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EXPLANATORY NOTES ON THE INTERNATIONAL HYDROGEOLOGICAL MAP OF EUROPE 1 : 1.500.000 SHEET B2 REYKJAVÍK

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GEOLOGY IN BRIEF

Iceland is a young volcanic island. Its bedrock is predominantly effusive igneous rocks. The volcanics are mostly made of basic rocks, basaltic lavas or palagonite.

Acid and intermediate rocks are of much less occurence. Sedimentary strata between the lava layers are most often very thin. Intrusions are numerous and most often in form of dykes. Their hydrological importance is unquestionable.

Iceland is on the Mid-Atlantic Ridge and is thought to be on the margin of the N-American and the European plates. Active volcanic zones cross the country. According to the theory of plate tectonics the island is drifting out from the volcanic zones in both directions. The continuous volcanism immediately fills up the gap between the plates. (Morgan 1968, Pichon 1968). The age of the bedrock reflects the drift roughly. The rocks are youngest in the active volcanic zones but get older farther from the zones, the oldest rocks are to be found in the East and the West fjords. The majority of the flood basalt in the icelandic lava pile in originated in crater rows, sinder cones or in shield volcanos. These volcanoes erupt only once and produce always basaltic lavas.

Central volcanoes produce nearly all the acid and intermediate rock in Iceland. These volcanoes are characterised by great but concentrated volcanic activity and lavas of developed magma. They can reach different size. The smallest of them consist only of few andesite or rhyolite lavas but the biggest ones are vast volcanic cones which stand high above their environment, made of thick strata of rhyolite, andesite, ignembrite, tephra and lots of basaltic rocks.

The best chronology for Icelandic geology is optained by use of the geomagnetic reversal time scale. Iron minerals (magnetit) in the lavas, preserve very well the orientation of the magnetic polarity, dominant when they were erupted. Magnetic reversals therfore play a big role in all geologic exploration in Iceland. On the hydrogeological map the two most important reversals are indicated, the Brunhes-Matuyama reversal of the age of 0,7 m.y. and the Gauss-Gilbert reversal 3,35 m.y. old.

In Iceland it has proved to be convenient to divide the geological history into four epochs: Tertiary, Eo-Pleistocene, Neo-Pleistocene and Holocene. (fig. 1). The strata piles of these epochs have strong characteristics of their own. The Tertiary pile consists more than 90% of lavas, predominantly basaltic. Between them are thin interbeds, most often thinner than 1 m. The regularity of the layering is disturbed in some places by central volcanoes buried in the strata. They are characterised by irregular layering, local tectonics, dyke swarms and various petrology. The rocks are often hydrothermally altered and highly zeolitisised.

The Pleistocene pile is marked by the cold climate of the ice age, glacial erosion and subglacial volcanism. It is quite different from the Tertiary one. The erosion changed its character and the volcanism too. Eruptions under water or ice sheet do not form ordinary lavas. An eruption at a great depht and under pressure forms pillow lava, but eruption at shallow dephts mostly produces tephra, that later consolidates into palagonite (G. Kjartansson 1943). The Icelandic palagonite mountains therefore often have a core of pillow lava. About half of the Quaternary volcanics are in the form of palagonite and related rocks. This heterogeneity causes very various permeability from place to place. Old palagonite is thought to be one of the most impermeable rock found in Iceland but the pillow lava, one of the leakiest.

The small scale of the hydrogeological map makes it impossible to separate the palagonite and the lavas of the Quaternary pile.

It is customary in Icelandic geology to put the Tertiary-Quaternary boundaries about 3 m.y. years ago. The oldest signs of extensive glaciation in Iceland are of that age. After that about 30 glaciations seem to have periodically overridden the country.

More periods of glaciation, or interstadials, are known from Iceland than any other country in the world. There are two main reasons for this. Firstly because of the volcanism. In each warm period , lavas have been formed that cover extensive areas. Under them moraines and palagonite from latest glaciation are protected from being eroded away by the glaciers of the next glaciation period . That way the moraines and palagonite indicate glaciations but the lavas warm ice-less times. Secondly the great number of glaciation periodes are due to the northerly position of Iceland and its mountainous landscape. Fluctuations in the weather conditions are immidiately followed by recessions and transgressions of the glaciers.

The main differences of the Eo- and Neo-Pleistocene formations are that the Eo-Pleistocene pile is deeply eroded and the secondary mineralisation is well on its way. The Neo-Pleistocene formation is moderately eroded and the secondary mineralisation is of low degree.

The central volcanoes of this last epoch are often outstanding in the landscape as high pretty looking strato volcanoes. Calderas often form in these mountains, vast fissure swarms cross them and high teperature areas are common.

The Holocene formations include all the unconsolidated surface layers of Iceland and the recent lavas. They will be described later.

THE PERMEABILITY OF THE BEDROCK.

The permeability of icelandic geological formations seems decrease with increasing age. This is a general rule as for effusive, intrusive and sedimentary rocks. Three main reasons are causing this: Secondary mineralisation and alteration, compression and intrusion of dykes. At Icelandic conditions these phenomena increase with age.
The secondary mineralisation makes the rocks densier by filling up and narrowing the pores and gaps.

The Tertiary strata pile has, since it was formed, been overflown and ~~dug~~ buried by younger lavas and other beds. Under a great pressure of the overlaying strata, compression takes place and makes the layers very imprevious. The layers which originally were leakiest, such as scoria and loose sediments, have got the highest compression.

At the same time, when these layers were dug into the pile, they were intruded by dykes and intrusions. These intrusives often form dense walls and thresholds which act as barriers on the groundwater flow. The oldest bedrock of Iceland has become so dense that it is almost impermeable. It is to be found in the lowest part of the Austfirðir pile at the east coast.

Hydrothermal alteration and zeolitisation occur because the rocks are buried under younger lavas and sediments and are subjects to great heat and pressure. As a general rule it can be stated that the older Icelandic rocks are, the more zeolitisised they are. However there are some exceptions. Old rocks in the mountaintops of Vestfirðir seem never to have been under any considerable pressure. Anyway they look rather fresh and are without secondary minerals. Their permeability is therefore rather high. Rocks of the same age in Austfirðir are on the other hand highly zeolitisised and dense. Number of dykes in Austfirðir, in the east, is more than in the west and this increases the difference of these regions. This difference is reflected in the behaviour of the groundwater flow. In Vestfirðir, springlines are formed at the top of the zeolite zone and rivers are more perennial than in the east, where most rivers are more or less intermittend at their uppermost parts. In the West, thermal springs are common. The groundwater seems to penetrate easily into the dephts. In the East thermal springs are rare. The deep layers seem just about impermeable. The reasons for these difference are surely many. But the main reason must be different state of erosion in these regions. The main direction of downfall in Iceland the last millions of years has been from the southeast. Therefore the glaciers of the iceage have always been thickest and most enduring in the East and Southeast and eroded these regions greatly. This statement is indicated by the present erosion due to the glacier Vatnajökull. The north west penisula has on the other hand been in the shadow of precipitation from these glaciers and been moderately eroded.

Hydrological influences of Tertiary central volcanoes are not known at present, but there are reasons to believe that they are even denser than their surrounding bedrock. They are the most zeolitisised parts of the bedrock, thermal metamorphism and high temperature hydrothermal alteration is common, the number of dykes and faults is high and intrusions are not rare.

The younger central volcanoes have quite a different character from the older ones. Most often they stand above the environment and form heights on the groundwatertable. The role of intrusions and dykes is not known, but great active fissure swarms that often cross these mountains probably increase the permeability. The great fissure swarmes of Iceland seem always to be in close connection with the central volcanoes or high tempeture areas. They influence strongly the groundwater flow. Many of the biggest Icelandic springs and springareas seem to be in connection whith the swarms such as

Vellankatla at Þingvellir, Gvendabrunnar and Elliðavatnslindir near Reykjavík, Hafragilslindir and Blikalónslindir in Melrakkaslétta.

The lavafields of Iceland are valuable freshwater aquifers. The lavas are highly permeable, 10^{-3} m/s in their dense part and 10^{-1} m/s in the scoria at their upper and lower part. Almost all precipitation falling on the lava fields and does not evaporate, penetrates into them and runs off as groundwater.

Icelandic lava fields are in some ways similar to the karst regions in Europe. Vast amount of water can be discharged in limited areas. The volume of the flow often reaches tens of m^3/s in a spring area. The springs in Vaðalda discharge 20 m^3/s and the spring area of Mývatn 25 - 30 m^3/s. In the same way rivers can suddenly disappear in the lavas.

In other ways the circumstances in the lavas are quite different from those in the karst. The water does not stream along in tunnels or veins but flows through the porous scoria layers underneath the lava or in fissure swarms from one crack to another. The water gets a good filtering on its way in the lavas and the lavaspring most often discharge a marvellous drinking water.

UNCONSOLIDATED ROCKS.

Loose sediments in Iceland are in most places very thin. Sediments thicker than 50 m are rare. The causes for this are that the glaciers of the iceage covered just about the whole island and swept all sediments into the sea. The outer part of Icelands shelf in made up of these sediments. There they are several hundredmeters thick (L. Kristjánsson 1976).

