Ágúst H. Bjarnason

Vegetation on lava fields in the Hekla area, Iceland
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by
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Doctoral dissertation from the Department of Ecological Botany to be publicly defended in the lecture room at the Department of Ecological Botany, Uppsala University, on May 15, 1991, at 10:00 A.M. for the Degree of Doctor of Philosophy

ABSTRACT

The vegetation development on 13 dated historical lava fields around the volcano Mt. Hekla is described. The lava fields have been divided into three main topographical categories, the main surface, holes and crags. The investigation was concentrated on the main surface at 22 sites in the 11 oldest lava fields, the oldest from 1158, the youngest from 1947. At each site the topography, substrate (profile, pH and loss on ignition), flora and the physiognomy and the floristical composition of the vegetation were studied. Local climatic conditions (temperatures) are described for one lava field. The vegetation description included a floristic inventory, quantitative analyses (releves) of the vegetation both of permanent and non-permanent plots, drawings and photographic documentation. The total number of analyses made were: 1566 for the main surface, 81 for the holes and 13 for the crags. At each site the following abiotic factors were recorded: (a) the irregularity of the topography, (b) the age of the lava field, (c) the elevation, (d) the number of deposited tephra falls, (e) the quantity of deposited aeolian material between the tephra layers, (f) the cover of tephra and (g) the surface roughness was judged for every plot. In studies of the colonization of plants in the youngest fields records were also made of: (a) the position within the layer of cinders, (b) the microsurface (texture) of the lava blocks and the age of the lava field when the analyses were carried out.

The analyses made of the main surface were treated with the clustering and relocation program TABORD and with the ordination program Canonical Correspondence Analysis (CCA, CANOCO program). First, local clusters were obtained for each of the lava fields. These primary clusters were then clustered again to obtain a set of second-order clusters. The CANOCO results were used to check whether the second-order clusters were ecologically and floristically homogeneous or needed to be subdivided.

The classification results were compared with vegetation types described earlier. Due to the phytosociologically incomplete floristic composition of many clusters an ad hoc typology was used with three hierarchical levels: communities, variants and facies. Eleven communities, some variants and facies are described and their distribution interpreted in terms of the prevailing environmental conditions. The dynamics of the vegetation in the historical lava fields is summarized as a clear case of primary succession with elements of regeneration after disturbance by tephra fall, accumulation of wind-blown material and grazing. The early development of the moss carpet of Racomitrium lanuginosum, prohibiting the development of further successional phases is considered as a first example of the inhibition model in primary succession.

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1 Introduction

1.1 Aims

The present investigation is aimed at describing the physiognomy, floristical composition and dynamics of the vegetation of historical lava fields around the volcano Mt. Hekla, Iceland. About 10% of the area of Iceland is covered with two types of lava flow, heluhraun and apalhraun, often called pahoehoe and aa respectively, words which are Hawaiian in origin. ‘Historical lava fields’ are the fields resulting from eruptions after the settlement of Iceland. According to Landnámabók (The Book of Settlement) the first settler was said to have arrived in A.D. 874.

The aims can be specified as follows: to study the influence upon vegetation of abiotic factors such as the accumulation of aeolian material, altitude and topography; to elucidate the development and succession of vegetation, especially in regard to *Racomitrium lanuginosum*; to attempt a classification of the plant communities and to illustrate the importance of different ages of the lava fields to the vegetational development.

1.2 Previous ecological investigations on Icelandic lava fields

The flora and vegetation of Icelandic lava fields, mainly prehistoric, attracted much scientific interest at the end of the 19th century and in the beginning of this century, probably for two reasons. Firstly, foreign scientists who began to visit Iceland from 1880 onwards were impressed by the characteristic environment of volcano substrates with which they were quite unacquainted. Secondly, they were surprised by the locally varying mosaic-complex of often lush vegetation of some lava fields, which was unexpected on this otherwise largely eroded island.

The Danish botanist Chr. Grønlund (1884) was the first to mention the vegetation on lava in connection with his investigation of *Racomitrium* heathland. He presented a brief description of the growth (succession) from a nearly bare lava with scattered growth of lichens and mosses to later stages with vascular plants. His countryman C. Ostenfeld (1899, 1905) wrote an introduction to the lava vegetation in the Reykjanes peninsula, but without considering the ages of the lava fields.

The most important contribution to the knowledge of the lava field vegetation was presented by the Icelandic botanist Helgi Jónsson (1867-1925). During many excursions his attention was drawn to the vegetation of different lava fields, leading to a series of important publications (1899, 1901, 1906a and 1906b). The two latter works included a compilation of his previous research on succession (i.e. Krakatindshraun of 1878 in the Hekla area), in which earlier studies (Grønlund 1884 and Ostenfeld 1899, 1905) were elaborated to some extent.

Early this century the lava vegetation was considered to be well documented. In lowland lava fields Jónsson (1906a) distinguished the following stages:

\[\text{Krat} \rightarrow \text{Lynghede} \rightarrow \text{Græsmark} \]

\[\text{Nøgen} \rightarrow \text{Spredte mossor} \rightarrow \text{Grimmiahede} \rightarrow \text{Urtemark} \rightarrow \text{Græsmark}\]

Jónsson mentioned one or more lava fields as examples of each stage; he indicated that certain lava fields had only reached an early stage of plant colonization, whereas others had advanced to later stages. He also recognized that this development depended not only on age but also on abiotic factors, such as height above sea level, climatic conditions and accumulation of aeolian material. In some cases, the succession is quite different, e.g., when the surface becomes sandy, and the field develops into a meagre grassland in the course of time.

Jónsson’s main conclusion was that the plant cover of the lava streams could not be assigned to any single plant-formation, because according to the age and the
progressive development of the vegetation, the lava may carry all possible kinds of plant-formation. Jónsson’s descriptions of the vegetation of the lava fields and their successional relationships have been the basis for all further studies in this area. His conclusions have been confirmed by later studies (e.g., Steindórsson 1964). Hesselbo (1918) made three journeys to Iceland, mainly to collect bryophytes. He also provided detailed descriptions of bryophyte communities, summarized earlier investigations, and gave an account of his own studies which covered various lava fields of Southwest Iceland and the historic lava field from 1728 around the farm Reykahlíð in North Iceland. He recognized that the vegetation of the lava surface is decidedly xerophilous, i.e. the habitats are very dry, but that a more luxuriant vegetation with ferns, flowering plants and continuous carpets of mosses and liverworts occur in the bottoms of broader clefts and in lava vesicles. As a rule, the 

\[
\text{Racomitrium} \sim \text{heath, in which other bryophytes such as Dicranum scoparium, Hylocomium splendens and Ptilidium ciliare occur.}
\]

scattered, covers the greater part of the lava fields. Furthermore, he came to the conclusion that the lava fields in South Iceland resemble each other, and the same essential species constitute most of the vegetation types. He also pointed out the difference in composition between the more xerophylic bryophyte vegetation, both on exposed surfaces and in clefts and crevices in North Iceland, and the more hygrophilous in West and Southwest Iceland.

Gallóe (1920) investigated lichens of Iceland in the course of one summer (1913). He remarked that the lava field usually becomes covered with a carpet of 

\[
\text{Racomitrium}, \text{which can develop into heaths, but that lichens frequently colonize those areas which do not immediately become moss-covered. The lichens may develop on the rock-substrate itself, usually in the sequence: crustaceous} \rightarrow \text{folaceous} \rightarrow \text{fruticose lichens. Probably, the latter are more frequent in places where mosses had first been growing. He also gave a description of a crustaceous-lichen and a folaceous-lichen association. Although he had no frequency data available, Gallóe concluded that folaceous lichens were in the majority.}
\]

Steindórsson (1945, 1957, 1964) has published many important works about the vegetation of the lava fields. In his survey of Icelandic vegetation, Steindórsson (1964) described the vegetation in lava fields, pointing out that one lava field does not include one homogeneous community. His general division is the following: ‘Bruni’ (bare lava), scattered bryophytes and lichens on crags and boulders; ‘Mosáembja’, 

\[
\text{Racomitrium}
\]
carpet covering most of the surface, often with very few vascular plants; ‘Móleni’ (heathland) covering mounds and growing down to shallow depressions, occasionally with 

\[
\text{Betula pubescens}; \text{‘Hraungjótá’}
\]

(cracks and crevices), bloom mats, often with a very lush vegetation.

Jónsdóttir Svane (1964) described the vegetation in 1951 and 1952 of the Pingvallahraun lava fields and their vicinity, suggesting the classification of the 

\[
\text{Racomitrium}
\]

community using Raunkiaer’s method.

Einarssson, E. (1986) concluded that age and height above sea level are the most important factors determining variation in vegetation of some lava fields in Snæfell, Iceland. He considered the helluhráun to be more vegetated, on average, than the apalhraun (no data presented). This chiefly concerns the shallow depressions and sufficiently illuminated fissures, deep enough to shield the plants. Like earlier authors, he pointed out that the vegetation may change drastically within a few meters from deep depressions up to the high crags.

Blážková (1973) studied the vegetation of vesicular lava cavities in Northern Iceland. From this particular habitat, connected with the surface by a single opening, a new fern association Cystopteri-Distichietum capillacei was described.

Venzke (1982) surveyed the development of the habitat and vegetation in lava fields. He distinguished between an organogenic sere and a psammogenic sere. After the initial phase, the organogenic sere differentiates into an oceanic and a continental variant. He concluded that the final phase for both seres is 

\[
\text{Betula}
\]

woodland.

