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Interglacial Lava Flows in the Lowlands of Southern Iceland and the Problem of Two-Tiered Columnar Jointing

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ABSTRACT

The present paper describes a major occurrnce of non tilted interglacial lava flows in Southern Iceland overlying a tilted basement of Quaternary plateau basalts. The geology of the basement rocks, referred to as Hreppar Series, is outlined. The secondary mineral content of the Hreppar Series rocks is discussed in order to help determine the degree of erosion prior to the emplacement of the interglacial lavas. From these data the probable thickness of rocks removed was found to be some 500—700 m. The interglacial lavas, which were erupted after the main features of the present landscape were formed, cover an area of about 250 km². The most coherent cover lies to the southeast of the river Thjórsá in the lowlands of Rangárvallasýsla, and remants of the lavas are also found to the north of the river capping some of the hills. The structure of the lavas and the paleomorphology of their basement make it obvious that to the north the lavas ponded into valleys and depressions where they developed columnar jointing, whereas to the south they flowed into the open country. A peculiar division of the flows to the north into a lower colonnade and an upper chilled entablature is explained by water flooding the lavas while their interior was still molten. Petrographically the lavas are tholeiites poor in olivine to the north of Thjórsá but olivine bearing basalts to the south of the river. The greater erosion of the lavas north of Thjórsá and the less advanced denudation of the Hreppar Series prior to the eruption of the interglacial lavas in that area make it probable that the tholeiites are older. The interglacial lava flows have normal magnetization limiting their age to the present (Brunhes) normal polarity epoch. The olivine basalts are considered as possibly of last interglacial age but the tholeiites are thought to have been erupted during an earlier interglacial period. The site of eruption is unknown in either case but certainly lies outside the mapped area, most probably to the east or northeast within the eastern limb of the active volcanic zone.

INTRODUCTION

Non tilted interglacial lava flows in Iceland occur mainly within or near the active volcanic zone that extends across Iceland from SW to NE. Outside this volcanic zone such lavas are known in the Snæfellsnes region in the west and in Skagafjördur and Húnavatnssýsla in the north. This paper describes a recently discovered occurrence in the lowlands of Southern Iceland, more precisely in the districts Hreppar west of the river Thjórsá and in the western part of Rangárvallasýsla east of the river (for location see Fig. 1).

The interglacial lavas have been overlooked by most geologists who have worked or travelled in the area. This may be due to the unusually thick and continuous cover of sediments and soil leaving only steep scarps or riverbeds exposed. The general geology of this area was established by *Kjartansson* in 1943, 1958 and 1962. He regards all rocks underlying late Pleistocene to recent sediments and postglacial lava flows as late Tertiary and/or Pleistocene in age and proposed the local term Hreppamyndun (Hreppar Series), which he later (1962) included in the "old grey basalts" of his Geological Map of Iceland. Rocks of the Hreppar Series are tilted plateau basalts with abundant intercalations of hyaloclastites and tillites exceptionally well exposed in the Hrepp-

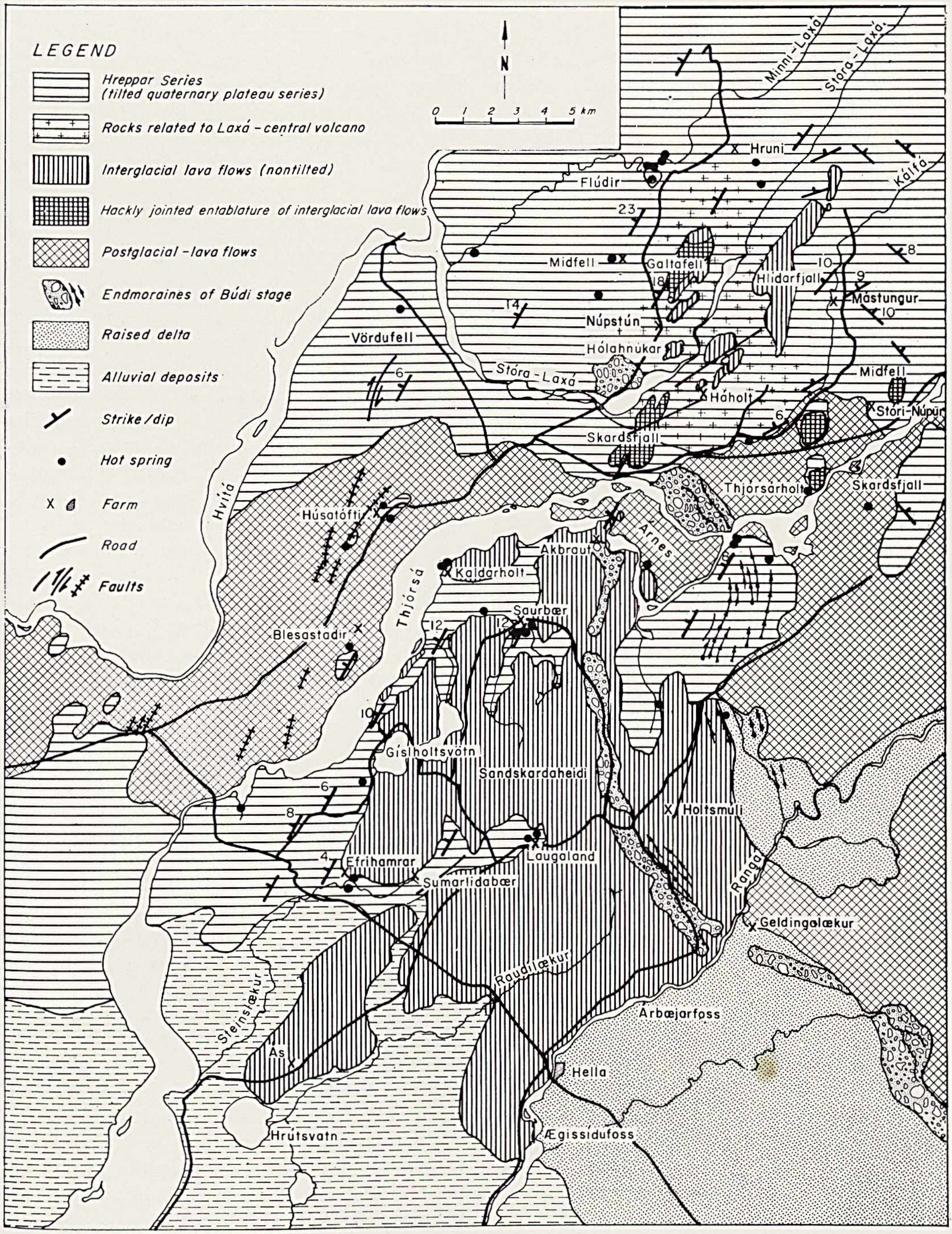

Fig. 1. Geological map of the Hreppar–Holt area.