On the hydrogeological map the loose sediments of Iceland are divided into four classes and due to the permeability put into two groups. Highly permeable layers are: fine fluviatiles and coarse fluviatiles. Semipermeable layers are: moraines and valley fillings. Moraines are only shown on the map where they have considerable thickness and extent. The permeability of a moraine can be very different from one place to another. It depends mainly on the clay and silt fraction. Where there is much silt and clay the moraines are dense and impermeable. The less silt it contains the leakier is the moraine.

In most of the bigger valleys of the country, valley fillings have been formed in finiglacial and Holocene time. They are made of rather heterogeneous sediments. There are layers of moraines, marine sediments, fluviatiles, glacifluvial sediments and soil with various thicknesses. The permeability is therefore also heterogeneous, but as a whole it is rather low. Fluviatile and glacifluvial deposits have the most extent on the south coast. The majority of these deposits come from the glacier rivers but a good deal is volcanic ash, especially in Mýrdalssandur and Skeiðarárdandur. The tephra there, comes from two of the most active volcanoes in Iceland, Katla and Grímsvötn. Both these volcanos are covered by glaciers. Subglacial eruptions always produce a lot of tephra. Besides the eruptions vast glacier bursts (jökulhlaup) overflow great areas on their way to the sea and bring millions of tons of sediment down to the lowlands beneath the glaciers (H. Tómasson 1974).

RIVERS

Icelandic rivers have strong individuality according to their origin. Rivers flowing side by side are often of different character. One may have tremendous floods once in a while when the other does not change its flow the year around indipendent to the weather. One river is always crystalclear, its neighbour has a permanent dark brown colour. One river sreams quietly even under thick winter ice, while the neighbouring streams flow unfrosen all winter long. Iceland has been called the child of ice fire. Continuous struggle between these two elements of nature have formed the country and their opposite character is reflected in the variousfeatures of the rivers. The common and general hydrological phenomena of Iceland cannot be explained nor understood exept digging deep into the laws of glaciers and the nature of volcanism.

Icelandic rivers have been divided into three well characterised groups between which all intermediate stages exist. The groups are: Direct run-off Rivers (dragár), Spring-fed Rivers (lindár) and Glacier Rivers (jökulár), (G. Kjartansson 1945). (See fig. 2).

Direct run-off Rivers are to be found where the bedrock is dense, that is on the Tertiary areas in west,north and east Iceland. These rivers usually have no distinct origin but are made of contributions from a number of small brooks and intermittend creeks. Their flow is very much dependent on the weather, they increase when it is raining and then decrease and may dry up in dry seasons. In the same manner the water temperature responds quickly to variations in the air temperature. The water is warm in summer but cold in winter. Ice is quickly formed in the rivers as the airtemperature goes below 0°C. In frost period the direct run-off rivers are small and can easily disappear. As thaw sets in,the rivers grow all of a sudden and burst open the icecover that it has formed over the winter with a great tumult. Ice dams are often formed under such a conditions and the river overflows its banks.

The floods of these rivers carry great volume of mud, but when they are not flooding they are crystal clear.

A good example of direct run-off river is Grímsá in East Iceland. Its average run-off is 30,7 m^3/s. Maximun flow, not disturbed, was 312 m^3/s but in flood crest caused by icedam burst, it has reached 800 m^3/s. In special weather conditions (frost and snowstorm) it has entirely dried up. (S. Rist, 1956).

The spring-fed rivers are in most respects entirely different from the direct run-off rivers. They are mainly found in areas of porous Quaternary bedrock and recent lavas. The spring-fed rivers have distinct origins, often gushing springs, in which case the flow reaches its full capacity not far from the headsprings. The flow is very even all year round, and so is the temperature. The temperature of the most springs is in the interval 3 - 5°C depending on the rock temperature of the drainage area. They never freeze near the headsprings eaven in the hardest frost. Floods are rare and occur only in thaw periods in winter or early spring, when the ground is frozen and the water cannot penetrate it. Example for springfed river is Ytri-Rangá in South Iceland. It´s average run-off is 38,5 m^3/s and takes very small variations. (S. Rist, 1956).

Glacier rivers originate in the glaciers and are fed by their meltwater. Their flow is very fluctuating and is in close connection with the air temperature. The precipitation is of much less importance. The flow increases in early summer and is great in July and August.

The winter reaches the glaciers in September and then there is a sudden decrease in the meltwater flow. The glacier rivers are very small all through the winter.

In places where a violent torrent is gushing from an ice tunnell at the glaciers edge on a hot summer day there may be just an insignificant brook or even no water at all in late winter.

In the same way as the flow follows the annual temperature cyclus, it takes daly fluctuations along with the temperature. The temperature of the water is close to 0°C at the glaciers edge the year around.

The main characteristic of the glacial rivers is their brown or greyish colour which results from the mud originated in the glaciers bed.

Vast amounts of gravel and sand are carried from the glaciers bed and these form great sands immediately as the river reaches flat area and the current velocity goes down. There it forms braided stream of uncountable brances, constantly changing their courses because of their load and fluctuating flow.

The course fluctuation of glacier streams can be separated into two kinds, internal and external changings. The internal and most obvious ones are changes of the flow and location of the rivers branches. They can take daily fluctuations and are usually irregular.

The external changes are that the whole river, with its triangular branch system, changes its location. These changes are slow but often regular and can take tens of years or even centuries. (See fig 3).

The main cause of the fluctuation is the deposit of glaciofluvial sediments in the river bed.

Now the main groups and characteristics of Icelandic rivers have been described. Near to their origins the rivers are very typical but farther out their character becomes more unclear because there the rivers usually are more or less mixed with other streams. (S. Rist, 1956).

GLACIER BURST

One phenomenon of the glacial streams which has made them most famous in foreign countries are the so called glacier bursts (jökulhlaup), the violent outbursts of water at the margin of the glaciers. They originate mainly from two causes:

Firstly, glacier dammed lakes. A glacier moving down a main valley passes the mouth of a tributary valley, prevents all flow of wather from it, thus damming up a lake. At last, if the dammed water can reach depht equal to 9/10 of the thickness of the glacier, it breaks its way through under the glacier, forming a glacier burst. Such glacierdammed lakes often outburst periodically. In a long time scale these lakes are short living phenoma. The fluctuating glaciers make them very unstable.

Secondly, subglacial geothermal and/or volcanic activity. In geothermal areas covered by glaciers the ice melts and water accumulates in meltwater chambers. Periodically a glacier bursts rushes from these chambers. Volcanic erupions sometimes cause or are accompanied by such bursts.

The flow of a glacier burst may be from few cubucmeters per second up to tens of thousands of cubicmeters per second. The most violent glacier bursts in Iceland are acompanied by eruptions in Katla or Grímsvötn. The maximum flow in glacier bursts in Katla have been estimated 100.000 - 200.000 m^3/sec. or the same order of magnitude as the largest rivers of the world. The total quantity of water discharged in these bursts may be several km^3. Glacier bursts do not last for long time, usually only one or two weeks whith very sharp maximum peak. They may occur any time on the year. (See fig. 4 and 5).

LAKES

In Iceland there are many lakes but only few are of large size. Their basins have been formed from several causes. In the Quaternary areas the basins have often been formed by volcanic and/or tectonic activity. Volcanics such as lavas and palagonite formations dam up valleys. Explosive eruptions sometimes form deep circular craters (Maar) that fill up with water. After great eruptions, central volcanoes may collapse into a caldera in witch a lake forms. This happended in 1875 after a violent outburst of Askja and Icelands deepest lake, Öskjuvatn of 220 m depht, was formed. Grabens are not rare in Iceland. The most famous of them is the Þingvellir area. The largest lake of the country Þingvallavatn is partially due to the graben. Glacier formed lake basins are also to be found in the Quaternary area. In the Tertiary areas, lake basins eroded by glaciers are the most prominent. Landslides have in a few places dammed up heads of valleys thus, forming small lakes. Already mentioned are the icedammed lakes. Finally, lagoon lakes are frequently found, parted from the sea by narrow gravel banks. These lakes are differentiated from ocean lagoons only by the fact that their water is fresh or only very slightly saline.

Table 1

The largest lakes of Iceland.

Þingvallavatn	82 km^2	Subsidence, lava dam.
Þórisvatn	70 -*	Glacier eroded, lava dam.
Lõgurinn	52 -	Glacier eroded valley lake.
Mývatn	38 -	Lava dam, subsidence.
Hópið	29 -	Lagoon lake.

* This was before Þórisvatn was changed into a reservoir. Now its size is variable.

Altogether there are 27 lakes, of the size 5 km^2 or more and little over 80 are 1 km^2 or more. (S. Rist, 1956).