In connection with the investigation on the volcanic island of Surtsey, created during the submarine eruption in 1963, several reports have been published (Surtsey Res, Progr. Rep. I- VI, 1965-1972). Some floristic records may be mentioned here. Only two years after the creation of the island (1965), 

\[
\text{Cakile edentula}
\]

was found and in the next year (1966) 

\[
\text{Leymus arenarius}
\]

was also found. These plants soon died. In 1967 two species of vascular plants were recorded (Honkenya peploides and Mertensia maritima), in addition to two species of bryophytes (Funaria hygrometrica and Bryum argenteum). Probably the bryophytes are being dispersed by man (Einarssson 1968). The number of bryophyte species rapidly grew: 16 species in 1970, 37 in 1971 and in 1972 the number had risen to 72, of which 3 species from 1971 were not rediscovered (Bjarnason, Á.H. & Friðriksson 1972, Friðriksson et al. 1972a, 1972b, Magnússon & Friðriksson 1974).
It was not until 1970, thus after seven years, that the first lichens were recorded on Sursey, despite careful searches in earlier years. These species were *Trametella coarctata*, *Placopsis gelida* and *Stereocaulon vesuvianum*. By 1973 the number of lichens had increased to 12 species, and in addition to those previously mentioned, *Stereocaulon cf. capitellatum*, *Cladonia incana*, *Acarospora*, *Bacidia* sp., *Lepraria capitellatum*, *Lepraria incana*, *Lepraria vesuviana*, *Acarospora*, *Lecania cf. lapidicola* and *Lecanora* sp. were also recorded (Kristinsson 1974).

Apart from the description of the vegetation in the Hekla area by Jónsson (1906a) there are few others. Most scientific publications on Hekla mainly deal with the geology and geography. Flora and vegetation are only mentioned in general terms. The only detailed studies were made by Jóhannsson and Kristinsson in 1967 and 1968 of the lava field from 1947 (unpublished). They have kindly given me permission to use their material (see 7.14.5). The vegetation of the Hekla area has also been mapped (1:40,000) by the Agricultural Research Institute as part of the vegetation map survey of Iceland (see 2.2).

In addition to above-mentioned studies of lava fields, more general vegetation studies have been published in which lava vegetation is touched upon, notably *Racomitrium* heathland (see 7.2).

### 1.3 Comparable investigations elsewhere

About 500 volcanoes have been active in the world during the last 10 thousand years (Einarsson, p. 1985). The volcanoes are found scattered within zones where earthquakes are common as well. Most of the volcanoes are situated in the folded mountain area from the Cenozoic era in the Mediterranean (e.g., in Italy) and in the 'Ring of Fire', which means the chain of volcanoes which girdles the Pacific Ocean (e.g., in Antarctica, in the Andes, Mexico, U.S.A. (i.a. Alaska), Kamchatka, Japan, Philippines and Indonesia). Other volcanoes are related to the East African rift system, which stretches thousands of kilometres from the Red Sea, into Ethiopia and through Africa. Finally, many volcanoes occur on submarine ridges, in the Pacific Ocean (e.g., on Hawaii), Indian Ridge (e.g., Reunion) and on the Atlantic Ocean Ridge (e.g., Bouvet Island, Tristan da Cunha, St. Helena, Azores, Iceland and Jan Mayen).

As may be expected, colonization and vegetation succession from barren volcanic rocks (comprising both tephra and lava) to vegetated areas has often been the focus of ecological interest. Central points of interest in these studies are the invasion and establishment of plants and the speed and direction of vegetation development on the newly arisen bare substrate. Additional questions are: which kinds of species act as pioneers, from how far away do the diaspores originate, how are they carried, and how are nitrogen supplies built up.

The best-known studies are from Krakatau after the mighty eruption of 1883. The first steps of plant succession have been described in the classical study by Treub (1888). Treub considered the hygroscopic-gelatin colonies of slime, produced by Cyanophyceae, as the first step in the colonizing of vegetation on volcanic substrate, providing facilities for an initial colonization by bryophytes and ferns and later by vascular plants. Many other scientists have carried out research on Krakatau, e.g., Ernst (1907), Campell (1909), Docters van Leeuwen (1921) and Backer (1929). Apparently Treub's investigation had a limited scope and his conclusions have been doubted by later scientists, especially by Backer.

The Hawaiian lava flows are another famous object of study. The earliest scientific studies were probably those by Forbes (1912) and MacCaughey (1917). Robyns & Lamb (1939) made an ecological survey of the islands and Skottsberg (1931, 1941) discussed plant succession on the recent lava fields. Skottsberg (1941) found that vascular plants were slower to colonize aa lava compared with the pahoehoe type. On the other hand, lichens were fast colonizers and *Stereocaulon* rapidly changed the colour of the surface of the aa lava. Further contributions by, e.g., Doty & Mueller Dombois (1966), Smathers (1966) and Smathers & Mueller Dombois (1974), focussed on succession on new volcanic rock substrate and invasion and recovery of vegetation after volcanic eruptions. For example, three habitats were distinguished on volcanic rocks: (a) barren lava without vegetation, (b) tephra flats with dead trees and (c) tephra flats with surviving trees. Fosberg (1967) studied differences between the pahoehoe and aa lavas. He found several ferns and herbs in the numerous crevices in the pahoehoe and in sheltered places in the aa lava. On the barren lava, on the other hand, species of *Stereocaulon* and *Cladonia* grew together with *Racomitrium lanuginosum*. Many other authors have dealt with similar qualitative aspects of vegetation problems and arrived at similar results (Eggler 1971, Beard 1945, Skottsberg 1941).

Eggler (1959) discussed the mode of plant invasion of volcanic deposits in connection with his studies of the Paricutin and Jorullo volcanoes in Mexico. He also...
briefly treated the rate of vegetation establishment on volcanic material in different parts of the world. Colonization, primary succession and growth of plants and dynamics of vegetation recovery on volcanic rocks, mainly tephra, on Mount St. Helens, Washington, have been studied, i.e., by del Moral (1983), del Moral & Clampitt (1983), Wood & del Moral (1987) and del Moral & Wood (1988). The successive development of plant communities on different sorts of volcanic rocks was studied by Freiberg (1985) in South Chile.

Both floristical and vegetational studies have been carried out in Japan, especially on the volcano Komagatake after the eruption in 1929 and the volcano Sakurajima, which erupted with large quantities of lava in 1476, 1779, 1914 and 1946 (publications mainly in Japanese, see Tagawa 1964, 1965 and 1966). Especially Tagawa treated many aspects and many of his conclusions are comparable with results obtained from the Hekla area. The pioneer stage of primary succession does not start with an algal community but with lichen-bryophyte communities, with fruticose lichens (not crustaceous) and xerophilous mosses as dominant species. These cryptogams invade the lava field by means of their wind-transported spores and probably also by fragments of gametophytes. Invasion of vascular plants takes place simultaneously with the cryptogams. Soil formation on the lava substrate progresses rapidly through accumulation of volcanic ejecta.

Volcanic activities are few in the Antarctic area. In 1967 cinder cones arose within Telegraph Bay, Deception Island, South Shetland Islands. New eruptions occurred in 1969 and 1970, joining the island to the mainland. In 1968, the new island was investigated as to the establishment of microorganisms and cryptogams. In moist ash at the shore of crater lakes and around a fumarole on the island, a microbial colonization was found (Cameron & Benoit 1970). The dominant mosses in depressions in ashes and scoria were Polytrichaceae species and the hepatics Lophozia excisa and Cephalozia exiliflora. Numerous lichens were prominent as well, e.g., Cladonia spp., Stereocaulon glabrum and Usnea antarctica. After an obliteration in 1970 by a jökulhlaup, several patches of diminutive scattered moss shoots were observed in the area, which appeared completely barren. These included Ceratodon cf. purpureus, Bartramia patens, Drepanoclados uncinatus and small radiating circular colonies of Polytrichum alpinum and P. juniperinum (Smith 1984). The bryophyte flora of the Deception Islands is somewhat similar to the Icelandic one. Out of a total of 35 mosses and four liverworts, eight species are common to the lava fields in the Hekla area (Ceratodon pur-

### 1.4 Terminology and abbreviations

**Aa:** see apalhraun.

**Apalhraun:** A type of fragmented lava flow characterized by a rough, jagged and spinose surface. The word aa, Hawaiian in origin, means apalhraun.

**Clinker:** Lava material which has broken off the main flow and forms larger and smaller blocks (scoria blocks).

**Clinker layer:** The loose clinker lying on top of the massive central part of the lava as well as below it.

**Crag:** Perpendicular outcrop, often jagged.

**Ef 1158:** The Efrahvolfshraun lava field dating from the 1158 eruption.

**Helluhran:** A type of lava field characterized by a smooth, billowy, orropy surface. The word pahoehoe, Hawaiian in origin, means helluhran.

**Historical lava field:** A recent lava flow resulting from an eruption after the settlement of Iceland A.D. 874.

**Hole:** A depression with steeply sloping walls, or a crevice.

**Hollow:** see hole.

**Hraun:** see lava.

**Isopach:** Line on map joining places which have the same mean tephra thickness.

**Kr 1878:** The Krakatindshraun (Nyjahrn) lava field dating from the 1878 eruption, non-Hekla lava.

**Lava:** The term lava is used 'to signify all molten material flowing from the crater' (Thorarinsson 1954). In Icelandic: hraun.

**La 1913:** The Lambafitjarhraun lava field dating from the 1913 eruption, non-Hekla lava.

**Lf 1693:** Hekla lava from the 1693 eruption.

**Lf 1766:** Hekla lava from the 1766 eruption.

**Lf 1947:** Hekla lava from the 1947 eruption.

**Lf 1970:** Lava fields from the 1970 eruption, Hekla lava.

**Main surface:** The more or less flat parts of the lava field, ranging from shallow depressions to small hillocks with more or less continuous plant cover, usually including a moss carpet.