Mynd 1. Jarðfræðikort af rannsóknarsvæðinu í Holtum og Hreppum. Ungu hraunin eru sýnd með lóðréttri strikun, en kubbaberg er rúðustrikað.

ar district, but actually filling the whole gap between the two limbs of the active volcanic zone in Southern Iceland. The only written account of young, non tilted interglacial lavas in this area is an unpublished report to the State Electricity Authority by *H. Tómasson* (1962), where he describes the geology around Árbaejarfoss, a planned power plant site. He noticed non tilted lava flows in the river bed of Rangá, as well as an outcrop near Raudilaekur.

THE UNDERLYING HREPPAR SERIES

The interglacial lavas (hereafter referred to as the young lavas) appear everywhere to overlie plateau basalts of the Hreppar Series. The Hreppar Series includes the characteristic intercalations of hyaloclastites and tillites and a varied suite of rocks in the northeastern section of the map (Fig. 1) including rhyolites, andesites and a large intrusive body (*Fridleifsson* 1970). South of Hlídarfjall an extensive zone of propylitization is found. These are characteristic phenomena only found in connection with central volcanoes recently recognized in great number within the Icelandic plateau basalts.

As shown in Fig. 1 the Hreppar Series dips northwestward in most of the area. Only in the northeastern section of the map is the dip directed towards northeast. The largest dip of more than 20° is found north of the river Stóra Laxá. Towards the south the dip is not as steep, the values ranging between 4° to 12°. The northeasterly dip is rather constant between 8° and 10°.

The change in direction of dip is related to the Hreppar anticline (*Th. Einarsson* 1967, *Saemundsson* 1967), that extends some 50 km northeast of the map. The development of this anticline most probably is a result of accumulation of volcanic material in the two limbs of the active volcanic zone to the west and east (*Saemundsson* 1967). The occurrence of tillites and thick hyaloclastites among the oldest strata near the axis of the anticline in Stóri Núpur, Mástungur and Thjórsárholt indicates that the whole succession was formed after the first glaciation set in.

Dykes are occasionally found in rocks of the Hreppar Series. They usually stand perpendicular to the enclosing rocks. The thickness of the dykes ranges from less than 1 m to 10 m. The dykes usually strike NE–SW but veins can be found showing deviation from this direction.

SECONDARY MINERALS OF THE HREPPAR SERIES

Rocks of the Hreppar Series often contain secondary minerals such as zeolites, calcite and silica minerals. A preliminary study of these was made and a distribution pattern established that allows conclusions to be drawn about the amount of erosion of the Hreppar Series prior to deposition of the interglacial lavas. Fig. 2 shows the sampling localities of secondary minerals and the assemblage found in each.

The secondary mineral assemblage produced is dependent of the rock type and is controlled by isotherms within the lava pile (*Walker* 1960).

Detailed petrographic examination of the basaltic rocks themselves was not made but both olivine basalts, tholeiites and porphyritic rocks occur. As expected the tholeiites are characteristically poorer in secondary minerals. In the olivine basalts only chabazite and some thomsonite and opal are found in most places. Scolecite was found in some localities in the northern part of the area and was especially abundant in hyaloclastites outcropping between Minni Núpur and Mástungur. It occurs as a devitrification product of basaltic glass. Amygdales in the same rock contain chabazite and thomsonite. Chalcedony, and quartz occur in a few places.

The intensity of zeolitization is very low throughout the area and the secondary minerals are small in size. Chabazite cubes usually do not exceed 2 mm and radiating clusters of thomsonite are usually only a few mm long. Scolecite aggregates containing more than 1 cm long needlelike crystals occur in the Stóri Núpur–Mástungur hyaloclastite. Phillipsite occurs in amygdales near Hruni.

Other secondary minerals found include levyne, apophyllite and calcite, which is particularly abundant in and around the hydrothermal aureole of the Laxá-volcano.