GLACIERS

Iceland has got its name from the glaciers that cover the highest mountains of the country. The glaciers of Iceland are the largest ones in Europe. They cover 11-12% of the country. The biggest one is Vatnajökull 8400 km^2, then come Langjökull nearly 1000 km^2 and Hofsjökull just over 900 km^2. Mýrdalsjökull is 700 km^2. The thickness of Vatnajökull is in most places 600-800 m, but can reach 1000 m. Its volume was estimated 3520 km^3 in 1955, since it has diminished much. The total volume of glacier ice in Iceland is 4000-4500 km^3. The glaciers reached their maximum extent around 1890, but have been recessing all the time since. The limits between ablation and accumulation zones in glaciers are named equilibrium line. Above it the glacier has a net gain of mass over the year, below it there is a net loss. The height of the equilibrium line depends on the temperature and precipitation. In southern slopes of Vatnajökull it is 1000-1100 masl. but in 1300-1400 masl. in the northern slopes. The equilibrium line is lowest in north-west Iceland 700-800 masl. in the glacier of Drangjökull. Glaciers act as vast reservoirs of water, some times they swallow considerable fraction of the precipitation and keep it for decades but give it back later when the climate changes. The total shrinkage of Vatnajökull in the interval 1894-1968 has been estimated around 310 km^3 of ice and the shrinkage of Langjökull for same interval is thought to be 31 km^3 (G. Sigbjarnarson 1967,1970). This has considerable influences on the run-off in the glacier rivers and in fact some of the springfed rivers too. In cold periods as in the decades before 1890 all glaciers were retreating and the average run-off in rivers fed on water from the glacier was relatively low. In warm periods as in years of 1890-1965 all glacier were recessing and the average run-off of these rivers was high.

COLD GROUNDWATER

Due to heavy precipitation and little evaporation the average run off from km^2/sek in Iceland is the highest in Europe or about 55 1/sek.km^2 (S.Rist 1956). Where the bedrock or the surface layers are permeable, springs are very common. Just few the largest ones can be shown on a small scale map. On the Internat. Hydrogeol. map of Europe only springs or springgroups discharging more than 1 m^3/sek are indicated. 75 such springs are shown.

Just about all these gigantic springs, are inside the volcanic zone and always connected to lava fields and/or fissure swarms.

Wery little is known about groundwater divides in Iceland and they are nowhere shown on the map. In the volcanic zone they are somwhere thought to differ from the surface water divides. In the older parts of the country, the Tertiary regions, they are most likely in close connection to the topography.

In most cases the groundwater flow in the upermost groundwater layers is thought to be parallel to the dip of the groundwater-table. Anisotrophy might rise in the special circumstances when a fissureswarm cuts the rocks oblique to the dip of the groundwater-table.

In deeper aquifers the groundwater flow is charcterised by a great anisotrophy between horizontal and vertical permeability. In a lavapile the permeability is much higher parallel to the layering than perpendicular to them.

Icelandic aquifers can be divided into three classes as shown in table 2.

Table 2.

Aquifers of Iceland

1. Aquifers in unconsolidated rocks.
    a. Gravelly and sandy fluviatile and fluvioglacial deposits.
    b. Rock slides and screes.
    c. Eskers and terraces.

2. Aquifers in recent lavas.

3. Aquifers in permeable bedrock
    a. Interglacial lavas and fresh Tertiary lavas.
    b. Pillowlavas.
    c. Active fissure swarms.

In addition to the third class there are thermalwater aquifers in the depths. Their nature is unknown at pressent.

In the Tertiary regions aquifers of class 1. are the most important. In the Quaternary regions outside the volcanic zones, aquifers of class 3 are the most important. In the volcanic zones, aquifers of class 2 are the most important.

THERMAL WATERS

Iceland is characterised by very high geothermal gradient. It ranges from about 40 C°/km in the oldest Tertiary rocks to about 160 C°/km in the Eo-Pleiskocene rocks adjacent to the volcanic zones. Still higher gradient is to be found inside the high temperature areas. Assuming thermal conductivity as the most effective form of heat transport, the thermal gradient should continue increasing towards the volcanic zone axis, but due to water circulation in the Quaternary strata which becomes increasingly permeable towards the zone, a trend reverse to that of the regional gradient is found (G. Pálmason 1973).

In view of this high geothermal gradient it is no wonder that a widespread hydrothermal activity exists in Iceland. (Fig 7, 8 and 9).

Thermal waters of Iceland are divided into two groups high thermal waters and low thermal waters. This division fits well the general classification of thermal and thermomineral water. In general the terms mineral spring and thermomineral spring is restricted to springs that contain more than 1000 ppm of total dissolved solids. The main exceptions from the classification are the soda springs and sea water intrusions which both are thermomineral water according to the Icelandic classification. (See table 3).
Thermal water flow seems to be at great depths under most parts of the country. Generally it is streaming outwards from Mid-Iceland mostly independent of small scale topography, (B. Árnasson 1976). Here and there the water rises to the surface because of a fault or a dyke that act as a threshold on the flow causing low temperature springs. In high temperature areas the water seems to get an extra heat, probably from melted intrusions at considerably little depht. (Fig 6).

More than 250 low temperature areas exist in Iceland. Their size is very variable, from one single thermal spring up to tens of them. The run off from these areas is variable too, or from just about nothing to 150 l/sek.

The worlds largest thermal spring Deildartunguhver discharges 120 l/sek of boiling water.
The total natural discharge has been estimated approximately 1500 l/s of 75°C thermal water. The temperature of the water in depths is always less than 150°C and all the water is in the liquid state. In the springs themselves the temperature is seldom over 100°C. Dissolved elements are most often between 200 and 400 ppm. (Table 4).

The low temperature areas are not connected to the volcanic zones as the high temperature ones. They are spread all over the country but in east and southeast Iceland they are rare.

The thermal water of the low temperature areas is discharged in hot springs, boiling ponds and sometimes geysers.

Geysers appear both in high and low temperature areas. The grandfather of them all Geysir in Haukadalur is now inactive, but the neigbouring geysers Strokkur, Smiður and Óþerrishola erupt periodically. Geysers are to be found in a few other places in Iceland.

Geysers are rather shortliving phenomena and variable from time to time. Earthquakes affect them much, they may stimulate active geysers or even form new ones, as well as they may destroy others.

Geysers are extremely rare. Outside Iceland they are best known in Yellowstone USA, New-Zealand and Kamchatka.

The high temperature areas of Iceland are 15-20 (The number depends on the definition). All of them are inside the volcanic zones and most often connected to central volcanoes. Their water is characterised by very high temperature, 150-300° C at shallow depths. The amount of dissolved solids can be between 1.000-40.000 ppm. Somewhere a high fraction of the thermal water is in the form of steam The most common form of springs are fumaroles (steam vents), solfataras (mud springs). Geysers are somewhere to be found.

TABLE 3

THE HIGH TEMPERATURE AREAS OF ICELAND.

NAME	HEIGHT	AREA	NOTES
Reykjanes	20-40 masl	3 km^2	Thermal brine, fumaroles, geysers.
Svartsengi	40-60 --	2 -	Thermal brine, heating service.
Krísuvík-Trölla-dyngja	135-350	25 -	Thermal brine, fumaroles, solfataras, old sulphur mine.
Brennisteinsfjöll	500 --	< 1 -	Old sulphur mine.
Hengill	50-500	75 -	Fumaroles solfataras, soda spr.
Geysir	100-150		Geysers.
Kerlingarfjöll	880-1020 -	13 -	
Hveravellir	600-640	1 -	Geysers.
Torfajökull	600-1050 -	120 -	Fumaroles.
Vonarskarð	100-1100	11	Solfataras.
Grímsvötn	1300-1719	~ 55	Covered by glacier
Sólheimajökull			" " "
Kverkfjöll	1500-1920	30	Fumaroles, solfataras
Askja	1050-1200	25	Solfataras
Hrúthálsar	≃1000	3	
Fremri námar	820-930	3	Old sulphur mine.
Námafjall	340-450	11	Solfataras, fumaroles
Krafla	500-680	25	Solfataras, fumaroles, geothermal power plant
Þeistareykir	280-320	20	Fumaroles, old sulphur mine.

SALINE GROUNDWATER

Saline groundwater is to be found in Iceland, both warm and cold. The salt content rises from two sources. Most often it comes from seawater that can mix directly whith groundwater in some places. This type of water includes all the cold saline groundwater and the majority of the thermal saline water too. It is indicated by the $mgNa^+/mgCl^-$ ratio approximately 0,6.

At high temperatures, water can easily wash out Na^+ and Cl^- from the bedrock. The high temperature areas in most places discharge such a water. Its $mgNa^+/mgCl^-$ ratio varies between 9,3 and 1,9 depending on the temperature and rock type. (B. Árnason 1976).

Somewhere seawater is to be found in silty marine layers of late glacial times.

The biggest seawater intrusion in Iceland is the one in Reykjanes penisula. The penisula is mostly made up of young lavas and palagonite formations. The regional permeability is so high that in spite of considerable percipitation, no surface runoff exists. Seawater is to be found in all the western part of the penisula underneath a lens of fresh groundwater. On the border of the fresh and saline water is a thin mixing zone. Evidence points at deep partially confined thermal water flow westwards the Reykjanes penisula. This water gets more and more mixed with saline water the farther it flows west as is shown by rising saltcontent in the high temperature areas on the penisula. (F. Þórarinsson et. al. 1976, J. Elíasson et. al. 1977).