**Mosaembaliya:** A main surface in a lava field characterized by a more or less thick moss carpet or bolsters of Racemion lanuginosum (pemba, inflation).
Na 1845: The Næfurholtsbraun lava field dating from the 1845 eruption, Hekla lava.
No 1389: The Norðurhraun lava field dating from the 1389 eruption, Hekla lava.
Pá 1554: The Pálstevinshraun lava field dating from the 1554 eruption, non-Hekla lava.
Pahoehoe: see heluhraun.
Primary tephra: Tephra in a lava field formed during the contemporary eruption.
Scoria block: see clinker.
'Selsund pumice': A prehistoric rhyolitic tephra layer from one Hekla eruption.
Su 1300: The Suðurhraun lava field dating from the 1300 eruption, Hekla lava.
Tephra: The term tephra (Greek: tephra ‘ashes’; Indo-European dheg-h-‘burn’), a shorter word for pyroclastic material, comprising all ‘the clastic volcanic material which during an eruption is transported from the crater through the air’ (Thorarinsson 1954), including a wide range of fragments of different size.
Tephra patch: Used for a depression with more or less thick and permanent tephra accumulation.
Tr 1725: The Trippafjallahraun lava field dating from the 1725 eruption, non-Hekla lava.
2 General description

2.1 Physiographical background

Iceland is located on the North Atlantic Ridge, between 64° 24' and 66° 32' N and 13° 30' and 24° 32' W. The island is built up of volcanic strata. It is mountainous and 75% of the land area rises above 200 m. The major part of these highlands consists of a 500 to 700 m high plateau, with many mountains. The highest is Öræfajökull, 2,119 m. About 11% of the land area is covered by ice caps and glaciers and 10% by Holocene lavas.

The Icelandic climate is cool-temperate and oceanic and the weather is rather shifting. The most peculiar features of the weather conditions are sudden, alternating invasions of polar air from the north and warm or transitional air masses from the Atlantic. Many of the vigorous North Atlantic cyclones originate or regenerate in the Newfoundland region, move northeastward, and reach their maximum intensity in the vicinity of Iceland. A depression that becomes stationary or slow-moving off the southwestern coast of Iceland may maintain a relatively warm or semi-warm flow of Atlantic air over the country for a considerable time period. This causes thaws in winter, and rainy and rather cool weather in summer in the southern part of Iceland. In other cases the depressions may cross the country and slow down or almost stop over the sea between its eastern coast and Norway. This situation, frequently combined with a high pressure over Greenland, causes a persistent flow of polar air over Iceland and a spell of cold weather, especially in the north. The central highlands, with mountains and glaciers, form an effective weather barrier between the various districts of Iceland, i.e. by creating fohn effects. Therefore the northern and southern coasts, or the eastern and western ones, will rarely have quite the same kind of weather simultaneously.

According to Köppen’s climatological classification, Iceland is intermediate between Cfc and ET (Einarsson, M.Á. 1976). In the south and west, and also in the interior of north and east Iceland, the average temperature for the warmest month of the year is higher than +10 °C, and the average temperature for the coldest month higher than – 3 °C. The climate is classified as temperate and humid (oceanic). On the peninsula in the north, and also in the highland, the temperature does not reach +10 °C in the warmest month and the climate is classified as arctic. The mean temperature for July in the lowland of southwest Iceland is just above +10 °C and the annual precipitation is 800 - 1,200 mm (Einarsson, M.Á. 1976).

The Icelandic soils are basaltic in origin. Basaltic rocks cover only 1-2% of dry land on earth and do not occur elsewhere at such high latitudes. Hence, Icelandic soils have properties different to those of neighbouring countries (Helgason 1990). The soils are aeolian sediments derived from volcanic tephra. These soils cannot be classified as ‘loess’ in the strict sense of the word, because certain properties are lacking (Emilsson 1931). Only a minor part of the windblown material originates from glaciofluvial deposits or can be classified as products of physical weathering of the bedrock, therefore, the term ‘volcanic loess’ has been proposed for this type of loessial soil and other aeolian sediments of volcanic origin (Sigbjarnarson 1969).

The main component of the soils is redeposited tephra from the extensive unvegetated sand areas or tephra flats of the interior of the highland. The soil thickness varies greatly in different parts of the country, depending on how fast the aeolian material accumulates. On average, the thickness ranges from 55 cm in West Iceland to 150 cm in South Iceland (Jóhannesson 1960).

The vegetation of Iceland is largely semi-natural, resulting from human use for over a millennium (Bjarnason, Á.H. 1979). Reliable historical and scientific evidence supports the view that most of Iceland was covered by birch trees or shrubs (Betulapubescens) at the time of settlement in AD 874. “At that time (i.e. of the settlement) Iceland was covered by woods from the sea shores to the mountain-sides”, was written by Ari Fróði (the Learned) between 1122 to 1133 in the ‘Íslendingabók’ (The Book of Icelanders), the oldest and most reliable of the Icelandic chronicles. Many other documents, such as the Sagas, written in the 12th and 13th centuries, Church registers and Farm registers from the beginning of the 18th century, in addition to

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Fig 1. Aerial view of Mt. Hekla seen from the east (towards the west). Mt. Hekla is always easily noticeable as it is fairly isolated in the landscape. By virtue of its location, the mountain can be seen from almost every hill in the district. Its shape looks different from different angles. From the northwest and southeast sides, Mt. Hekla looks like an upturned boat as it is a volcanic ridge; but from the direction of the volcanic fissure (northeast-southwest) it looks like a typical stratovolcano, similar to Popocatepetl in Mexico and Fuji in Japan. - Photo: O. Sigurðsson, 1977.

place names (Hallgrímsson 1970), all provide evidence of extended woodlands in earlier times. Pollen analyses and macrofossils also indicate the occurrence of birch woodland before the settlement (Einarsson, P. 1957). The present potential timber line probably lies below the 7.5 °C isotherm which is mainly between 300 and 400 m a.s.l. and, excluding wetlands and sandy beaches, covers about 27% of the land area. Nowadays Betula pubescens covers only 1% of the land area (Sigurðsson 1977).

The causes of this progressing devastation, which is witnessed all over Iceland have been discussed many times. Many observers blamed it on climatic deterioration, volcanic eruptions, avalanches, landslides or glacial bursts. For example, it is noticeable that the biggest remnants of woodland in South Iceland are located close to the most active volcanoes. Nowadays it is an established opinion that the primary causes of devastation of the vegetated areas in Iceland, are the agricultural practices and other human interference (e.g. Bjarnason, H. 1942, 1947, 1974, Thorarinsson 1961).

2.2 The Hekla area

The biggest lowland plateau in Iceland is situated in the middle of the South Iceland region. It stretches from Eyjafjöll in the east to Reykjanesfjallgarður in the west. The southern coast consists mostly of sandy beaches. In the western part, the elevation gently increases inland and the border between the lowland and highland is hard to define. In the eastern part mountainranges mark the border between the rural region and the highland.

The most impressive mountain in this mountain-range is the ridge-shaped Mt. Hekla (63° 58’N and 19° 39’W; 1,491 m). It is located in the rural district Rangárvallahreppur (often named Rangárvellir) between the rivers Eystri- and Ytri-Rangá, in the county of Rangárvallasýsla (Fig. 1). For a long time the mountain was also called Heklufell or Heklufjall.

The location of the Hekla area in the southern part of the highland, about 50 km from the southern coast, is seen on the map (Fig. 2). A map of Mt. Hekla and its vicinity (Fig. 3), showing recent lava flows, has been constructed from two maps by Thorarinsson (1967, 1970). For more details of topography and geology, see the maps The General Map of Iceland, sheet 6, South-Central Iceland (1:250,000, 1984) and Geological Map of Iceland, sheet 6, South-Central Iceland (1:250,000) compiled by Kjartansson (1962). The borders of each lava field are, however, very diffuse on these maps and only the year and name of a few fields are given.

Chromicles and other historical evidence show that Rangárvellir has been inhabited since the time of settlement. The farms stood apart and were rather isolated, each within the borders of their large homelands, but never in clusters or villages. Four inhabited farms are now situated in the neighbourhood of the lava fields around Mt. Hekla: Æfurholt, Hólar (from 1943), Haukadalur and Selsund; the farm Kot was abandoned in 1981. Compared with other farms in Iceland, they
are relatively small. The vegetation outside the historical lava fields is largely influenced by grazing and trampling of sheep and horses, and only remnants of former vegetation can be found (Fig. 4). A few districts have been damaged by wind-blown sand and erosion, such as Rangárvellir. About 2/3 of the local farms have been abandoned in the course of time (Gúmundsson 1952). The prehistoric lava fields of different sizes and sand- or tephra-flats in the surroundings are sparsely vegetated in the north and east. In the south and west there are remains of vegetation and soil on otherwise barren and denuded land. These remnants are usually restricted to ‘rofábarð’, the high earth banks formed by erosion of the volcanic loessial soil. The main vegetation types occurring on these banks are *Racomitrium* heaths, grassland or dwarf shrub communities. On the northwestern slopes of the hills, east of the river Ytri-Rangá, ‘rofábarðs’ are covered by isolated patches of *Betula pubescens*.

