations on the geomorphology of south-eastern Iceland and the eastern fjords suggest decidedly that marine erosion as well as alpine glaciers are mainly responsible for the landscape which we find there today.

GLACIER THICKNESS AND ICE FREE AREAS

Glacier thickness may be estimated from the geomorphological forms left by the glacier, which again to some extent depend on the rate of flow of the ice.

The thickness of those glaciers which formed the alpine landforms, covering a quarter of the country, has been touched upon (Figs. 3 and 4). The landforms only give an estimation of the mean thickness of the glaciers which formed them, but I do not consider that there is any reason to conclude that those glaciers have ever been much thicker. It is possible that they have at some time reached a greater ice thickness, when conditions of glacier formation were at a maximum, but erosional features left by such glaciers should be found since erosive capability rapidly increases with ice thickness.

If one considers the distribution of alpine areas in Fig. 3, it can be seen that their position around the country suggests that glacier thickness in the central highlands has never been, at least in late Quaternary time, so great that the outflowing glaciers from there have buried these areas, but rather that the glacial valleys and fjords have always managed to transport the glacial ice away. It suggests further therefore that glacier flow from the central highlands has continually adapted to the landscape and this is true of the ice centres too as pointed out by *Trausti Einarsson* (1977). In other words, there have therefore continuously been many ice centres and ice ridges in the main highland areas and glacial flow has been from there in all directions or similar to what can be seen in the present glaciers.

The height of móberg mountains has been used as an indication of the minimum thickness of the glaciers (*Guðmundur Kjartansson* 1943, *Kristján Sæmundsson* 1979). I think it is likely that this gives not only an idea of minimum thickness but also the approximate maximum thickness. A superficial observation of the structure of móberg mountains in the southern highlands of the country south of the Tungnaá river and Thjórsá river show that nearly all those eruptions they formed in, reached above the glaciers, since they are first and foremost built of hyaloclastics, pillow lava formations being infrequent. On the other hand the proportion of pillows and cubic jointed basalts increases greatly, to the north of the Tungnaá river and elsewhere within the central highlands. This suggests a considerably

smaller glacier thickness in the southern highlands than in the central ones.

One of the characteristics of alpine glaciers is that nunataks are usually associated with them as well as ice free slopes and spurs. It is thus likely that this has been the case in Iceland in previous glacial periods, and indeed this viewpoint agrees well with research by some botanists, as *Steindór Steindórsson* (1954, 1962) on those places where plants have held out and survived previous glacial periods, even though it is questioned by some others (*Sturla Friðriksson* 1962). It could be said that in all alpine areas it is possible to find some plants having a limited distribution. In addition the opposite could be said, that all plants having a limited distribution can be found associated with alpine areas. I believe all the evidence points towards there having been ice free areas on promontories and slopes along the coast, not only during the last glaciation but throughout all of the Quaternary Era.

The age of the interglacial lavas in Víðidalur (*Koerfer* 1972) and Quaternary formations in Lón and Hornafjörður (*Helgi Torfason* 1979) suggest that valley development has been well advanced at least a million years ago. I think this indicates that the main features of the landscape and possibly the continental shelf had already been formed early in the Quaternary or even to some extent before the end of the Pliocene period.

In glacial periods there would always have been many ice centres in Iceland with the main ice divide between the north and south flowing glaciers close to the present water divide and glacier thickness would not have been much thicker than that of Vatnajökull today, generally 200-800 m but possibly up to 1000 m in deep valleys.

Time does not permit discussion of the conditions of glacier formation in previous glacial periods. Examination of those weather maps most likely to compare with the prevailing climate in glacial periods (*Lamb* 1977), suggest that all precipitation was considerably less especially in southern and south-eastern Iceland, where the prevailing precipitation direction was northeasterly to northerly. They could have been comparable with those prevailing in October to December 1981.

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ALPAJÖKLAR OG ÖLDUBRÍJÓTAR

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Orðið *alþajöklar* er hér notað sem safnheiti yfir öll þau jökulform sem myndast í fjallendi, þar sem landslagið stjórnar í megin dráttum skriðhreyfingum jökulíssins. Jafnan er nokkuð um ísvana svæði, þar sem alþajöklar eru ráðandi. Meginlandsísskildir og stórir hveljöklar eru andstæður alþajöklanna, þar sem þeir kaffæra allt það landslag, sem undir þeim liggur, og skriðhreyfingar þeirra stjórna af yfirborðshalla jökulíssins, fremur en af landslaginu sem undir þeim liggur. Þau rofform, er jöklarnir á jökulskeiðum kvartertímans hafa markað landið með á hverjum stað, ráðast verulega af því, hvort þar hafa alþajöklar eða hveljöklar verið ríkjandi.

3. mynd sýnir kort af Íslandi, þar sem þau svæði eru merkt sérstaklega, þar sem jökulrofið einkennist af því, að alþajöklar hafi verið þar ráðandi á undangengnum jökulskeiðum, og er það um fjórðungur alls landsins. Aðrir hlutar landsins sýna í megin dráttum rofform eftir meginjöklana. Rofformin benda þó til, að það hafi ávallt verið nokkuð margar ísmiðjur og jökulskriðið hafi fylgt stórformum landslagsins. Á 4. mynd eru Fáskrúðsfjörður og Stöðvarfjörður valdir sem einkennissvæði fyrir alþalandmótun, þar sem helstu auðkenni þess eru merkt inn á kort, en á 5. mynd af Mið-Héraði eru dregin fram einkenni landmótunar meginísskjaldarins. Landmótunarform alþajökla finnast meðfram ströndunum allt umhverfis Ísland (3. mynd), en stærstu og samfelldustu svæðin eru á Mið-Norðurlandi og á Austfjörðum allt suður um Skaftafellsýslur, þar sem þau eru jafnframt ótvíræð og skýrust.

Brimaldan hefur verið hvað athafnamesti rofvaldurinn allt umhverfis landið, og á 3. mynd eru sýnd öll þau brimklif sem ná meira en 60-80 m hæð, hvort sem þau eru alveg við ströndina eða eitthvað lengra inn til lands. Finna má nokkurt samband milli alþalandslagsins og háþróaðra brimklifa og fjarðarmúla. Vakin er athygli á þýðingu samspils

sjávarrofsins annars vegar og rofi fjarðajöklanna hins vegar við myndun strandflatarins. Dregin er sú ályktun, að brimklifin og fjarðamúlarnir hafi þróast á undangengnum hlýskeiðum jökultímans, en strandflóturinn við þetta samspil jökul- og sjávarrofs. Bent er á, að þróun strandflatarins er mismunandi á sunnanverðu landinu, frá því sem hún er á

því norðan verðu. Orsökina fyrir því getur verið minni jökulþykkt við suður og suðaustur strendur landsins heldur en fyrir norðan. Jökulrofformin á suðausturlandi benda eindregið til hins sama. Grein þessi birtist því sem næst óbreytt á íslensku í afmælisriti Dr. Sigurðar Þórarinssonar (1982): Eldur er í norðri.