Saline thermal water is common in boreholes in the lowland of south Iceland. The extent and origin of this water is unknown at present.

Seawater intrusions are to be found in some other places but they have not been studied sufficiently to be mapped.

TABLE 4

Chemical composition of typical waters from the main groups of Icelandic groundwater. Concrentations in ppm.

	1	2	3	4	5	6
Temp. C°	270	84	98	57	2	3,8
pH/C°	6,27/270	8,7/84	8,8/98	6,72/19	6,21/22	7,22/20
SiO_2	592	509	127	219	77	12,8
Na^+	9854	209,0	78,8	451,2	660,0	7,1
K^+	1391	22,4	2,1	34,2	26,8	0,4
Ca^{++}	1531	0,8	4,1	86,8	256,1	4,7
Mg^{++}	1,15	0,03	0,01	20,7	60,5	1,4
CO_2 tot.*	1437	136,6	13,5	1500	4100	12,7
SO_4^{--}	28,7	114,5	62,1	41,2	125,4	3,1
H_2S tot.**	31,5	0,7	0,7	0,1	0,1	0,0
Cl	18827	122,0	56,3	80,0	239,0	12,2
F^-	0,1	11,5	2,1	5,0	0,61	0,1
Total	33653	1133	372	1649	2584	54,5

* $H_2CO_3 + HCO_3^- + CO_3^{--}$ ** $H_2S + HS^- + S^{--}$

1. Reykjanes thermal brine.
2. Geysir high temperature area.
3. Reykjavík (Laugarás) low temperature area.
4. Lýsuhóll thermal soda spring. (Vell no. 6).
5. Ölkelda Snæfellsnes. Soda spring.
6. Lækjarbotnar Mosfellshreppur fresh water springs.

References: 1,2,3 S. Arnórsson 1974
4 and 5 J. Benjamínsson pers. inf.
6 Þ. Þóroddsson pers. inf.

THE TUNDRA

No real tundras occur in Iceland because the highlands of the country are mainly bare lava fields, sand-gravel-deserts and ground-moraine. The soil of vegetative areas is very thin. Considerable areas covered by vegetation occur here and there especially in north of the great glaciers. In these vegetative highland areas palsa and cryokarst forms occur in almost every large moor and swamp region. They are most common at heights of 450-700 m above sea level. The upper limit of palsa areas are the limit of close vegetation. The lower limit is controled by the climate conditions. Palsa and cryokarst are due to long time climachanges. In the warm years of 1930-1960 they declined a lot but after 1965 they have been increasing.

Palsa and cryokarst are the Icelandic form of the tundra.

WATER RESOURCES MANAGEMENT

The power sources of Iceland are to be found in the water. Rivers and streams produce nearly all electric power of the land. Geothermal water heats the majority of the houses.

Generation of electricity amounted in the year of 1977, 2602 GWh. 96.9% by hydropower, 0,6% by geothermal power and 2,5% oilpower. In 1977 were 25 hydroelectric stations in the country. They are supposed to produce 3320 GWh in a year average. 14 of these hydroelectric stations have reservoirs of total capacity 1540 Gl. The 210 MW hydroelectric station at Búrfell has alone 1062 Gl reservoir in the lake Þórisvatn.

Geothermal water has great economical importance for Iceland. 60% of the inhabitants live in houses heated by geothermal heat. The biggest geothermal power station in Iceland is Reykjavík Municipal Heating Service. It is 450 MW, or larger than any hydropower plant in the country. The numerours swimming pools all over the country use nearly all geothermal water. The greenhouse industry, which is of considerable importance, is entirely based on geothermal heat. Two geothermal hydro power plants are in construction and the generation of electricity will increase much in the next years.

The geothermal water is also used as drinking water. Annual water consumption from public water works in Iceland has been estimated 55,6 million tons. 48,4 million tons or 87% is groundwater but 7,2 million tons or 13% is surface water. In addition the geothermal water consumption is approximately 38,9 million tons or about 41% of the total water consumption.

TABLE 5

HYDRO POWER STATIONS AND STORAGE RESERVOIRS

Hydro Power Stations	Generation Capacity in an Average Hydrological Year GWh	Storage Reservoir 1966 Gl	Storage Reservoir 1966 GWh	Storage Reservoir 1977 Gl	Storage Reservoir 1977 GWh
Sigalda[1]	800,0	.	.	150,0	25,0
Búrfell	1.640,0	.	.	1.062,0	298,4
Sogsstöðvar	500,0	166,2	28,1	166,2	28,1
Elliðaár	4,5	2,0	-	2,0	-
Andakíll	32,0	31,7	3,3	31,7	3,3
Rjúkandi	7,3	0,0	-	0,0	-
Mjólká	49,0	0,4	0,2	4,7	4,5
Reiðhjalli	2,8	0,0	-	0,0	-
Fossavatn og Nónhornsvatn	5,0	0,8	-	0,8	-
Sængurfoss	2,0	.	.	0,0	-
Blævadalsá	1,0	.	.	0,0	-
Mýraá	0,3	.	.	0,0	-
Þverá	4,2	9,8	0,9	9,8	0,9
Laxárvatn	3,7	21,2	0,7	21,2	0,7
Gönguskarðsá	8,9	0,0	-	0,0	-
Skeiðsfoss	20,0	28,5	2,5	28,5	4,5
Garðsá	1,1	0,0	-	0,0	-
Laxá	160,0	0,0	-	0,0	-
Lagarfoss	48,8	.	.	50,0	2,0
Fjarðará	1,2	2,0	-	2,0	-
Grímsá	18,0	5,0	0,4	5,0	0,4
Búðará	1,0	0,0	-	0,0	-
Smyrlabjargaá	10,0	.	.	5,5	1,1
Total	3.320,8	267,6	36,1	1.539,4	368,9

1) The generation capacity of Sigalda is the expected capacity of the power plant, 150000 kW at the end of 1978.

WEATHER AND CLIMATE

The hydrology of Iceland depends on the climate no less than geological circumstances. Precipitation and evaporation are the main climatic constituents which influence the hydrology. They decide the water balance. Water balance = precipitation - evaporation. Of much importance is also the snow part of the precipitation and how it melts (in thaw periods now and then in wintertime, or all in one flood in the spring). Frost in the soil affects the ratio of surface runoff vs. groundwater flow e.t.c.

Average runoff pr. km^2 in Iceland is among the highest in Europe, because of high precipitation and little evaporation. The highest average runoff pr. km^2 is on the southern flanks of the glacier Vatnajökull and Mýrdalsjökull i.e. about 140 l/km^2 sek. but much lower in the north or about 25-30 l/km^2 sek. Mean average runoff for the whole country is about 55 l/km^2 sek. Following is a brief comment of the climate of Iceland, with special attention to the parts which are of hydrological significance.

The climate of Iceland is oceanic near the shore but the character is more continental in the central highlands, it is cool but tempered by the Gulf Stream. Although Iceland touches the polar regions, the average January temperatures along the coast resemble those of New York. The annual temperature range is narrow. The summer cool but the winter rather mild. Precipitation is high and a considerable part of it falls as snow. According to the climatic classification of W. Köppen (1846-1940) Iceland is on the boundaries of two climatic regions. On the South and West and inland in the North and East, the mean temperature of the warmest month of the year is above 10°C and mean temperature of the coldest above -3°C. At the northernmost points of the mainland, and in the central highlands the mean temperature does not reach 10°C during the warmest month, which means that the climate is arctic. Snow begins to gather in September and usually reaches its peak in March and April. Exceptions from this are common due to short periods of thaw during the winter. Such periods of thaw while the ground is frosen often cause small floods in spring-fed rivers which otherwise have relativaly stable flow. Spring thaw usually starts in April and reaches climax in May and the beginning of June. At the same time we have maximum peak in the flow of direct run-off rivers. The annual peak of glacial melting is in July and August, when also the glacial rivers are biggest.

The annual mean temperature in Southern Iceland is about 5°C but about 3°C in the Northern part. Usually the coldest month is January, but July is the hottest. Yearly temperature amplitude is averaging at 12°C. Days of frost (that is when temperature falls below zero) are usually around 100 in the South, but in the North 150. Temperature below zero is rare during the period 1.6-15.9. The ground is usually unpermeable due to frost during the period Nov-Apr. (Fig. 10).

This regularity in the average temperature hides far more unstable conditions as regards the types of weather, especially in winter. A characteristic of Icelandic weather is rapid atmospheric circulation and very changeable weather due to the semipermanent low pressure area off Labrador. Conditions of low pressure therefore prevail, through the meeting of warm oceanic air, coming from the south, with tongues of cold polar air. Changes of wind and temperature are quite frequent. This results during the winter in a wide fluctuation in temperature and numerous changes between freezing and thawing conditions.