The only land use of the historical lava fields today is a limited amount of grazing. The livestock is mostly sheep, as it has been since the settlement. During the last 20 years the number of winter-feeding sheep (ewes) has been about 1,200 on these farms, and including new-born lambs the summer population is more than 3,000. Some sheep are used for grazing in the highland far away but about 1,700 sheep stay in the area around Mt. Hekla. Of these 1,700 not more than 50% are found to be grazing in the historical lava fields, mainly in the three oldest: Efrahvolfshraun of 1158, Suðurhraun of 1300 and Norðurhraun of 1389 (Fig. 5). Small-scale cattle and horse grazing is restricted to areas outside the historical lava fields. Compared with other localities, the historical lava fields, especially those younger than 100 years, are most likely the areas least influenced by man, when considered as a whole. Direct human influences are small and restricted both in time and place. The sheets of the three vegetation maps (1:40,000) covering the Hekla area are numbers 194 (Búrfell, 1968), 195 (Hekla, 1982) and 214 (Lóðmundur, 1968). The edges of the lava fields are not drawn, except for a small part of the lava from 1980/81. It is impossible to distinguish between, for example, Næfurholtshraun of 1845, Efrahvolfshraun of 1158 and the lava field of 1947 where these three fields merge. The classification of vegetation on these maps is based on Steindórsson’s ‘A list of Icelandic plant associations’ (1951, 1974). Furthermore, information in a 3-point scale is provided on the part of the surface which is without vegetation. X: less than 1/3 of the surface without vegetation. Z: 1/3-2/3 of the surface without vegetation. P: more than 1/3 of the surface without vegetation. Almost all lava field vegetation on these vegetational maps is classified as ‘*Racomitrium* heath’ (A1), partly as ‘*Racomitrium* heath with dwarf shrubs’ (A4), partly as ‘*Racomitrium* heath with *Kobresia myosuroides* and dwarf shrubs’ (A7) and, finally, those

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Fig. 2. Location of Mt. Hekla in relation to the volcanically active zones. - From Jakobsson 1979 (revised).
Fig. 3. Map of Mt. Hekla and its vicinity before the 1980 eruption. The map shows recent lava flows of basaltic andesites (historical Hekla lava) and basalts (historical non-Hekla lava). From Thorarinsson (1967, 1970).
Fig. 4. The shape of the *Betula pubescens* trees is highly influenced by grazing.

without vegetation (-) are included. The small areas covered by *Betula pubescens* are classified either as ‘*B. pubescens* with graminaceous plants’ (C4) or ‘*B. pubescens* with dwarf shrubs’ (C5). References to the legend on the maps covering all sites, where subsequent investigations were carried out, are given in Table 3 (see 3.2).

At the time of settlement the Hekla area was covered with birch, but the vegetation has gradually been reduced to such an extent that only scattered remnants are left today. Written sources from 1397 mention a birch forest around the farm Næfurholt (næfur, birch-bark; holt, forest). According to the ‘Járðabók’ (Farm Register) of Magnússon & Vidalin of 1709 there were charcoal and firewood woodlands on the farms of Næfurholt, Haukadalur and Selsund. Most of these woodlands were found on the hills outside the lavas, except in the lava field of 1158, Efrahvolfshraun. When the farm tenants in Rangárvallasýsla were called to give information on their holdings to the authors of the Farm Register, 17 farms had the right of use from the woodland of Næfurholt, mostly yielding charcoal and firewood. Some of the farmers pointed out, however, that volcanic activity of Mt. Hekla was destroying the woodland at an alarming rate. Others admitted that the woodland was deteriorating because of ‘treatment and utilization’ by the farmers (Magnússon & Vidalin 1913).

Regarding wildlife, foxes and mice occur throughout the area. The most common birds are Snow Bunting (*Plectrophenax nivalis*), Meadow Pipit (*Anthus pratensis*), Golden Plover (*Pluvialis apricaria*), Arctic Skua (*Stercorarius parasiticus*), Pigeon Hawk (*Falco columbarius*) and Ptarmigan (*Lagopus mutus*). Dropings from mice and ptarmigan have often been found in the older lava fields. The influence of wild animals on vegetation is small and decreases rapidly with decreasing age of the lava fields.

Climatological data relevant to the Hekla area are poor and sporadic. They are available from two official meteorological stations: Leirubakki (110 m a.s.l.), for precipitation measurements only, located 15 km west of Mt. Hekla and from Búrfell (250 m a.s.l.) located 12 km northwest of Mt. Hekla. To outline the general climate the yearly fluctuations of temperature and precipitation at Búrfell are given by a climograph (Fig. 6) for the period 1971-1980.

The average precipitation in South Iceland shows...
great variations depending on the local presence of valleys and mountains, with figures between 1,600 and 2,800 for the Hekla area (Jónsson, T. 1986). Such figures are expected for the southwest to southeast slopes of Mt. Hekla and increase with elevation. On the other hand, the precipitation in the region northeast of Mt. Hekla may be closer to the lowest figure, because of the shadow effect of the mountains around.

The average annual precipitation in the period 1971-1980 at Búrfell was 955.6 mm; varying from min. 41.0 mm in May, to max. 104.9 mm in October, which is the main feature of the distribution of the precipitation. Most of the precipitation coincides with southern to southeastern winds.

The average annual precipitation in the period 1971-1976 at Leirubakki was 1,075.8 mm; varying from min. 990 mm in 1976 to max. 1,157 mm in 1973. In the period 1977 - 1980, on the other hand, the average annual precipitation was 774; varying from min. 662 mm in 1977 to max. 992 mm in 1978.

No reliable observations are available for snow cover, but this is probably most variable within the region. According to some farmers, it may be expected that the first snow comes before the middle of October and that the last snowfall often takes place in the first week of May. The ground may be snow covered from early November until early April. There are, however, many exceptions and the circumstances naturally become quite different with increasing elevation. The first sign of green in pastureland may appear from the middle of March, as in 1974, to late May, as in 1979 (Veóráttan 1974, 1979).

The geology of the Hekla area is well documented. Kjartansson (1946) presented an extensive description of the topography and geological history of the Hekla area, including a geological map (1:100,000), which was the first attempt to distinguish most of the lava fields. The volcanism, especially during historical times, has been treated by several authors (e.g., Thorarinnsson 1954, 1967, 1968, Kjartansson 1946, 1957, Einarsson, T. 1949, Jakobsson 1979, Grønvold et al. 1983, Sigvaldason 1974).

The upper part of the rural district Rangárvellið consists of nearly continuous Holocene lava fields. Most of these lavas originate from Mt. Hekla, but some from fissures in the vicinity. In the eastern part, however, there are lavas from Vatnafjöll, a mountain-range south and east of Mt. Hekla. The border between the lavas from Mt. Hekla and from the mountain Vatnafjöll lies straight across the district, about 25 km from the coast. Hyaloclastite mountains and hyaloclastite ridges occur beneath the recent lavas. These hyaloclastic formations appear to the southwest and northeast of Hekla and on both flanks of the volcano itself (Kjartansson 1962). The hyaloclastite ridges, originating from subglacial eruptions, probably during Weichselian or former glacial periods, run in the same direction as most other fissures in the area. There is nearly no surface water on the lava fields. All precipitation percolates readily through the lava, although in some places small springs appear at lava fronts and edges. Southwest of the lava fields the land is quite flat and sandy except for an approximately 10 km broad zone near to the coast, where there are widespread wetlands.

2.3 The Hekla system

Recent volcanism and Holocene lava fields (last 10,000 years) are almost exclusively confined to volcanic zones with an area of approximately 25,000 km², divided into 29 volcanic systems. The term 'volcanic system' generally includes both a volcanic fissure
swarm and a central volcano, but some systems have no
developed centre (Jakobsson 1979). Eruptions have
occurred every five years on average during historical
times. Thus, 200-250 eruptions have occurred during
the past 11,000 years. The activity is confined to about 50
eruption sites, in ca. 15 of the 29 systems.

Two active volcanic zones extend through the cen­
tral part of South Iceland, from southwest to northeast.
They are divided into two separate zones by a Plio­

tic or ophitic diorite, which has a C14 age of 6,150 years (Thora­

2.3.2 Chemical composition of the eruptives

The historical eruptions in the Hekla system can be
distinguished as follows: (a) Hekla eruptions proper,
sp oradic eruptive activity (Heklugjá) and a crater row', producing both tephra and lava. It is,
morphologically speaking, a linear volcano, develop­
ing into a stratovolcano. Mt. Hekla is one of the very
few exceptions to the rule that volcanic fissures erupt
only once (Thorarinsson 1967).

2.3.1 Volcanic activity of the Hekla system

The Hekla system has shown postglacial volcanic
activity since the outburst of the acid, rhyolitic tephra
layer H5, which has a C14 age of 6,150 years (Thorarinson 1971). This eruption has been considered to
mark the beginning of the volcanic history of Mt. Hekla
as we know it. Other known prehistoric eruptions
include the vigorous outbursts of tephra 4,000 years
ago (tephra layer H4) and 2,900 years ago (H3). The
distribution and age of the tephra layer H2 is more or
less unknown but H1 dates from the first historical
### Table 1. Chemical analyses of lava and tephra (parts of Tables X and XI in Thorarinsson 1967). Lava: 1. Efrahvolfshraun lava field from 1158 (Hekla eruption) and 2. Lambafiþjarhraun lava field from 1913 (non-Hekla eruption); tephra produced by Hekla: 3. from the eruption of ca. 1104 (silicic tephra) and 4. from the eruption of 1693 (basaltic andesite).

<table>
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<td>1.64</td>
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<td>0.12</td>
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### Table 2. All known eruptions in the Hekla area. (from Table III in Thorarinsson 1970 and Table 3 in Grønvold et al. 1983).