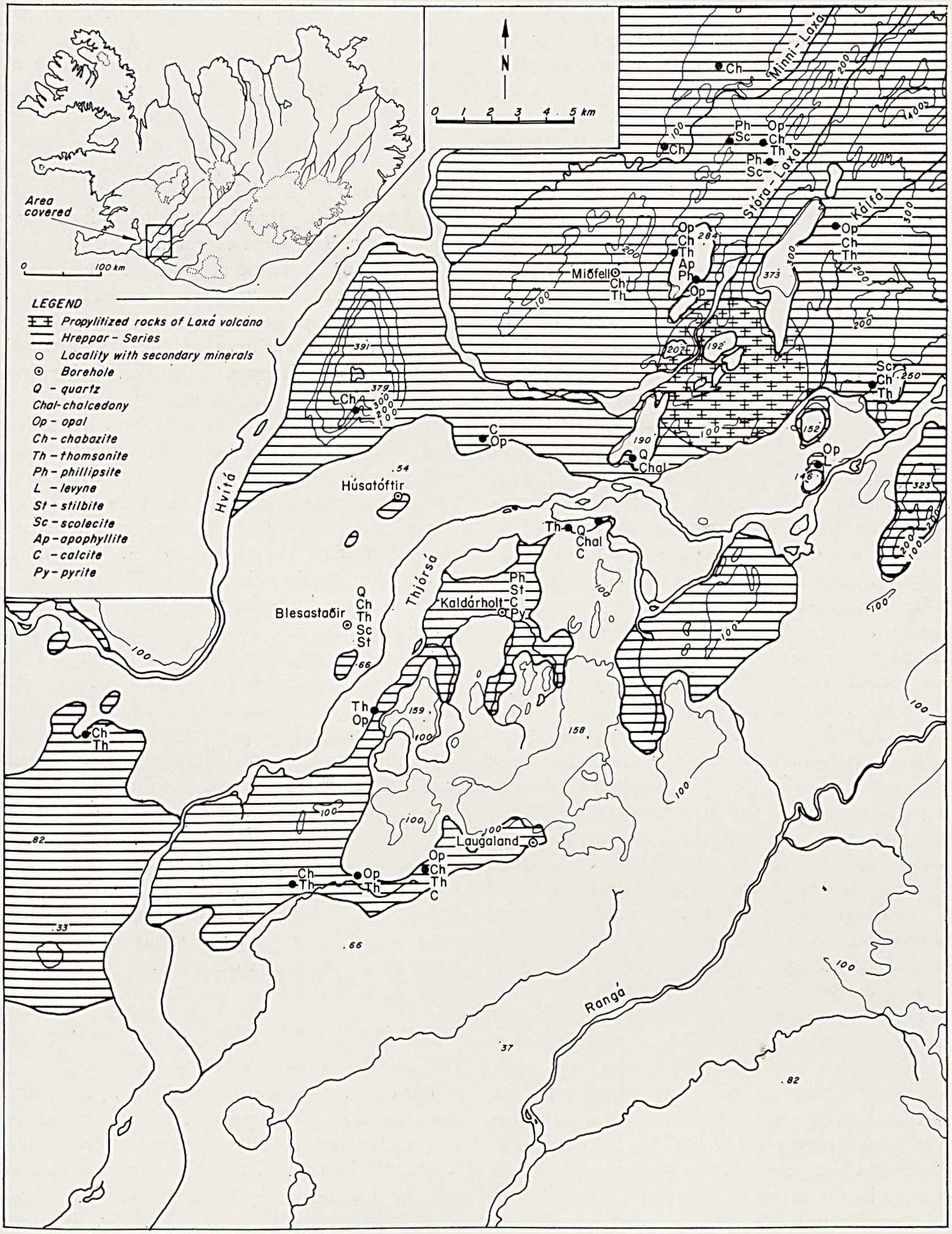

Fig. 2. Secondary minerals in the Hreppar Series in the Hreppar–Holt area.

Mynd 2. Steintegundir myndaðar við ummyndun og útfellingu í berglögum Hreppamyndunar.

Several boreholes have been drilled in recent years throughout this area, the deepest of which are in Midfell (347 m) and Blesastadir (270 m). Cuttings from these boreholes and also cores from a 100 m deep borehole near Kaldárholt were examined for secondary minerals. Chabazite and thomsonite are still by far the most abundant secondary minerals in all the boreholes followed by some scolecite, stilbite and some calcite.

The restricted assemblage of secondary minerals found in the Hreppar Series and the low intensity of zeolitization corresponds well to the lower half of the chabazite-thomsonite zone of *Walker* (1960) established for Eastern Iceland. In rocks of the Hreppar Series analcite, the index mineral of the zeolite zone next below the chabazite-thomsonite zone, was neither found in the exposed rocks nor in the borehole cuttings. The highest level at which zeolites were found is in Berghylsfjall at 250 m altitude on the northern border of the map (Fig. 2). Here a group of olivine basalts contains abundant chabazite, besides some thomsonite and opal. The top of the chabazite-thomsonite zone thus must lie higher than this and the top of the lava pile may originally have been several 100 m higher. *Walker and Charmichael* (1962) assume a combined thickness of 800—1000 m for the chabazite-thomsonite zone and a pile of rocks void of secondary minerals on top of it. According to this in Hreppar a considerable thickness of rocks possibly some 500—700 m has been eroded before the outpouring of the interglacial lavas.

As compared to Eastern Iceland, however, several factors complicate the reconstruction of secondary mineral zoning and the determination of the top level of the succession.

Most significant are probably abundant hyaloclastites within the Hreppar Series, since basaltic glass is particularly liable to devitrification and zeolitization. The Hreppar Series is of relatively young age, but it has nevertheless been strongly tilted and eroded. It is possible that the geoisotherms reached their highest level only subsequent to the deepest burial of the Hreppar Series. In other words the process of zeolitization may have been interrupted by rapid erosion. The present day high geothermal gradient and widespread hydrothermal activity of the lowlands of Southern Iceland probably is the surface expression of the process of zeolitization still taking place at depth in this region.

FAULTING

The area described here has been much affected by faulting that has continued into postglacial time. The most common trend of faults is N 15°—30° E. These are normal faults some of which have a downthrow of several tens of meters and they are arranged in a step fault pattern with downthrow to the east towards the axis of the Hreppar anticline. Strike slip faults exist in Vördufell trending N 10—25° E and probably also in Midfell and south of Hruni, trending N 50—60° E. In Vördufell strike slip movement of about 6 m with right lateral movement was measured in one case, where several dykes had been moved apart along a fault trending N 20° E. This fault forms the continuation of a fissure swarm mentioned by *Tr. Einarsson* (1967) and interpreted by him as indicating strike slip movement of the same sense as the fault in Vördufell. Faults are sometimes seen to cut through the young lavas. In Skardsfjall a fault trending N 60° E evidently is present and another with the same trend occurs in Háholtsfjall. To the south of Thjórsá, the only faults were found along the course of Steinslaekur trending N 30° E, and north of Holtsmúli, trending N 15° E. To the west of Thjórsá open fissures occur in the districts Skeid and Hraungerdishreppur in postglacial lava where conditions are favourable for their preservation. These are the only recent faults observed.

DISTRIBUTION OF THE INTERGLACIAL LAVA FLOWS

With a sharp unconformity (Fig. 3) the tilted basement of the Hreppar Series is overlain by extremely fresh looking but strongly eroded horizontal lava flows. These young lavas extend over an area of nearly 250 km^2 mainly between the rivers Thjórsá and Rangá (Fig. 1). The easternmost occurrence is along the river bed of Rangá from Geldingalaekur down to Aegisíðufoss. East of Rangá extensive river deposits

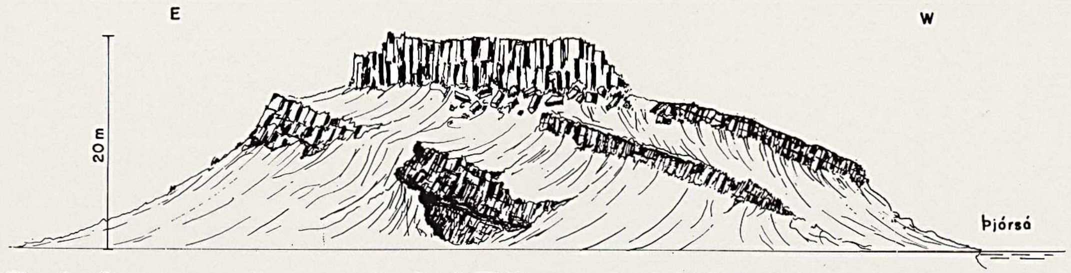

Fig. 3. Exposure on the eastern bank of Thjórsá north of Gíslholtsfjall, showing unconformity between Hreppar Series (base) and an interglacial lava flow (top).