Iceland lies in the route of depressions, coming from the ocean in the South saturated with moist. The most common direction of wind is the South Eastern, and Southern and these are also the directions of most precipitation. In the Southeast and the Eastfjords, there is high precipitation, nearly everywhere above 1400 mm/y on the lowland, and with two distinct areas of maximum precipitation. One is south of the glacier Vatnajökull the other south of the glacier Mýrdalsjökull with annual measured prec. 2000-3000 mm/year. The maximum areas of precipitation are on the glaciers themselves. On the Southern part of the glacier Vatnajökull and on the glacier Mýrdalsjökull, the annual prec. is estimated above 4000 mm/year. In the South West lowlands up to Vestfirðir in the North the prec. is 1000-1600 m/year in most stations. In the North and North East the prec. is much lower than in the South. In this part of the country, the highlands drain much of the precipitation of the southern winds. The northern wind brings the majority of the precipitation,but because of the lower temperature of the air it contains much less water. In the lowlands the precipitation is therefore only 400-600 mm/year in most places. The highland north of Vatnajökull is the driest part of the country with precipitation below 400 mm/year. This is the effect of the glacier which causes a precipitation-shadow. (Fig. 11).

Usually the precipitation is highest in October but lowest in May.

In South Iceland one can expect 200 days of precipitation but 140 in the north, annually.

How much of the precipitation falls as snow is very variable from one part of the country to another. From November to April the snow often covers the whole country. On the south coast the snow stays seldom for long time because of frequent periodes of thaw.

In wintertime when the ground is frosen and the majority of the precipitation falls as snow, very little water is added to the groundwater storage.

Rain and snow that melts in thaw periodes in wintertime, mainly runs off on the surface. In spring most of the melt water runs off on the surface too.

In the porous areas of the volcanc zones water always drains to the groundwater storage however.

Evaportranspiration in Iceland is highest in June and lowest in January. In summer it reaches somewhere 100 mm/month and in wintertime it is around zero, especially upland.

Annual evapotranspiration is mostly between the values 360-540 mm/year. Maximum point is north of Vatnajökull where the climate is dry and the radiation high. Minimum point is in the western part of the Central highlands.

Great majority of Iceland has positive annnual water balance. Most favorable is the water balance in southeast Iceland where the precipitation is highest.

The climatic characteristics are unfavourable to vegetation. Woods are rare and close to their northern limits. The island is on the boundary south of the 10°C July isotherm, which represents fairly well the northern extent of forests. The vegetation is subartic with extensive grassland, which serves as a pasture for sheep. It is easily subject to overgrazing and thus open to erosion hazards under unfavourable climatic conditions. In fact during 1100 years of habitation almost half of the area originally covered with vegetation has been destroyed.

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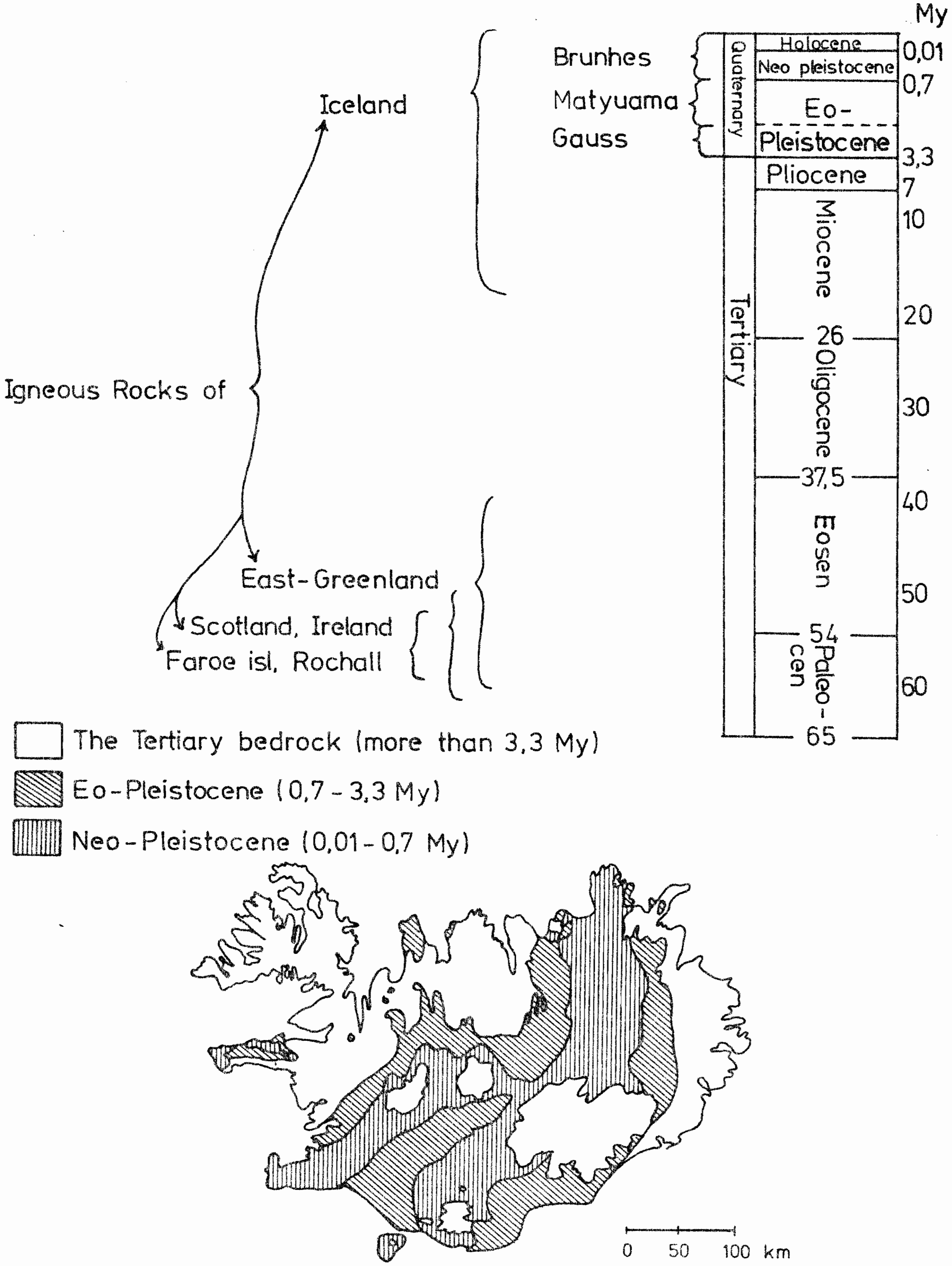

Fig.1 The divition of the Icelandic bedrock and its age related to neighbouring basaltic areas.

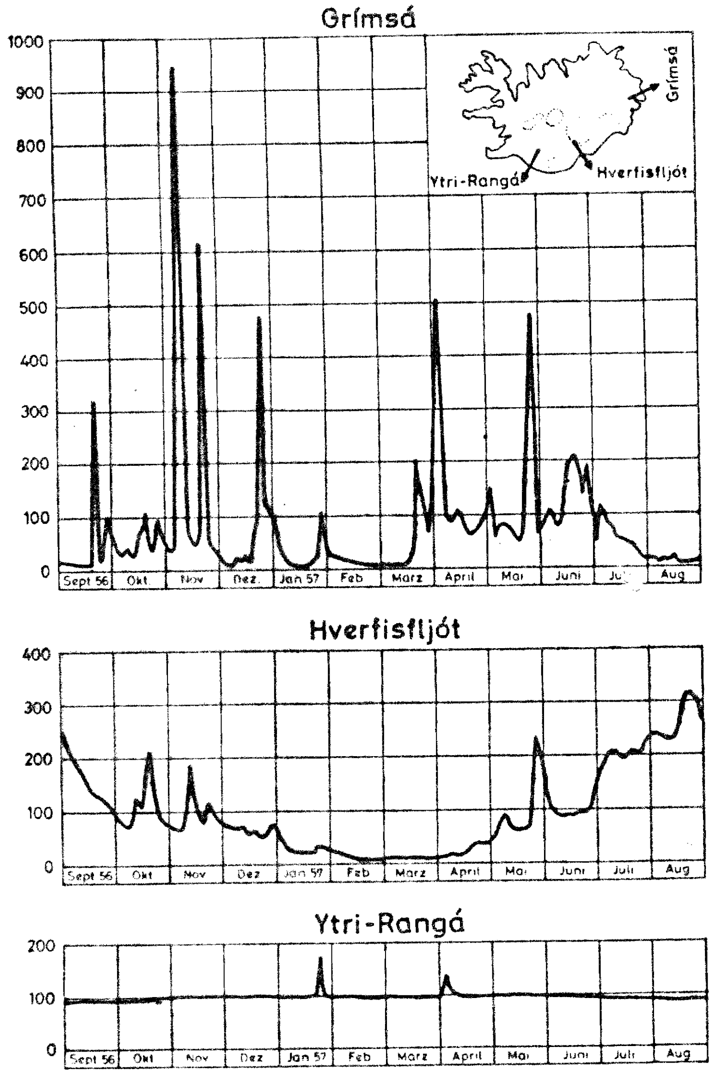

Fig.2 A comparision of the flow of the three types of Icelandic rivers during a year, given in % of the mean flow. (G. Kjartansson 1943).