<table>
<thead>
<tr>
<th>Yrs.</th>
<th>Volume of lava 10⁶ m³</th>
<th>Volume of tephra 10⁶ m³</th>
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<td>ca. 1104</td>
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</tr>
<tr>
<td>1158</td>
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<tr>
<td>1300</td>
<td>&gt;500</td>
<td>500</td>
</tr>
<tr>
<td>1341</td>
<td>not known</td>
<td>(80)</td>
</tr>
<tr>
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<td>&gt;200</td>
<td>(80)</td>
</tr>
<tr>
<td>1510</td>
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<td>70</td>
</tr>
<tr>
<td>1980/81</td>
<td>123</td>
<td>58</td>
</tr>
</tbody>
</table>

Table 2. All known eruptions in the Hekla area. (from Table III in Thorarinsson 1970 and Table 3 in Grønvold et al. 1983).

The majorit y of the 20th century eruptions have been either tephra- or lava-eruptions. Mixed eruptives have also occurred in one and the same eruption. Basaltic and andesitic eruptions, as in the Hekla system, typically produce freely flowing lava flows and the forceful degassing in the vent produces tephra (pyroclastic material; tephra and lava, see 1.4).

The volcanism of the Hekla system has at times been very vigorous and often had catastrophic consequences for the economic situation of the inhabitants, not only for adjacent farms but also for a large part of the population. The tephra falls have caused more damage than the lava flows, because they produce a variety of secondary effects. Some are only detectable in the immediate proximity of the volcano, others are perceptible more or less in the whole country. Many farms had to be abandoned, and even some districts became almost desolate. Chemical effects of tephra are based on the relatively high fluorine content. Fine-grained tephra contains more fluorine than coarse-grained, because it is absorbed as calcium fluoro-silicate on the glossy surface of the grains (Öskarsson 1980). Fine-grained tephra is transported further away than coarse-grained tephra and adheres more easily to the plants. Consequently, fluorosis in grazing animals often becomes more serious in districts far away from the volcano than close to it.

### 2.4 Volcanic rocks

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2.4.1 Tephra

Mt. Hekla has been the largest producer of tephra in Iceland during historical times. In most of Hekla’s eruptions the greatest volume of tephra is released in the initial phase. It has been estimated that the total volume of freshly fallen tephra on land in historical times is almost 5 km$^3$, which, calculated as dense rock, is about 1 km$^3$. Half of this volume was produced during the first eruption in 1104. During the 1947 eruption the volcano ejected tephra at an estimated rate of 75,000 m$^3$/sec. for the first half hour. The total volume of tephra during the first day of the eruption was estimated to 30 million m$^3$.

The Hekla tephra was carried by the wind over most parts of the country. The tephra fall depends on factors such as wind direction, time of the year, coarseness of the tephra and the scenery. Weather conditions influence the bulk of the tephra falls. A jumbled mass of irregular tephra fragments gets stacked up around the vent but the prevailing wind forms a more fine-grained tephra sector on the lee side of the volcano. The thickness of the tephra diminishes gradually with distance, following an exponential curve.

Each tephra eruption has left a more or less demarcated tephra layer in the soil (see 5.2.2). These layers provide the base for tephrochronological studies (Bjarnason, H. & Muus 1934, Bjarnason, H. & Thorarinsson, S. 1940, Thorarinsson 1944, 1967). The construction of an isopach map for the deposits from each individual eruption of Mt. Hekla and in its vicinity has provided a detailed picture of the history of the volcano. Using this method, supported by studies of historical records (annals etc.), Thorarinsson (1967, 1968) dated almost all the historical eruptions in the Hekla area. His tephrochronological work and mapping of the different lava fields have been used as a base for my research.

One type of damage caused by tephra acts upon vegetation. The degree of damage depends on the thickness and coarseness of the tephra, season of the year and the type of vegetation. The physical influence of tephra mainly consists in a differently thick covering which diminishes the assimilation of plants. The influence becomes more destructive if windblown tephra becomes locally accumulated into low drifting ridges. Especially, windblown tephra also has a physical influence on the vegetation when damaging the plant tissues of many species and in that way diminishing the size of their assimilating parts. Also, a few examples of physical influence of tephra from the eruption in 1970 on the vegetation will be discussed later in detail (see Chapter 10).

Some positive effects of tephra falls can be mentioned, although they are not important compared to the destructive ones. A voluminous production of tephra tends to smooth out irregularities on the ground, thus creating a ‘soft’ landscape. The carpet of tephra is a filling between hillocks or ridges and spires in the lava and helps to make the Hekla area more inhabitable. A positive chemical effect may also occur as mineral nutrients enrich the soil to some degree. Farmers said, for example, that the tephra from the eruptions in 1947 and 1970 increased the harvest of their grasslands (see also 10.5).

Fig. 7. Irregularly shaped lumps form the scree-covered front of a typical apalhraun issued in the eruption of 1980. The youngest lava fields are traversed by people only exceptionally and domestic animals keep away from this rough landscape.

2.4.2 Lava

A great amount of extrusive rock (about 8 km$^3$) has flowed down the flanks of Mt. Hekla. The mountain simultaneously gains height in this way. The lavas spread far over the adjacent territory. The melting lava streams cause more local damage than the tephra. Large pastures have been covered by lavas, e.g. Lambafit, and several farms have been covered during historical times.

Depending on the character of the surface, the lava fields are separated into two groups: helluhraun and apalhraun. Helluhraun (Icel. hella, flat rock; hraun, lava), pahoehoe or stratified, ropy lava, is formed by a fast flowing and gas-depleted magma. Its surface is smooth, hummocky, ropy or billowy. These lava fields are easy to traverse.

Apalhraun (Icel. apall, pebble), aa or scoria-lava, is
solidified viscous, rather gas-rich magma. It is a more common type than helluhr aun in Iceland. The morphology of the historical lava fields in the Hekla area is fairly uniform. They are all of the typical apalhraun type (aa), and being relatively young, they show only small signs of erosion and weathering (Fig. 7).

A profile of an apalhraun flow manifests a thick layer of clinker or scoria blocks both in the bottom and on the top, with a massive, jointed central part in the middle (Fig. 8). The thickness of the upper layer of clinkers (scoria blocks), which covers the massive central part, ranges from a few decimeters to several meters but is difficult to estimate exactly.

The surface of the clinker layer, which is composed of individual clinker (scoria blocks), is rough, jagged and spinose, literally made up of scoria blocks heaped up and loose. Each cinder-like boulder, making up the jumbled chaotic surface, is crumbly, highly-irregular in shape and covered with razor-sharp protrusions. The scoria blocks on the surface are like a coal-heap or irregular heap of stones. Between the scorias there are many holes and crevices of various shape. Due to the

multifarious surface, there are hardly any habitats exactly similar to each other. The topography is as irregular as it can be. It is difficult to traverse these lava fields and every step is a balancing act. They are “almost indescribably rough and jagged, cutting stout boots to ribbons within a few days” (Wentworth & MacDonald 1953).

Scoria blocks vary in size, ranging from small pebbles up to big blocks, but frequently 10 - 150 cm in diameter. Many of the jagged boulder-like masses are not loose at all, but are sprouts and crags firmly connected with the continuous ledge beneath (Jaggar 1930).

The surface of a single scoria block varies much, regarding both the macro- and microstructure. As to the general feature the surfaces can be most variable, from glassy to very spongy surfaces (see 4.3). Altogether these scorious blocks form a very irregular microsurface. The texture can be linked to the composition of the magma and many other factors, such as the loss of gas and crystallization. The blocks continue to be modified in shape during movements, resulting in deformation due to collision against each other. The spineose character results partly from the pulling apart of plastic surfaces and partly from granularity caused by crystallization (Wentworth & MacDonald 1953).

There is very little sorting of unequally big blocks, although the smaller blocks tend to fall down between the bigger ones. At least three main types of habitats can be identified: (a) the bottom of the layer of clinker, i.e., the depressions between blocks protected against powerful winds, (b) the middle part, at the intermediately positioned scoria blocks and (c) the top of the layer of clinker, i.e., the uppermost surface of raised lava blocks freely exposed to wind and sun.

Primary tephra, broken pieces of the scoria blocks and drift sand, all of which retain water to some degree, become certainly more prominent in the depressions than on the uppermost blocks. Owing to irregularity and roughness, however, fine loose textured material is also present on the uppermost blocks, at least during the first decades. Thus, rain water does not run off as fast as it falls (cf. Eggler 1959). Nevertheless, physical conditions are somewhat more favourable in the depressions than higher up in the lava fields, although the light is more limited.

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3 Physiography of the thirteen historical lava fields

3.1 Introduction

The following account is a brief summary of the origin, local circumstances and general description, with some remarks on each lava field and of the investigated sites. The information provided is at least to some extent important to the understanding of the description of vegetation given below ( Chapters 5, 7 and 8). It is mainly based on Thorarinsson (1967, 1968, 1970), Kjartansson (1945), some other quoted papers and my own observations. The topographical names are used in accordance with published maps, with some exceptions: The correct names of Suðurhraun and Norðurhraun are Selsundshraun syðra and Selsundshraun nyrðra respectively. The name Rauðubjállar, erroneously entered in books and maps, has been altered to Vondubjállar, according to the inhabitants of the district. The topographical name Austurhraun includes almost all the lava fields southeast of Mt. Hekla, but here it is only restricted to the lava field there of 1766. The name Trippafjallahraun is from Jakobsson (1979). Generally, abbreviations are used for the names of the lava fields as follows: Ef1158 means the lava field Efrahvolfshraun of the eruption which occurred in 1158, Su1300 means Suðurhraun from 1300, etc.; fields without name are here abbreviated Lf followed by the year of formation. The tephra layers which originate from the eruptions of Katla (in the glacier Myrdalsjökull) and Lakagigar, are identified by abbreviations, e.g., 1918(K) and 1783(L).