Mynd 3. Holt á austurbakka Þjórsár norðan við Gíslholtsfjall. Mislægi milli Hreppamyndunar og ungu hraunanna.

completely cover the underlying solid rock. The western border of the young lavas forms steep escarpments. The escarpment north of Efrihamrar and Sumarlidabaer near the main road is very prominent since it runs perpendicular to the strike of the Hreppar Series. The western border of the young lavas north of Ás is even more conspicuous forming a 20 m high scarp. West of the lakes Gíslholtsvötn the young lavas reach the eastern bank of Thjórsá. From there northwards they are well exposed up to Árnes. The young lavas form an almost continuous sheet in the south and become increasingly eroded towards the north where they disintegrate into a number of hills. North of Thjórsá a broad, dissected range of hills extends towards the southwest between the rivers Hvítá and Thjórsá. The young lavas overlap the southern part of these hills and have been preserved as erosion remnants on Galtafell, Hlídarfjall, Skardsfjall and some others. On Hlídarfjall the young lavas reach their highest point of elevation at 373 m above sea level.

The number and thickness of the young lavas vary from one exposure to another. In Galtafell (Fig. 4) 5 flows with a maximum thickness of about 80 m were seen. In Hlídarfjall the thickness is similar but the number of flows is less. In Skardsfjall there are 2–3 flows about 70 m thick. South of Thjórsá the number of flows is also at least 3 and their thickness is about 100 m as seen in Gíslholtsfjall and Sandskardaheidi.

The thickness of individual flows varies a great deal. The thinnest flow, only about 5 m thick, was seen in Galtafell and near Akbraut but others exceed 50 m in thickness.

SEDIMENTS BELOW THE INTERGLACIAL LAVA FLOWS AND THE PRE-LAVA MORPHOLOGY

In various places a thin sedimentary substratum below the young lavas was observed. It consists usually of conglomerates or sandstones that are easily recognized as fluviatile in origin.

In Hreppar a greatest thickness of 15 m was observed on the northeastern side of Galtafell where crossbedded sandstone and conglomerate outcrop over a distance of some 400 m. The crossbedding within the sandstone dips towards NE and N at this locality. On the northern side of Hólahnúkar 5 m of a pebbly sandstone outcrops. Above Núpstún farm a gray moraine-like sendiment underlies the young lavas. This can be followed over a distance of about 300 m. Usually the lavas rest directly upon the fluviatile sediment or moraine but in a few cases a 1–2 cm thick layer of black ash was found at the base of the lavas.

At Raudilaekur in the Holt area a sandstone with a thickness of 1 m is exposed below a young lava. The total thickness of this sedimentary layer, however, is unknown. Similarly at Árbaejarfoss a 25 m deep drillhole penetrated a 20 meter lava flow and ended in 5 m of sandstone

The sedimentary layer is thinner, in the western part of the area covered by the lavas. A

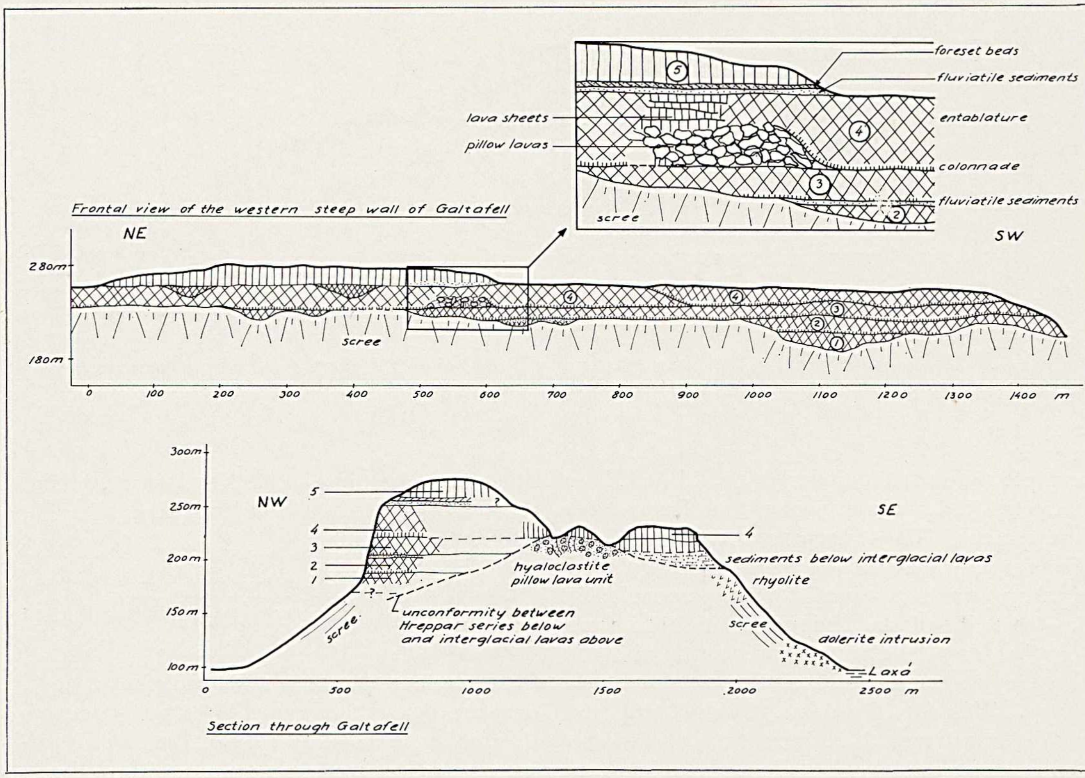

Fig. 4. Interglacial lava flows on the summit of Galtafell.

Mynd 4. Ungu hraunin í Galtafelli. Langskurður af vesturhlíð fjallsins og þversnið í gegnum fjallið. Ungu hraunin fimm talsins eru sýnd með lóðréttri strikun (stuðlaberg) og rúðustrikun (kubbaberg).

thickness of only 1 m was observed near Sumarlidabaer. Near Gíslholtsvötn the substratum was only seen where rocks of the Hreppar Series reach high up into the young lavas — again only reaching a maximum thickness of 1 m.

The localities where the sedimentary substratum outcrops usually do not coincide with the depressions of the old relief in which the greatest thickness of sediments would be expected. The borehole at Árbaejarfoss in which 5 m sediments were found at 24 m above sea level, may be located in a place where the sediments attian a considerable thickness. At Aegissídufoss at 14 m above sea level the base of the young lavas is not seen, however, sedimentary material squeezed into fissures from below may indicate the presence of the substratum at shallow depth.