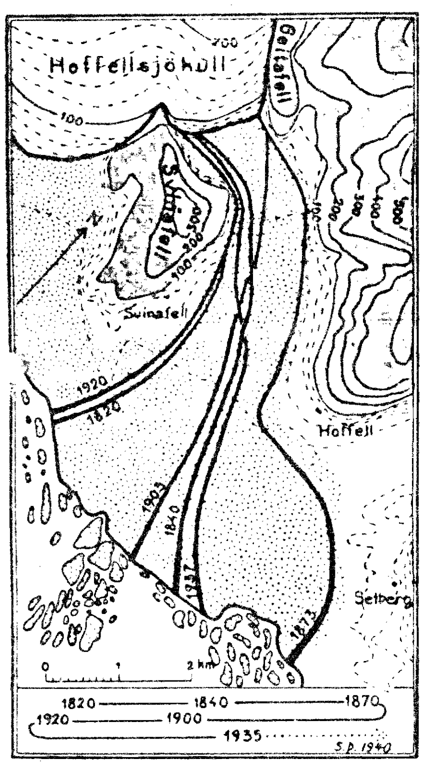

Fig.3 The braided glacier stream Hoffellsá SE-Iceland. The figure shows its fluctuations across its flood plain in the years of 1820-1937. (S. Þósarinsson 1940).

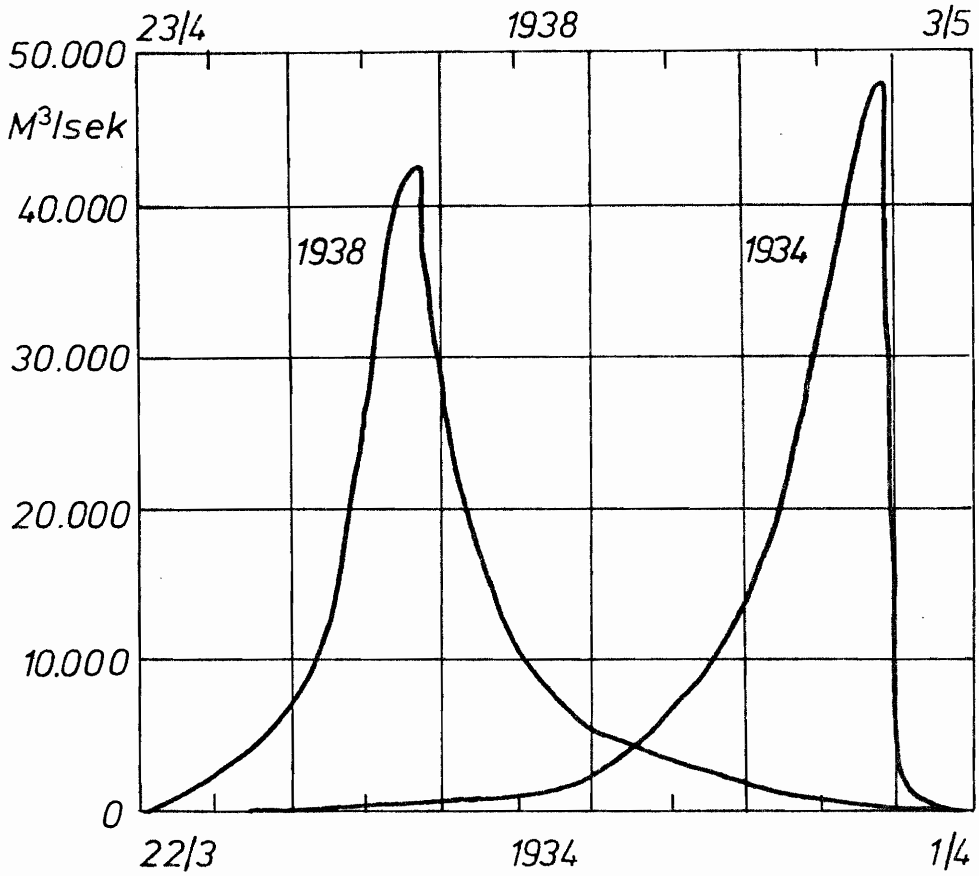

Fig.4 Graphs of the glacier bursts from the Grímsvötn central volcano in Vatnajökull in the years of 1934 and 1938. (S. Þórarinsson 1974).

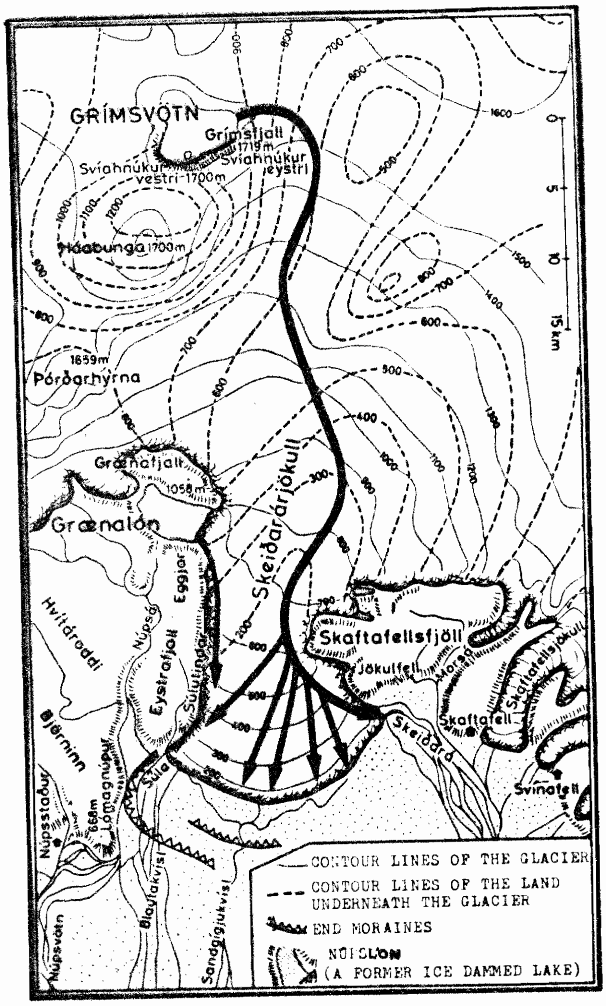

Fig.5 Courses of the glacier bursts from the meltwater chamber of Grímsvötn and the latheral lake of Grænalón. The end moraines of Skeiðarárjökull from the 18th and 19th century and the former latheral lake of Núpslón are shown.

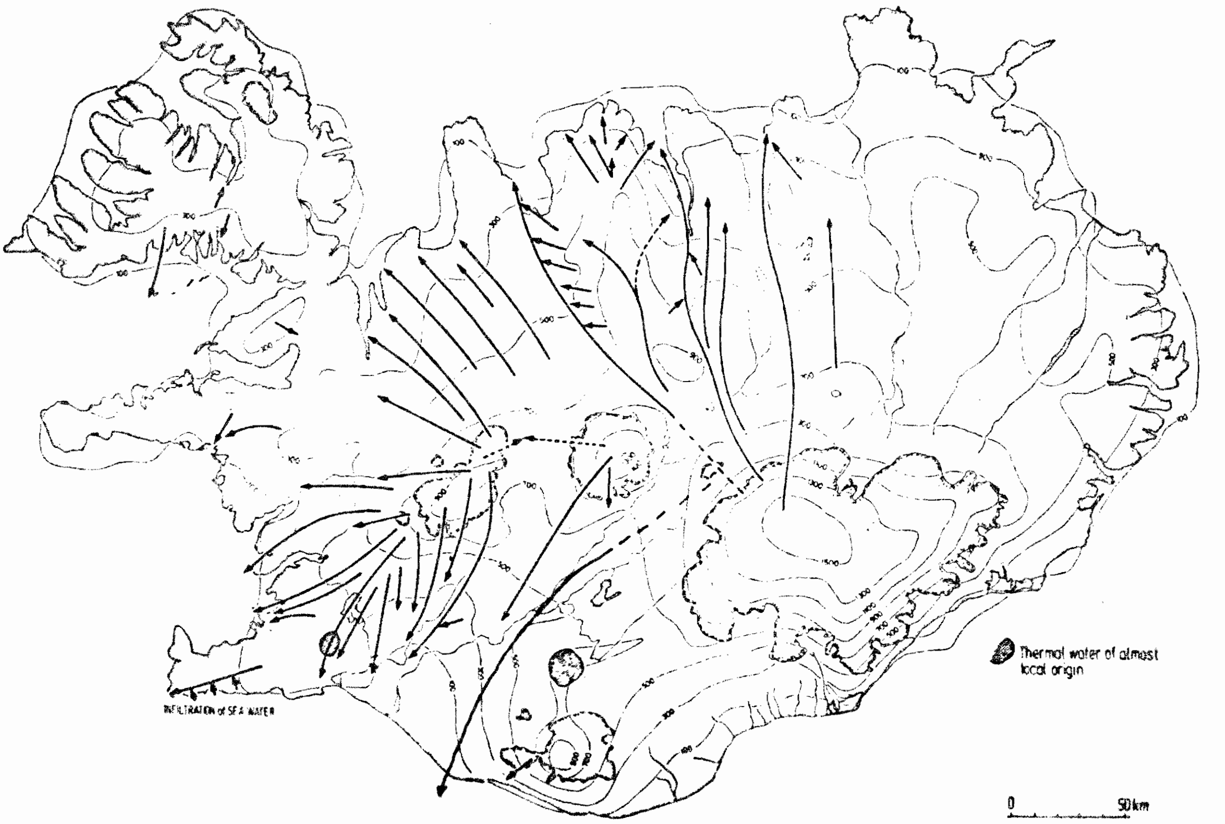

Fig.6 The recharge areas and the general pattern of flow of thermal groundwater systems in Iceland. The flow is shown by arrows joining the respective recharge areas as proposed from deutrium measurements. The isolines shown are average topographic heights in meters. (Based on B. Árnason 1976).