3.1.1 Efrahvolfshraun 1158

Presumably, no lava was produced during the first eruption of Mt. Hekla in historical times (1104). The second eruption probably occurred in 1158 and is probably responsible for the formation of Efrahvolfshraun (Thorarinsson 1967). Six annals together with other sources mention an eruption at that time. It has been verified that at least one or even two volcanic eruptions took place before the year 1180, according to foreign sources which mention eruptions in Mt. Hekla (cf. Weibull 1931, Einarsson, S. 1964). Ef1158 is doubtless the oldest known historical lava field around Mt. Hekla. Moreover, reliable studies suggest that there is no indication that Ef1158 is older than from the beginning of the 12th century.

Thorarinsson (1967) admitted that the lava field might be younger, perhaps from the year 1206 or 1222 (see also Brynjólfsson 1959). It is also worth mentioning that Ef1158 is given the year 1104 on the map by Thorarinsson (1970), but in the text the eruption is described as having occurred in 1158.

Kjartansson (1946) thought that Ef1158 was most likely formed after the settlement of Iceland, with the lava probably coming from the crater Rauðaldur. Later, that location was found to be apparently erroneous. Brynjólfsson (1959) states that Ef1158 was formed by an eruption in 1222 or earlier.

Thorarinsson (1967) considered the tephra fall to have been relatively small and supplied with a southwest axis of maximum thickness. Only small traces of the layer were found in profiles around Mt. Hekla. The tephra layers from the eruptions in 1104 and 1158 have now recently been dated in soil profiles in Jökuldalur, East-Iceland (Larsen 1982). The tephra layer which was called ‘hr’ by Thorarinsson, presumably from 1170 and created by a crater east of Mt. Hekla, originated in fact from the eruption in 1158.

Ef1158 is about 1.2 km² and is situated 250 - 300 m a.s.l. (Fig. 9). The lava field is characterized by thick accumulation of tephra falls. The soil thickness is up to 0.8 m in the deepest depressions, mainly made up of several tephra layers. The volcanic loess between the tephra layers is mainly fine-sandy. In comparison to other lava fields Ef1158 has a relatively smooth surface with alternating hillocks and depressions. The tephra deposits have left only few holes and crags and make the lava field fairly accessible. The thickest tephra layers are from the eruptions in 1947, 1766, 1721 (K), 1636, 1510, 1389 and 1341. A few layers, e.g. of 1970 and 1845, are very thin. Between the tephra layers of 1510 and 1721 (K), Thorarinsson (soil profile no. 18, 1967) only registered one tephra layer, 1636. Two tephra layers have been recognized by the present author, most likely from 1597 and 1693 (see also...
Fig. 9. Aerial view of Mt. Hekla and some historical lava fields from the west: a. Efrahvolfhraun lava field from the 1158 eruption, b. Norðurhraun lava field from the 1389 eruption (site III), c. Naðfurholtshraun lava field from the 1845 eruption, d. lava field from the 1947 eruption.
- Photo: O. Sigurðsson 1977.

Brynjólfsson 1959).

The name of Ef 1158 can be traced back to the farm Efri-Hvoll, in the district Hvolhreppur, which formerly had the right of use of the woodland there. The thriftiest birch wood of the lava fields is still growing there (see 10.5).

Studies of vegetation were carried out at one site: Ef 1158-I. Near the central part of the lava field, at ca. 250 m a.s.l.

3.1.2 Suðurhraun 1300

The fifth eruption of Mt. Hekla started in July 1300 A.D. It lasted for about one year. It is thought to be the second biggest eruption of Mt. Hekla during historical times. The tephra was carried northward by the wind and caused serious damage in North Iceland. According to Thorarinsson (1967) the lava field Suðurhraun was extruded during this eruption.

Previously, Kjartansson (1946) was of the opinion that the eruption in 1389-1390 was responsible for the formation of the Su 1300 including Pá 1554. Brynjólfsson (1959) was the first to date a tephra layer in a soil profile in Su 1300 from an eruption proved to have occurred in 1341 (cf. a soil profile no. 6, Thorarinsson 1967). Brynjólfsson concluded that Su 1300 is from the year ca. 1300 or perhaps from the year ca. 1200 (and consequently it follows that Ef 1158 was formed in the eruption 1104). Beneath the layer of 1341 there are a few centimeters of thick fine-sandy soil, directly on the lava surface. If compared with Thorarinsson’s profiles from No 1389 (no. 13 Pæla), only 8 km away, the lowest tephra layer there is apparently dated 1440. Thorarinsson suggested that the tephra layer probably originated from a crater in the immediate vicinity of Mt. Hekla in the southeast or south of the mountain.

The question arises why this tephra layer from the eruption in 1440 is not found in Su 1300. It is difficult to date one single tephra layer without a possibility to associate it to other layers. Probably, the formation of raw humus below the tephra layer of 1341 in Su 1300 is too thick to become created during a time period of only 41 years (see 9.2). At least 80 - 100 years are necessary for formation of such a continuous soil layer on a new surface of lava. Consequently, further investigation is needed to establish the age of Su 1300 (consequently also of No 1389). Probably Su 1300 is a lava complex, extruded during more than one eruption.

Su 1300 is 20 km long and has an area of about 25 km². It first appears at Trippafjöll at 500 m a.s.l. and follows the flank of the hyaloclastite mountain Selsundsfell, which has a southeast extension. At the southern end of the mountain Su 1300 turned north and flowed down the slope south of Fáilhmar. There the lava has spread over a level area and terminated in a high edge near the farm Selsund at 100 m a.s.l.

The lava field has been exposed several times to heavy tephra falls, both from Mt. Hekla and other craters; the thickest tephra layers are from 1510 and 1845. The accumulation of sand has also been very heavy, especially at the most elevated part north of Vondubjallar. In the eastern lower part Su 1300 is heavily influenced by light, drift-tephra, so called ‘Selsund pumice’, which covers and colours some
tracts along the northeast slope of Selsundsfjall.

The thickness of the soil is up to 0.8 m but in most depressions 0.30 - 0.55 m. It is mostly made up of several tephra layers and between them the loam is fine-sandy to sandy, often slightly coloured by Selsund pumice.

Su 1300 is a very heterogeneous lava field, both regarding surface structure and vegetation. The surface is very uneven between 100 and 200 m a.s.l. but at higher altitudes it is more level.

Studies of vegetation were carried out at three sites at different altitudes:

Su 1300-I. This part is situated about 150 m a.s.l. The surface is characterized by high and steep crags between more or less deep depressions of various depth. It is very irregular and uneven although at least 10 tephra layers have covered the field. The thickest one, of 1510, forms a layer about 20 cm thick.

Su 1300-II. The surface character of the lava field changes between 200 and 300 m a.s.l. It is not as irregular as at Su 1300-I. The surface is more even but still highly undulating. The depressions with sandy soil are very wide but not deep. Altitude: 250 m. The thickness of the soil is 0.2 - 0.4 m in depressions and the loam between the tephra layers is fine-sandy to sandy. At least 9 tephra layers were found in one soil profile but a careful study is needed before they can be dated.

Su 1300-III. In the highest position, at 480 m a.s.l., accumulation of tephra/sand has been heavy. A large part of the main surface is made up of a sandy surface with scattered patches of vegetation (70%), as a result of the eroding action of windblown tephra. Consequently, Su-III is less hummocky than other sites and can easily be crossed by horses.

No 1389 is situated in the long valley between the mountains Selsundsfjall (502 m) and Bjólfell (443 m). The lava field is 8.5 km long with an area of 12.5 km². It stretches in a southwest and northeast direction from Rauðöldur down to Kanastaðabotnar where a little brook bursts out of the lava front.

No 1389 has been totally or partly covered by tephra during several eruptions. The deposits of tephra from 1510 (and partly from 1597) are unusually thick with very uneven distribution. Other prominent layers are from 1947, 1918 (K), 1845, 1766, 1721 (K), 1693 and 1485 (K). Moreover, traces of other layers can be found, e.g., of 1970, 1636 and 1440.

This lava field is probably more influenced by sheep grazing in the region than others. Sheep from the farms Haukadalur and Selsund usually graze there from early spring to late autumn. In the Farm Register of 1709 (Magnússon & Vidalín 1913) No 1389 is called ‘Gráhraun’ (Gray Lava). It refers to the Icelandic name ‘grámosi’ for R. lanuginosum, and indicates that the species was conspicuous at that time. Another name is Svartahraun, the black lava. Its age is unknown to the present author.

The vegetation studies were carried out at four sites which differ regarding accumulation of aeolian material:

No 1389-I (Hrauntá). In the western part of No 1389 at 100 m a.s.l. The most prominent tephra layer here is from 1510. It is 15 - 20 cm thick, situated at an average depth of 26 cm (15 - 38). Below this tephra layer there is max. 15 cm thick fine-sandy loam down to the lava. The thickness of the soil is up to 60 cm in the deepest depressions and probably 20 cm on average.

No 1389-II (Breiðabugur). At 220 m a.s.l. Here, the lava field was originally very rough. In spite of a few heavy tephra falls it still has a highly undulating surface with many shallow and open depressions.

No 1389-III (Pæla). Situated in the eastern and the highest part, at 300 m a.s.l. (Fig. 9). No 1389-III has been highly influenced by accumulation of tephra (latest 1970) and other aeolian material. Compared to No 1389-I, the 15 - 40 cm thick tephra layer of 1510 is at ca. 50 - 70 cm depth but there is an only 2 - 12 cm thick sandy loam layer below, between the tephra and the surface of the lava.