It is evident that the main features of the present topography are older than the young lava flows, because the lavas spread in part over an erosional plain nearly similar to the one presently existing. North of Thjórsá only remnants of the lavas are left and variations in their base altitude indicate valley topography. The base of the young lavas to the north of Thjórsá rises continuously towards the north. In Hólahnúkur and Háholt the base lies at 150—180 m altitude. Further north it lies nowhere below 220 m. Just north of Thjórsá the base lies somewhere near 100 m. On the other hand the young lava flows immediately to the south of Thjórsá have their base below 60 m at least. From there the base falls off gradually to the south (24 m at Árbaejarfoss, 30 m at Raudilaekur, 14 m at Aegisídufoss, 10 m south of Ás). The relatively high base level (50–60 m) south of Gíslholtsvötn may be caused by faults (actually seen near Steinslaekur) but this level more likely reflects the uneven topography at the time of emplacement of the young lavas.

Thus, the lavas to the north of Thjórsá seem to have solidified in valleys with a southerly trend, but spread over an erosional plain further south. The lavas in the north piled up against the slopes of the valleys and attained a thickness of 80 m at least. The sediments below the lava flows indicate the presence of streams flowing along the bottoms of the valleys whereas the hillslopes were covered by moraine.

The greatest depression probably occupied by a major river depositing sand and gravel, lay in the eastern part of the area now covered by the lavas. To the west the relief may have looked similar as today (i.e. a typical glacial relief) except that the hills were more elongated in NE–SW-direction according to the strike of the rocks. Small lakes existed in the old relief that gave rise to hyaloclastite and pillow lava formation discussed below.

PETROGRAPHY OF THE INTERGLACIAL LAVA FLOWS

Petrographically the lavas fall into two distinct groups that occur in separate areas. To the south of Thjórsá the rock is an olivine basalt whereas to the north of the river the lavas are tholeiites. These are field terms widely used in Iceland in recent years. More correct designation would probably be olivine tholeiite instead of olivine basalt. The mineral compostion of the olivine basalt (Plate I, A) found by using a point counter is shown in Table 1.

Plagioclase occurs in the groundmass as lath shaped polysynthetic twins ranging in size from 0,05–0,6 mm. Zoning was observed in a few tabular crystals dispersed throughout the groundmass. A determination of refractive index of the plagioclase gave $n_\gamma = 1.570 \pm 0.002$ and $n_\alpha = 1.562 \pm 0.002$ corresponding to 65% An. *Pyroxene* is found as faintly coloured grains smaller than the plagoiclase showing intergranular relation to it. It seldom exceeds 0.3 mm in size. An average of 6 measurements of 2 V gave 48° which corresponds to augitic composition. *Olivine* forms equant, sometimes corroded and slightly altered grains similar in size to pyroxene. These two minerals are very similar and it is often difficult to distinguish between them. The olivine however is clearer and less coloured than the pyroxene. Besides the characteristic irregular cracks, the olivine has often a distinct cleavage parallel (010) indicating a fairly iron rich variety. *Ore* forms interstitial skeletal, needleshaped or ragged grains having about the size of pyroxene. It is probably mostly magnetic. Olivine is sometimes slithly altered to yellowish brown (non pleochroic) iddingsite. Plagioclase shows an incipient alteration to greenish or yellow montmorillonite. Cavities are sometimes lined with a thin layer of montmorillonite.

TABLE 1

	1.	*2.*
Plagioclase	49,2%	48,6%
Pyroxene	32,4%	34,2%
Olivine	8,6%	8,0%
Magnetite	9,0%	9,2%
Alteration products	0,8%	–

1. = Thinsection nr. 903. Sample from west of Lýtingsstadir (831 points).
2. = Thinsection nr. 907. Sample from Rangá south of Geldingalaekur (845 points).

The mineral composition of the tholeiite (Plate I, B) is shown in Table 2, as revealed by point counting of thinsections from the relatively well crystallized colonnade rocks.

Under the microscope the tholeiite is seen to be a microporphyritic rock containing about 13% microphenocrysts of plagioclase, pyroxene and subordinate olivine, partly grouped together as glomerophenocrysts, seldom more than 1 mm in size. *Plagioclase* microphenocrysts form lath shaped polysynthetic twins usually zoned up to 1 mm long. *Pyroxene* microphenocrysts, which may occur in ophitic relation to plagioclase, are up to 0.4 mm in size and often show hourglass structure. *Olivine,* which only occurs as microphenocrysts, forms heavily corroded crystals about the same size as pyroxene. It is usually somewhat altered to iddingsite. The groundmass of the tholeiites has intergranular texture and is more finegrained

TABLE 2

	1.	2.	3.
Plagioclase	39,6%	36,8%	37,8%
Pyroxene	42,2%	42,8%	45,4%
Olivine	1,2%	0,8%	1,1%
Magnetite	12,3%	10,0%	9,9%
Glass	4,7%	9,6%	5,8%

1. Thinsection no. 927. Rock from lower part of flow in Núpstúnskista (846 points).
2. Thinsection no. 924. Rock from lower part of flow in Skardsfjall above the farm Skard (842 points).
3. Thinsection no. 988. Colonnade rock from lower part of flow in Thjórsárholt (853 points).

than in the olivine basalts. *Plagioclase* forms unzoned twinned laths only 0.002–0.1 mm in size. The bulk composition of plagioclase laths and microphenocrysts near rims was found by measurement of refractive index $n_\gamma = 1.567 \pm 0.002$ and $n_\alpha = 1.558 \pm 0.002$ corresponding to about An 60%. *Pyroxene* forms grains only 0.001–0.05 mm in size. Measurement of 2V of the pyroxene showed the presence of both pigeonite with very low optic axial angles and augites of very much higher optic axial angles (2V average of 5 measurements = 50°). *Magnetite* usually forms equidimensional grains distinctly less ragged than in the case of the olivine basalts, although needleshape may also occur. A brownish glassy residum fills small interstices between crystals.

Rock from the upper part of the flows later referred to as the entablature is seen under the microscope to consist of an extremly finegrained glassy groundmass (Plate I, C) and microphenocrysts that are the same as in the coarser colonnades. It is impossible to state accurately the amount of glass in the thin sections but a value somewhere near 20–30% for the brown translucent glass cannot be very far wrong. An addtional 10–15% opaque glassy residue is crowded around the ore grains obliterating their margins.

FIELD CHARACTERISTICS OF THE INTERGLACIAL LAVA FLOWS

In hand specimen the olivine basalt is a rather coarse grained rock without phenocrysts, gray coloured when fresh but sometimes showing incipient yellowish alteration. The tholeiite is a fresh looking gray coloured rock that is fine grained, dense, and distinctly flow banded except in the glassier entablatures that are dark and flinty. Vesicles in both rock types are devoid of secondary minerals.