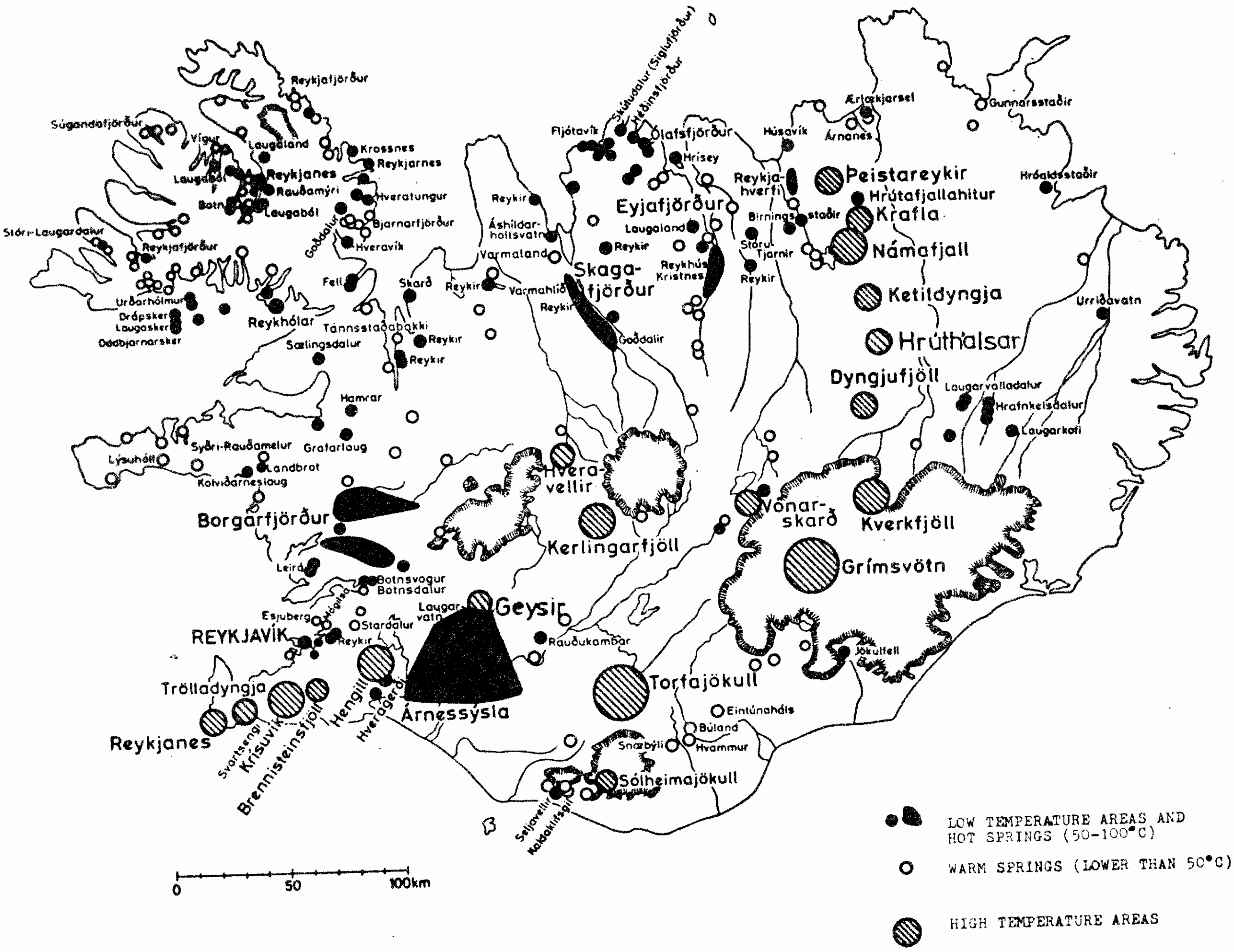

Fig.7 Thermal springs and springareas of Iceland. Figures 8 and 9 give a closer view on the thermal areas of Borgarfjörður and Árnessýsla. (Based on W. Schutzbach 1976).

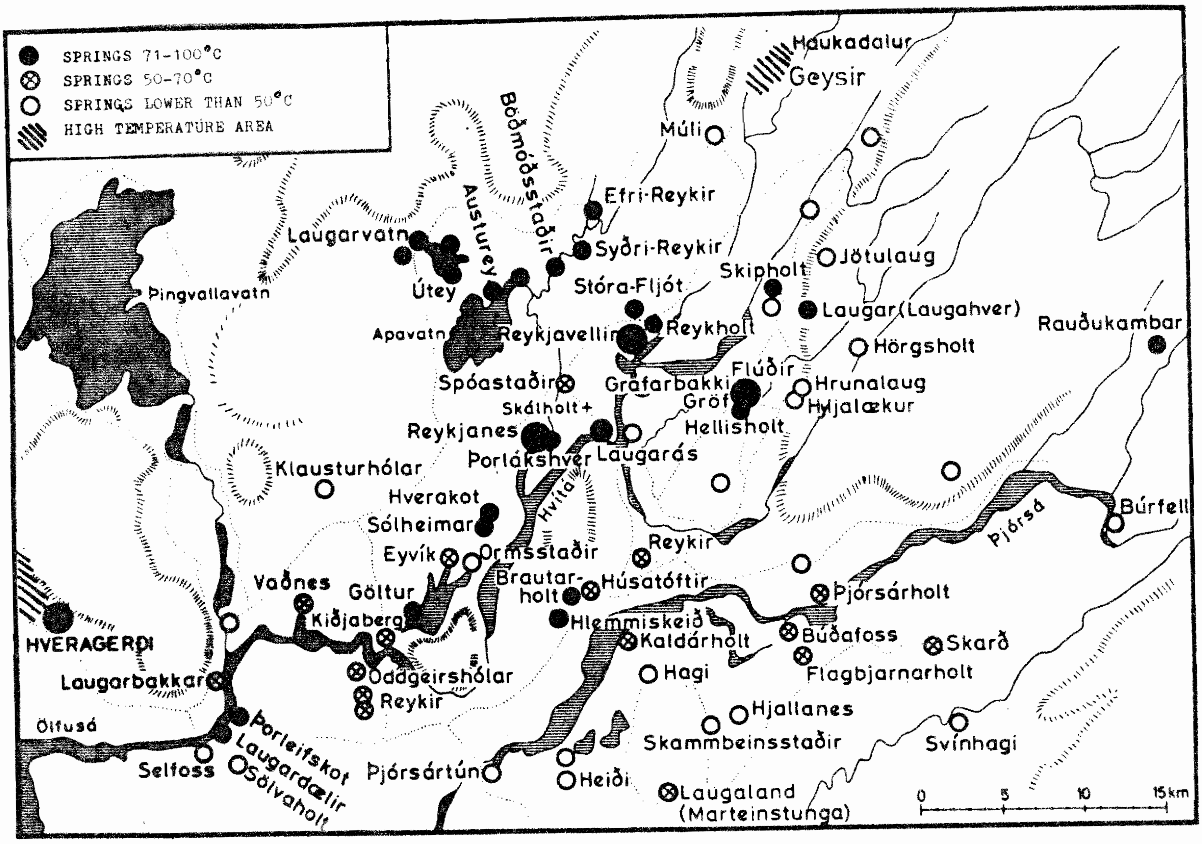

Fig. 8 Thermal springs of Borgarfjörður, (Based on W. Schutzbach 1976).