The soil in the deepest depressions, up to 0.7 - 1.0 m thick, is mostly made up of tephra layers. They have given the landscape a soft appearance with smooth, shallow depressions, rounded hills and only few crags.
No 1389-IV (beneath the mountain Botnafjall). At 200 m a.s.l. More than 90% of the main surface is a more or less barren sandy soil in a broad zone along the mountain, with scattered vegetation.

### 3.1.4 Pálsteinshraun 1554

An eruption began in the spring of 1554 in a 3 km long fissure, about 10 km southwest of Mt. Hekla. It lasted nearly six weeks. A crater row, which is called Vondubjallar, was built up during the eruption. According to Thorarinsson (1967), Pálsteinshraun was formed in this eruption. Kjartansson (1946) considered that it was only a part of Suð000, created during the period 1100 to 1766. Pá 1554 is about 8 km long and covers an area of ca. 10 km². It stretches from 400 m down to 200 m a.s.l. The surface is relatively even.

The successively supplied tephra deposits have been fairly small, except in the vicinity of Vondubjallar. It was difficult to find soil thick enough to determine the profile of the compact tephra layers. The stratigraphy could not be verified. Only 5 tephra layers were found. The oldest one dating from 1636 or perhaps 1693. Two layers, from 1783 (L) and 1660 (K), were not found (Thorarinsson 1967). The 2 - 4 cm thick tephra layer from 1947 is at a depth of ca. 7 cm and the layer 1918 (K) at 10 cm. Thorarinsson’s profile (no. 4, 1967) is different from other profiles in the neighbourhood. The following tephra layers are dated: 1947, 1918 (K), 1845, 1783 (L ?), 1721 (K) 1660 (K ?), 1636, 1597 and even 1485 (K ?). The definition of a tephra layer of 1485 may be a mistake.

The vegetation in Pá 1554 is very homogeneous except in a small, sandy area near Vondubjallar (no analyses). Sheep-paths in this area are few and grazing is restricted to the margins of the lava field.

Studies of vegetation were carried out at one site: Pá 1554-I. Close to the centre of the lava field at 350 m a.s.l.

### 3.1.5 Lava field 1693

The eleventh eruption of Mt. Hekla began in February 1693 with an enormous production of tephra, which caused considerable damage. The tephra covers about 22,000 km² on land but the lava that was presumably produced is almost unknown. A small lava field in the hillside above Rauðöldur may have originated in this eruption (Thorarinsson 1967). The lava field forms a narrow tongue, from slightly above 50 m to 400 m a.s.l., covering about 0.4 km². It has frequently been covered by thick deposits of tephra due to its location close to the summit fissure of Mt. Hekla. The thickest ones are from the eruptions in 1766, 1845, 1947 and 1970. Due to the thick accumulation of tephra deposits, the soil profile yielded only little information on the stratigraphy of the tephra layers.

Studies of vegetation were carried out at one site: Lf 1693-I. At 520 m a.s.l. The surface is relatively even, with low inclination to the west. The main surface is very sandy with only few crags. The surface is characterized by heavy accumulation of tephra with a sparse field layer. The dating of Lf 1693 may be inaccurate. However, because of the frequent deposition of tephra later on, this is of little consequence.

### 3.1.6 Trippafjallahraun 1725

According to contemporary descriptions, an eruption began east or southeast of Mt. Hekla in early April, 1725. The eruption was relatively small and no damage was noticed except due to some initial earthquakes. The production of tephra was most likely small (Thorarinsson 1967). According to known sources there may be some doubt whether Trippafjallahraun belongs to the mentioned eruption. The lava covered Pá 1554 and is partly beneath the lava of 1766. It was, therefore, formed in the period between these years. Tr 1725 is ca. 7 km long and stretches from 600 m down to 400 m a.s.l. The field is ca. 7 km².

The soil profile is very indistinct because of a heavy tephra fall and accumulation of sand in the area. Large quantities of tephra, mainly from the eruption in 1947, cover vast areas. A sandy surface or tephra-covered ground extends all around the lava field. Tr 1725 resembles more a stony flat than a real lava and is thus easily negotiable by horses.

Studies of vegetation were carried out at one site: Tr 1725-I. At 500 m a.s.l., south of the mountain Trippafjöll.

### 3.1.7 Lava fields 1766 (Austurhraun and Hringlandahraun)

The second largest amount of lava in a single eruption in Iceland in historical times originated in the twelfth eruption of Mt. Hekla. The eruption began in 1766 and lasted two years with an interval of six months. The eruption caused damage to many districts in Iceland.

The area of the lava field was estimated to 65 km² but...
it has partly been covered by younger lavas. Lf 1766 stretches from the summit of Mt. Hekla down to nearly 400 m in most directions. The biggest lava stream flowed mainly towards the south and covers the southeast slope of the volcano. The area is commonly named Austurhraun (Lf 1766-I). The lava streams which flowed in other directions are now mostly covered by the lavas from the eruptions of 1845, 1947, 1970 and 1980/81. One lava stream flowed also to the north and Hringlandahraun (Lf 1766-II) was most likely also produced in this eruption (Kjartansson 1946).

Lf 1766 has not attracted as much interest as might be expected. The reason may principally be that there are difficulties to define its boundaries. The Lf 1766-I, defined by Thorarinsson (1967) may consist of not only one lava field. There are many uncertain margins in the flows and the field is also partly covered by a thick accumulation of tephra, especially along the mountains Vatnafjall.

Studies of vegetation were carried out at two sites:

Lf 1766-I. Situated east of the mountains Trippafjoll at 650 m a.s.l. The deposit of tephra in 1947 on the lava became very thick, up to 45 cm. Therefore, the uppermost part of the soil is tephra or a sandy material.

Lf 1766-II. Situated west of Skjolkvívar at 450 m a.s.l. During the eruption of 1970 a small part of this lava was covered by a new one. Strangely enough, at the same time this area was not exposed to any tephra fall, although adjacent areas both to the south and north of it were heavily affected. In 1980 the lava field disappeared totally under a lava stream.

The main surface was more or less level. It was influenced by accumulation of sand and tephra from vast sand areas nearby and had only a few scattered crags. The soil was at least 40 - 60 cm thick. Lf 1766-II resembled more a moss-covered sand dune than a lava field.

3.1.8 Næfurholtsbraun 1845

The thirteenth eruption of Mt. Hekla started on 2 September 1845 and continued almost without interruption until 10 April 1846.

Næfurholtsbraun is the oldest historical lava field with both well known boundaries and age. Relatively detailed descriptions of the eruption were given by many contemporary authors (e.g., Schythe 1847). Later, Kjartansson (1946) stated that Næ 1845 was an enormously rough apalhraun, difficult to traverse, with loose clinkers covering the massive part which will remain unstable as Mt. Hekla has not yet covered it with tephra.

The lava flowed mostly to the west and northwest and covered about 25 km². The border of the lava field is mostly situated between 420 and 250 m.a.s.l. although a narrow tongue reaches down to 150 m a.s.l. (Fig. 9).

On four occasions the field has been partly covered by tephra (1918 (K), 1947, 1970 and 1980/81). The tephra fall in 1970 was very unevenly distributed (see 10.2). The thickness of the soil before 1970 in some depressions was usually 10 - 18 cm. There is up to 4 cm of soil under the 1918 (K) tephra layer and 2 cm between the tephra layers of 1918 (K) and 1947.

Studies of vegetation were carried out at three sites:

Næ 1845-I. West of the mountain Melfell at 250 m a.s.l. The lava flow filled a small valley along the hillsides of Markhlið in the Næfurholt mountains and surrounded the mountain Melfell where birchwood grows on its hillside.

Næ 1845-II. South of the mountainside of Suðurbjallar, just above 400 m a.s.l. The site looked like a black desert after the tephra fall in 1970 (10.2).

Næ 1845-III. Located in the middle of the steep hillside of Mt. Hekla, at 700 m a.s.l. The site was covered by thick tephra of the eruption in 1970. Previously, the site had been covered by heavy tephra deposits. This site becomes wet as it is supplied with water from thawing snow even until late in the summer.

3.1.9 Krakatindshraun (Nyjahrnaun) 1878

An eruption from a fissure began in the high-plateau about 10 km northeast of Mt. Hekla in late February 1878, located about 700 m a.s.l. and almost surrounded by 800 to 900 m high mountains. The eruption was comparatively small and involved no danger to the inhabitants. It lasted for three months. The tephra fall was slight and the tephra was carried by the wind to the unsettled part of the highland.

The lava flowed from the 3-4 km long fissure and stretched out on both sides of the craters, covering the area between the mountains Krakatindur and Krókagígljanda. The main lava flow in a northwest direction and finally a big lava stream gushed through a narrow gorge to the north, down the slope. There Krakatindshraun covers a wide plateau between the mountain range of the high-plateau and the mountain.
Valahnúkur. Kr 1878 has an area of about 15 km², extending from almost 750 m down to 400 m a.s.l. in the north.

The surface of Kr 1878 is very irregular. The clinkers consist of relatively big stones and boulders, but pebbles are not common. The surface is rather stable and the stones do not move so the field is quite easy to cross.

In 1918 there was a small tephra fall from Katla while there was a heavy fall during the eruption of Mt. Hekla 1947, especially in the southern part (>20 cm). The tephra has apparently vanished quickly down in the layer of clinkers or has been taken away by wind and water. In 1980/81 a good deal of tephra fell over some parts.

Accumulation of aeolian materials from surroundings has been fairly great in some places. There is high influence of shifting sand and the effect reaches partly inside the whole lava field but mostly the first 200 m. The accumulation has contributed to the stability of the clinkers by dropping down in hollows and crevices but has not leveled the rough surface.