Columnar jointing is most conspicuous in the tholeiites north of Thjórsá and in the northern part of the olivine basalt area. Well developed columns occur in Hólahnúkar where the lavas occupy a depression in the old basement with long, curved columns fanning upwards from the sides and bottom (Fig. 5). In this area conditions were given for solidification under static conditions when the lavas were ponded into valleys and depressions. At several localities in Hreppar the lavas consist of a lower regularly columnar portion and a hackly jointed upper portion (Fig. 6 and 7). In Galtafell five such flows are seen in the

EXPLANATION TO PLATE I

A Olivine basalt showing intergranular intergrowth of olivine, augite, plagioclase and ore. Ásmundarstadir, interglacial lava flow, thin section no. 906. Magn. ×100. Ordinary light.

B Tholeiite showing a glomerophenocryst of ophitic plagioclase and pyroxene set in a finegrained intergranular groundmass. Note euhedral shape of magnetite. Skardsfjall, colonnade of an interglacial lava flow, thinsection no. 986. Magnification ×100. Ordinary light.

C Tholeiite showing glomerophenocrysts as in B set in an extremely fine grained and glassy matrix. Skardsfjall, entablature of same lava flow as B, thinsection no. 987. Magnification ×100. Ordinary light.

Myndir af þunnsneiðum úr ungu hraunum, í ca. hundraðsfaldri stækkun.
A fremur grófkornað ólivínbasalt. B ólivínfátækt basalt úr stuðlabergi í Skarðsfjalli. C sama, en úr kubbabergi, mun fínkornaðra og glerkennara.

Plate I, A

Plate I, B

Plate I, C

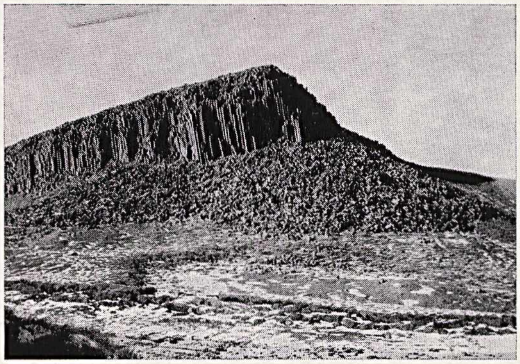

Fig. 5. Columnar jointing in the northernmost hill of the Hólahnúkar. The length of the columns is about 20 m. Photo: I. B. Fridleifsson.

Mynd 5. Stuðlaberg í Hólahnúkum.

precipitous cliffs along the western side. The two-tiered columnar jointing will be discussed in detail below. Within the olivine basalts this jointing habit is conspicuously absent. They usually show columnar jointing also but it is poorly developed except in the Akbraut area just south of Thjórsá.

Foreset breccias were found in a few localities, usually forming the basal facies of the young lavas. They attain a thickness of more than 10 m in the southern slopes of Gíslholtsfjall, where the base of the young lavas merges downwards into pillows, lobes, and southwesterly dipping steeply inclined sheets. An outcrop of a non stratified hyaloclastite with small lava lumps sealed with black glass can be seen above the Gíslholt farm. On top of it a small outcrop of westward dipping, stratified, finegrained hyaloclastite occurs. North of Gamla Akbraut, just above Thjórsá river about 3 m of pillow breccia occur at the base of the young lavas overlying a 2–5 m thick sandstone and conglomerate. Examples of hyaloclastite formation north of Thjórsá were seen in the southeastern part of Skardsfjall (Midhúsafjall) and in the western slope of Hlídarfjall where 15–20 m thick hyaloclastites occur below the young lavas. As in the former examples the hyaloclastites represent foreset breccias genetically related to the overlying lavas as a result of flow into lakes.

Pillow lavas. In the slopes of Galtafell entablatures can sometimes be seen to grade into pillow lavas and related breccias. Because of the loose consistency of these rocks the otherwise precipitous cliffs tend to be scree covered where this occurs. In the example reproduced in Fig. 4 an entablature is seen to continue for 100–150 m distance greatly reduced in thickness and partly disintegrated into a number of sheets. The attenuation is compensated by rounded pillows and irregular lobes of low porosity and a hackly jointed interior forming the lower part of the flow. The boundary between the pillow lavas and the attenuated entablature is fairly sharp, but pillow like downward projections are commonly developed. Glassy material between individual pillows is present although very insignificant at this locality. On the northeastern slope of Galtafell an entablature of another young lava flow (no. 3 of Fig. 4) grades into breccias with abundant glass containing pillows and lava lumps sealed with glass. The formation of the pillow lavas may have taken place where small water ponds developed, probably near the margins of an advancing flow. After they were dried up the flow could attain its usual characteristics.

Fluviatile deposits between the lava flows. In the western slope of Galtafell a sedimentary layer up to 3 m in thickness is developed between flows 1 and 2 and flows 4 and 5 of Fig. 4. These sediments are mainly composed of poorly rounded, coarse glass fragments and angular lithic fragments up to 30 cm in size. Well rounded boulders occur occasionally. The coarse lithic debris has been derived almost exclusively from the young lavas. It occurs in distinct layers separated by a more finegrained material. Cross bedding with southerly dips is characteristic of the sediments. A sort of torrential bedding, thus indicated, is in accordance with an origin related to catastrophic flooding immediately after the emplacement of the flows as referred to below.

INTERPRETATION OF THE TWO-TIERED FLOWS

The remarkable twofold division of flows such as observed in the Hreppar district has been known for many years, in various places throughout Iceland mostly in Quaternary rocks.

Fig. 6. Lava flows forming the summit of Galtafell show twofold division in a lower thin colonnade and an upper thick entablature. View towards north.

Mynd 6. Kubbabergslög í Galtafelli.

Lindal (posthumously published 1964) described interglacial lavas in Húnavatnssýsla, Northern Iceland, that apparently formed under similar conditions as those in Hreppar. In the Icelandic literature the irregularly columnar division has been named *kubbaberg* (boxrock) a term first proposed by *Lindal.*

Tomkeieff (1940) in his description of the basalt flows in the Giant's Causeway district used the term colonnade for the lower unit of some flows there with straight vertical columns and entablature for the upper unit with curved and twisted columns. These names are adopted here not considering the origin which may be quite different. As a rule the entablatures and colonnades of the Hreppar flows meet along a fairly sharp boundary deep within the lower half of the flows (Fig. 6 and 8). This indicates that cooling from the top of the flows giving rise to the entablature proceeded much faster than cooling from the base which produced the colonnade.