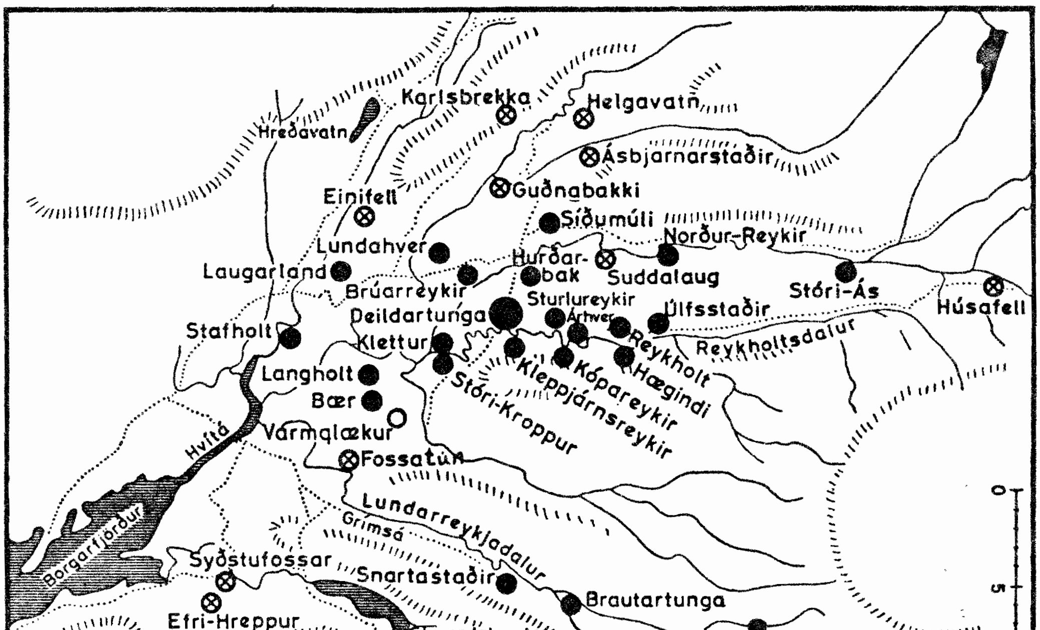

Fig.9 Thermal springs of Árnessýsla. (Based on W. Schutzbach 1976).

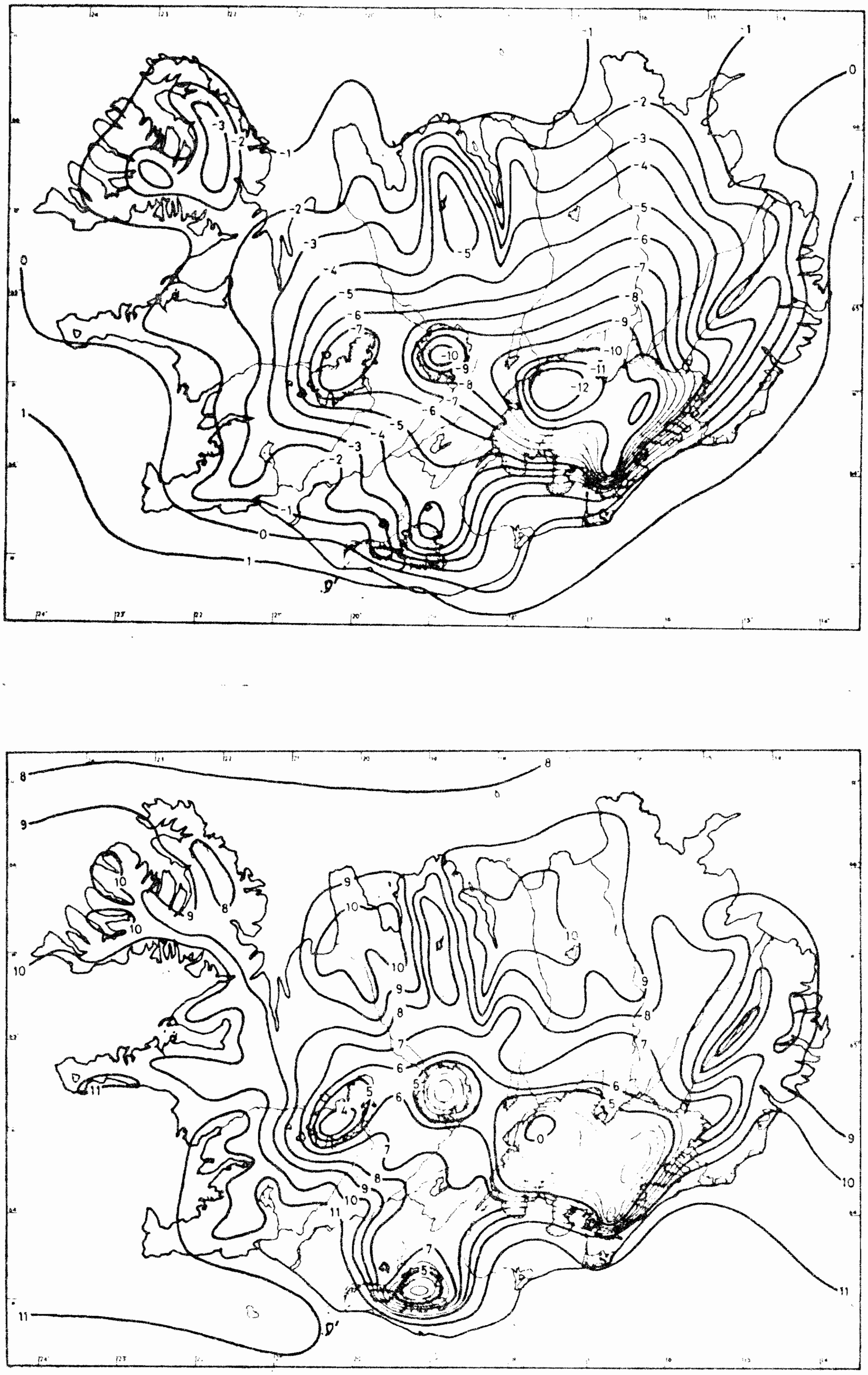

Fig. 10 The mean temperatures in January and July. Averages for 1931 - 1960. (Hlynur Sigtryggsson)

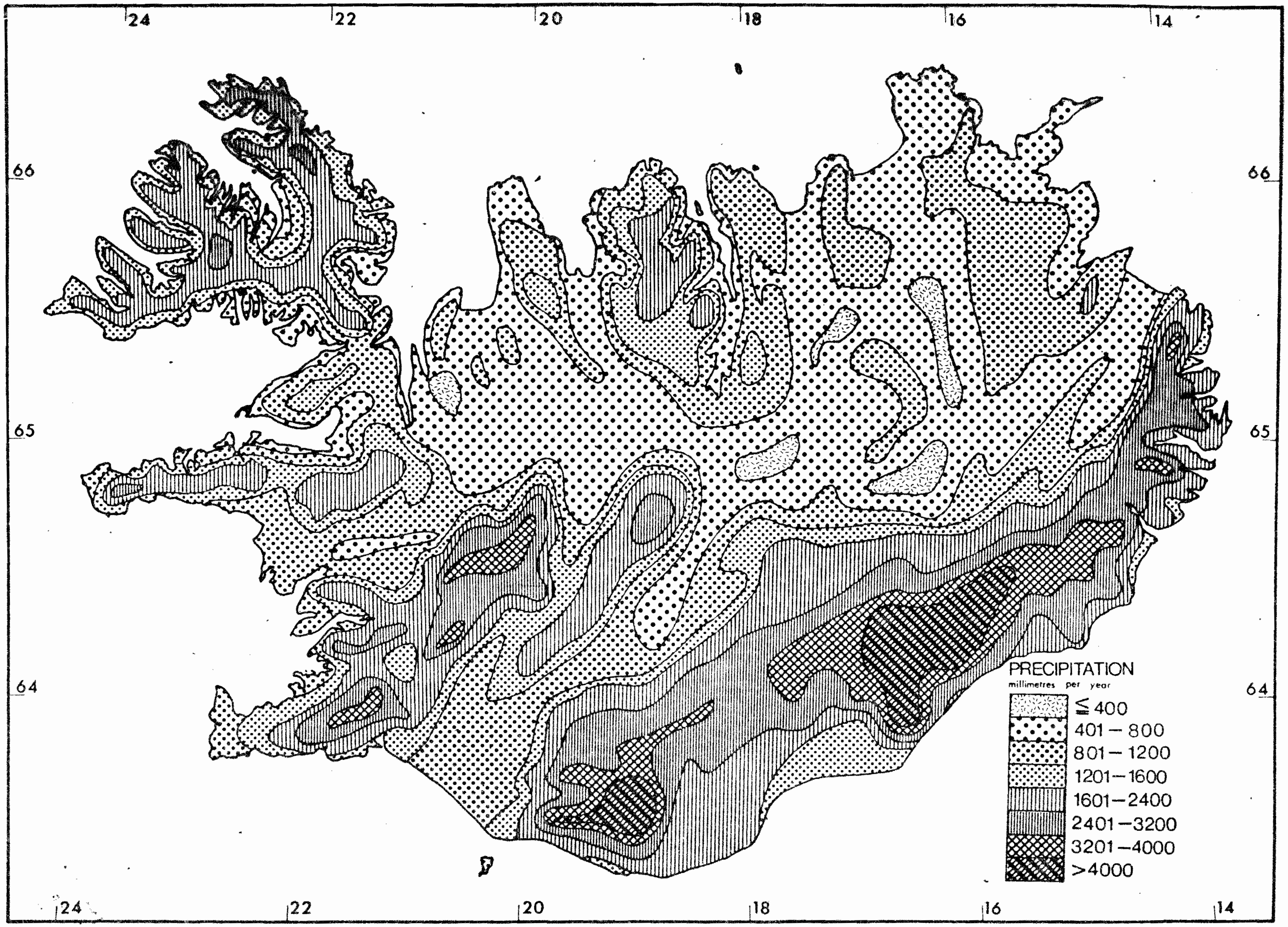

Fig.11 Distribution of presipitation. Averages for 1931 – 196o. (By Adda Bára Sigfúsdóttir).