Different rate of cooling within the colonnade and the entablature of the Hreppar flows is also evident from the entablature rock being darker and of a more finegrained and glassier texture than the colonnade (Plate I, B and C). Such textural difference has not been noted in the Giant's Causeway examples (*Spry* 1962). Another difference may be the much more pronounced hackly jointing of the entablature in the Hreppar examples. This probably indicates a different mode of origin. *Spry* (1962) favours an explanation of the Giant's Causeway flows, based on an irregular stress distribution in the centre of the flows even though the isotherm pattern is comparatively simple. He assumes that movement of a still fluid interior, taking place after the formation of a thick upper and lower layer, could produce a stress pattern necessary for the formation of an entablature. This explanation also applies to examples described by *Waters* (1960) from the Columbia River Plateau (cf. Fig. 1 and Plate 1 of his

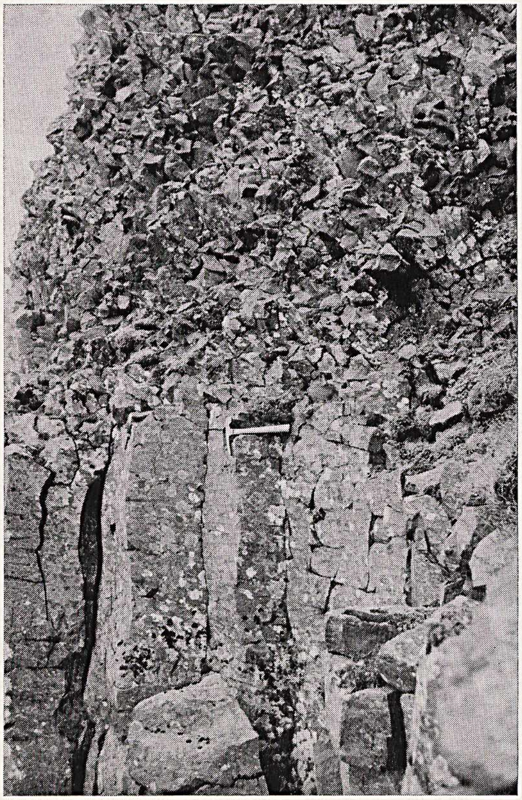

Fig. 7. Lava flow near the top of Galtafell (no. 4 in Fig. 4) showing the sharp boundary between a colonnade (base) and an entablature (top).

Mynd 7. Skörp skil milli stuðlabergs og kubbabergs í ungu hraunlagi í Galtafelli.

paper). Joints progressively developing towards the interior of a cooling flow from top and bottom tend to form an irregular jointing pattern where they meet. This may also result in a sort of entablature. A true kubbaberg-type entablature has however also been reported from the Tertiary Volcanic Districts of Scotland and Ireland, the Island of Staffa being a famous example. The same applies to the Columbia River Plateau (*Mackin* 1961).

The rapid cooling indicated by the glassier texture and great thickness of the entablature of the Hreppar lavas strongly suggests aqueous chilling. More conclusive evidence is provided by entablatures observed in the slopes of Galtafell grading into pillow lava and hyaloclastites (Fig. 4). As shown before the young lavas in the Hreppar all solidified within valleys with rivers flowing along them as indicated by the gravel beds that are often found below the lavas. These rivers may have been dammed up temporarily by the lavas and then flooded the valleys with the still partly fluid lavas on bottom. The lavas which possess an upper chilled entablature probably mark the channels of such floods. The rubble of the aa lava surface was already solidified at the time of flooding. The water flooding the lava therefore seems mainly to have acclerated the cooling process and caused extreme thermal stresses within the unconsolidated portion of the lava, responsible for the extremely hackly jointing.

The writer would like to mention two examples of the formation of entablatures in postglacial lava flows obviously caused by flooding shortly after their emplacement both from Jökulsá á Fjöllum in Northern Iceland (Fig. 8). The eruptive fissures of Hljódaklettar and Sveinar (*Thorarinsson* 1960) cut across the river and have poured lavas into the river bed. Later erosion of these lavas, first recognized as postglacial by *H. Tómasson* in 1967 (oral communication), revealed the typical twofold division also present in the Hreppar lavas.

It is interesting in connection with this discussion to point out similar processes actually observed during the Lakagígar eruption in 1783. Lava flows of this eruption dammed up the rivers Skaftá and Hverfisfljót. Both were drained out over the lava several months later when a great volume of water had accumulated behind the lava dams. (Eyewitness account of the spectacular phenomena by *Jón Steingrímsson* publ. 1907). It is uncertain whether textures and structures similar to those of the Hreppar lavas resulted there. However according to *Jónsson* (oral communication) an entablature was formed when some smaller rivers after torrential rain for several days flooded the still advancing lava just west of Kirkjubaejarklaustur. As a result the progress of the lava was stopped. The entablature is revealed in sections along the Skaftá at Eldmessutangi.

The theory of aqueous chilling causing the formation of entablatures is by no means a new one. *Waters* (1960), in discussing entablatures caused by late movement in a cooling lava flow, points out that they may also form in other ways such as when "water from an adjacent stream pours over the surface of a lava flow before the lava completes its solidification". *Saemundsson* (1967) adopting this view explained small patches of irregular columns within the top basalts of table mountains as due to water ingressions creating irregular cooling faces. Direct subaqueous origin of the kubbaberg-type entablatures is favoured by *Sigvaldason* (1968) who observed a sucession of flows consisting of three divisions in the socle of Herdubreid, Iceland's largest table mountain. The lowest division is composed of pillows, the upper two of columnar basalt and an irregularly jointed uppermost division. He interprets these lava flows as subaquatic since they occur at the base of a volcanic structure (i.e. a table mountain) that is in general interpreted as subaquatic. Similarly *Walker and Blake* (1966) report a subglacially emplaced lava flow from Eastern Iceland where the same type of jointing occurs in a basalt layer forming the basal portion of a pillow lava — hyaloclastite mass.

The question whether the kubbaberg-type entablatures were formed under water after flowing into an aqueous environment or by water from streams that poured on to a still hot lava must be considered individually. Probably generalizations as to one or the other cause of formation are not justified.

ORIGIN AND AGE OF THE INTERGLACIAL LAVA FLOWS

The eruptive source of the young lavas is unknown and it may be different in case of the olivine basalts and the tholeiites. The source of the olivine basalts probably lies to the east within the eastern limb of the active volcanic zone. The olivine basalts may have followed a similar path as did later the postglacial Thjórsá lavas (*Kjartansson* 1958). This is indicated by the altitude of their base, which diminishes towards the south and southeast. Foreset bedded hyaloclastite breccias, occasionally found at the base, dip toward the west or southwest, indicating flow from the east or northeast. The provenance of the tholeiites is more problematic. Their source almost certainly lies outside the boundaries of the map (Fig. 1) somewhere to the north or northeast. This is judged again from the increase in altitude of the base of the lavas towards the north. The center of eruption may lie as far as the active volcanic zone, but since a few volcanic eruptions are known to have occurred within the boundaries of the Hreppar Series as late as the end of the last glaciation, they may have a closer origin.

The younger age of the olivine basalts is indicated by their less advanced erosion as well as the generally much lower altitude of their base and top levels. This implies more advanced denudation of the Hreppar Series in the area covered by the olivine basalts and may in part be due to a longer period of erosion in this part of the area.

Fig. 8. Colonnade-entablature structure exposed in a postglacial lava flow at Vígabergsfoss in the river Jökulsá á Fjöllum. Photo: Bjarni Sigurdsson.

Mynd 8. Kubbabergsmyndun í hrauni runnu eftir ísöld. Forvöð við Jökulsá á Fjöllum.

The interglacial non tilted lava flows have normal magnetization whereas several reversals occur within the underlying Hreppar Series. With regard to their position and freshness the young lavas most reasonably belong to the present normal polarity epoch (Brunhes) giving a maximum age of 690,000 years (*Cox* 1969). The degree of erosion of the interglacial lavas is the only available means to estimate their minimum age. The area was overridden by a main glacier throughout most of the last glaciation (*Kjartansson* 1943, 1958) which has undoubtedly resulted in an enormous glacial erosion during this period. The present writer finds it possible that the olivine basalts south of Thjórsá were erupted during the last interglacial period. On the other hand the tholeiites are believed by the writer to date back from an earlier interglacial period.

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ÁGRIP

HRAUNLÖG FRÁ HLÝSKEIÐUM ÍSALDAR Á SUÐURLANDI OG MYNDUN KUBBABERGS

Kristján Sæmundsson

Í grein þessari er lýst víðáttumiklum hraunlögum frá hlýskeiðum ísaldar. Þau eru útbreiddust í Rangárvallasýslu milli Þjórsár og Ytri Rangár og í Hreppum finnast þau efst í nokkrum smáfellum, svo sem Skarðsfjalli, Galtafelli og Hlíðarfjalli.

Undirlag hrauna þessara er s. k. Hreppamyndun og er halli hennar yfirleitt norðvestlægur, víðast yfir 10°. Hraunlögin sjálf eru hins vegar hallalaus, mynduð eftir höggun og rof Hreppamyndunar. Út frá ummyndun, sem hefur leitt til myndunar zeólíta í ólivínbasalti og móbergi má áætla, að rof Hreppamyndunar hafi a. m. k. numið 500—700 m miðað við láglendi, áður en hraunlögin runnu, sem um er fjallað í greininni. Alls þekja þau um 250 km^2 lands, aðallega austan Þjórsár. Við Ytri Rangá hverfa þau undir sanda Rangárvalla, þannig að ekki verður séð, hver útbreiðsla þeirra er til austurs. Vestan megin enda hraunlögin venjulega í lágum en bröttum brúnum, t. d. vestan við Ás í Áshverfi og ofan við Efrihamra. Sunnan til eru hraunlögin mjög samfelld, en eyddari ofan til í Holtum og í Hreppum. Í Hreppum ná þau mestri hæð á Hlíðarfjalli (370 m y. s.). Heildarþykkt hraunlaganna er mest í Holtum, yfir 100 m í Gíslholtsfjalli og á Sandskarðaheiði. Í Hreppum ná þau 70—80 m þykkt í Galtafelli og Skarðsfjalli. Fjöldi og þykkt hraunlaga í einstökum þversniðum eru breytileg. Flest eru þau 5 í Galtafelli vestanverðu, en færri austan Þjórsár.

Undirlag hrauna þessara er yfirleitt völuberg eða sandsteinn, sem ber einkenni árframburðar, á einstaka stað er einnig jökulberg. Undirlagið er mishæðótt og bendir til, að hraunin hafi runnið í dölum og lægðum í Hreppum, en breiðzt út yfir smáhæðótt undirlendi austan Þjórsár.

Bergfræðilegur munur er allmikill á Hreppahraununum annars vegar og hraununum austan Þjórsár hins vegar. Það bendir til ólíks uppruna. Sennilega eru Hreppahraunin eldri, þar sem þau eru meira rofin. Upptök hraunanna eru ókunn. Hreppahraunin eru sennilega runnin norðan eða norðaustan að, en hraunin austan Þjórsár að öllum líkindum norðaustan eða austan að frá gosstöðvum í eystra gosbeltinu. Hraunlögin eru öll með réttri segulstefnu og því ekki eldri en 700.000 ára. Höfundur álítur mögulegt, að hraunlögin austan Þjórsár séu frá síðasta hlýskeiði, en telur Hreppahraunin vera frá eldra hlýskeiði.

Hreppahraunin eru að nokkru leyti af þeirri gerð, sem nefnd hefur verið kubbaberg hérlendis. Einkenni slíkra hrauna er tvískipting í hlutfallslega þykkan, smásprunginn og lítt eða óreglulega stuðlaðan efri hluta ofan á þunnu stuðlabergslagi með reglulegri stuðlun. Slíkt storkunarform í basalthraunum er algengt víða um land, einkum í kvarterum myndunum. Í greininni er sýnt fram á, að vatnsrennsli út á hálfstorknuð hraunin muni hafa valdið myndun kubbabergsins. Helztu rök með því eru þessi: Skilin milli kubbabergsins og stuðlabergsins eru ávallt nærri botni laganna, en það sýnir, að storknunin hefur orðið miklu hraðari ofan frá. Kubbabergið er smákristallaðra en stuðlabergið og jafnframt glerkennt, en það bendir til hraðari storknunar. Loks má sjá, að kubbabergið gengur á einstaka stað yfir í móberg og bólstraberg, en myndun þess verður eingöngu í vatni.

Bent er á dæmi frá Jökulsá á Fjöllum um kubbabergsmyndun í hraunum, sem runnu eftir ísöld. Þar hefur kubbabergið myndazt, er hraun fylltu farvegi ánna, en voru ekki fullkólnuð, þegar árnar brutust út yfir þau á ný. Vatnið hefur hraðað kólnun hraunanna og valdið við það spennu, sem leiddi til hinna óreglulegu kólnunarsprungna. Sömu aðstæður gætu hafa valdið kubbabergsmyndun í Hreppahraununum. Annars staðar gæti kubbaberg myndazt, þegar hraun rynnu undir vatni. Vari er tekinn fyrir því að túlka allt storknunarform, sem líkist kubbabergi, á þennan hátt.