As mentioned earlier, one part of Kr 1878 is between 600 and 800 m a.s.l. and another between 400 and 600 m a.s.l. There is a big difference in the physiognomy of the vegetation in these two areas. Therefore, the vegetation was studied at two sites:

Kr 1878-I. South of the mountain Valahnúkur, at 450 m a.s.l. The surface is very homogenous. Note that the depressions here are not as deep as in most other lava fields, rarely deeper than one to two meters.

Kr 1878-II. In the middle of the lava field at 710 m a.s.l. The 3-4 km long volcanic fissure, from which the lava emerged, is located in the middle of the plateau between 700 and 800 m a.s.l.

There is an unusually rough lava field on each side of the tephra cones. It is composed of relatively large, stable stones or blocks. The surface is composed of more or less large separated patches. The vegetation is very sparse in this broken ground and occurs on elevated surfaces separated from each other.

3.1.10 Lambafitjarhraun 1913

The lava field was formed during an eruption in 1913 from a 4 km long fissure. The fissure runs in a northeast direction from the hill Krókagiljabrún, crossing the river Helisskvísl and the hill Hraf nabjargarlað, and ends beneath the hyoloclastite mountain Hraf nabjörg (Kjartansson 1946). The eruption was small and caused no particular damage. Earlier, however, there was an productive pasture here with the name Lambafit. (Mundafellshraun was also produced that year, about 13 km southwest of La 1913. It is excluded from this study.)

Lambafitjarhraun is situated at about 400 m a.s.l. and is about 6 km² large. It is characterized by relatively small clinkers and an even surface between the crags. The layer of clinkers is very loose and unstable. Small depressions and holes are very common but big fissures are rare except near the craters, beneath Hraf nabjörg.

La 1913 has been covered by tephra on three occasions (1918 (K), 1947 and 1980/81). On all occasions the tephra falls were small and left hardly any traces. The tephra layer of 1980/81 was only 0.2-0.5 cm thick.

Beneath Krókagiljabrún the lava flow dammed the river Helisskvísl and a lake was formed there. In some years the fine sediments from the river make the lava watertight and the river changes its flow to the north along the western side of the lava field. When the water-supply is small a large area of sand becomes bare. The river has carried a good deal of material into the southern part of the lava field, making it locally sandy.

Studies of vegetation were only carried out at one site:
La 1913-I. At 420 m a.s.l.

3.1.11 Lava field 1947

The fourteenth eruption of Hekla lasted from 29 March 1947 to 21 April 1948. The total volume of tephra is estimated to 210 million m³, of which 180 million m³ fell during the first twenty-four hours. In the beginning of the eruption considerable amounts of tephra were carried with the wind, covering pasturelands and the settled districts in Fjóshlíð and Eyjafjöll in the district of Rangárvallasýsla, South Iceland.

At first the main stream of lava flowed to the east from the 5 km long fissure of Hekla proper and two narrow flows went to the south. Later the eruption was confined to one crater at the southwest end of the fissure and thereafter the main lava flowed to the west (Fig. 9). In some cases, new lava streams flowed over older ones. The thickness of the lava reaches about 100 m in some places. Owing to its young age the surface of each clinker is fragile due to little weathering, implying that the microstructure varies considerably.

The total area of Lf 1947 is about 40 km². It reaches from the summit of Hekla down to 250 m a.s.l. The
surface is very uneven with very loose, sharp-edged clinkers. According to the farmers it rarely happens that livestock or people try to cross the flow. The tephra fall in 1970 was very unevenly distributed (see 10.2).

The studies of vegetation were carried out at three sites:

Lf 1947-I. Southwest of the mountain Melfell, at 350 m a.s.l.
Lf 1947-II. South of the mountain Melfell, at 400 m a.s.l.
Lf 1947-III. North of the mountain Botnafjall, at 400 m a.s.l.

3.1.12 Lava fields 1970

The fifteenth eruption of Mt. Hekla started on May 5 and lasted two months. The eruption mostly took place in three fissures: (a) at the northeast edge of the ridge of Mt. Hekla (Lf 1970-I), (b) in the main fissure of Mt. Hekla furthest to the southwest (Lf 1970-II), and (c) in the southsouthwest side of Mt. Hekla (Lf 1970-III).

During the eruption, three separate lava fields were formed: (a) Lf 1970-I, often called Skjólkvíþraun, northeast of Mt. Hekla. In reality it consists of two lava fields emerging from two separate fissures (Óldugígar and Hlíðargígar) at a distance of 1 km, but they flowed together and cannot be distinguished. The jointly formed lava field extends from 600 m down to 300 m a.s.l., covering an area of 9.9 km². The thickness is about 15 - 20 m. (b) Lf 1970-II, without a name, in the southwest of Mt. Hekla, stretches from 850 m down to 400 m a.s.l. with an area of 2.1 km². The thickness is about 5 m. (c) Lf 1970-III, without a name, coming from craters called Suðargígar, stretches from 800 m down to almost 600 m a.s.l. with a area of 6.5 km² almost to the south of Mt. Hekla. The thickness is about 8 - 10 m. This field has been excluded from these studies.

Lf 1970 is typically apalhraun, although the lava fields differ somewhat from each other. Lf 1970-I is very rough with an uneven surface where depressions and crags alternate with a vertical range of 2 - 6 m. Lf 1970-II is more level with smaller clinkers. Lf 1970-III may be looked upon as a mixture of the two former fields as regards shape. These lava fields were covered by tephra in the eruption of 1980/81. The heaviest tephra fall was on Lf 1970-I, reaching 30 - 50 cm in thickness.

Of the three separate lava fields, two will be described here: Lf 1970-I and Lf 1970-II and were visited by the author in 1971, 1972, 1973, 1975, 1977, 1979 and Lf 1970-II also in 1980. Lf 1970-III is situated more apart from the two other fields and has therefore been visited more sporadically. In this case the sites were not as restricted to certain squares selected in advance as in other places, because of the bareness of the surfaces that were to be recorded for a period of years. Thus, the presence of species decided the choice of the sites:

Lf 1970-I, studies mainly at ca. 400 m a.s.l. Aeolian material carried by wind had already been transported into the lava field during the first year.

Lf 1970-II, studies at ca. 600 m a.s.l. Supply of aeolian
material is very small, because the site is surrounded by lava. However, traces of primary tephra covered the clinkers in depressions and holes to a greater extent than in Lf 1970-I.

3.1.13 Lava field 1980/81

The eruption started on 17 August 1980, only 10 years after the former one. After a plinian phase, lava was produced from a fissure along the Hekla volcanic ridge. The eruption lasted only four days. The bulk of the tephra fall had a northnortheast direction and covered about 17,000 km² on land. Tephra fall within the 20 cm isopach covered an area of 30 km². The total area covered by lava was 24 km², formed by six almost separate flows. A renewed activity started on 9 April 1981 from a new summit crater. It lasted only for eight days. The production of tephra was insignificant. The 1981 lava covers most of the flows from the 1980 eruptions, with a total cover of about 6 km² (Gronvold et al. 1983). The lava field was visited by the author only once (see 8.3).

3.2 Short description of the investigated sites

The study includes 13 dated historical lava fields. The total area including these fields is ca. 300 km². Within each field vegetation studies were carried out at 1 - 4 sites, depending on the extent of the fields and their general character. An overview of the investigated lava fields, their location, approximate area, and the studied sites is given in Fig. 10.

In accordance with the general rule, the temperature decreases by approximately 0.6 °C per 100 m altitudinal increase. Interpolated values of temperature were calculated for every 100 m increase of elevation (100 - 700 m) by using the constant for temperature changes with variable elevation (Fig. 11).

Table 3 below includes information on all studied sites: their age (a) in 1980 (Lf 1980/81 was investigated in 1981), altitude (b), estimated quantity of accumulated material (1-5) (c), the % proportion of the different topographical categories, the main surface (d), holes (e) and crags (f) according to the classification in the section 5.1, and the references to the legends on the vegetational maps at each site (g) where a subsequent investigation was carried out (see 2.2.).

Table 3. All the lava fields and sites studied. a = date of origin, b = m a.s.l., c = quantity of accumulated material, d = percentage of main surface, e = percentage of holes, f = percentage of crags, g = references to the vegetational maps.

<table>
<thead>
<tr>
<th>Material</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
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Fig. 11. Temperature diagrams (interpolated values) for every 100 m increase of elevation (100-700) for the period of 1971 - 1980.
4 Analysis of vegetation and vegetation-environment relations

4.1 Introduction

At each site the topography, substrate, soil, flora and vegetation were analyzed. Moreover, some measurements on soil profiles were carried out and existing tephra layers examined. The sites measured at least 50m × 50m, but most of them were much larger. In the youngest lava fields the occurrence of the plants was decisive for the delimitation of the sites. The choice of the sites was often difficult because of the irregularity of the topography and the mosaic structure of vegetation.

4.2 Vegetation description

The vegetation description included a floristic inventory, analyses of the vegetation both of permanent and non-permanent plots, drawings and photographic documentation. The selected sample plots, each of 0.25 m², were located in homogeneous and representative stands, usually 5 - 11 together in one part of the site. A smaller number of subplots was used when the total homogeneous area was too small, as in deep depressions. In many cases the microrelief has produced a small-scale variation in the composition of the plant cover, especially in the holes. Where floristically and ecologically heterogeneous surfaces occurred within a few centimeters of each other and the circumstances prevented a quantitative analysis, only presence or absence of species were recorded.

The total number of analyses used in this paper are as follows:

(1) 1566 for the main surface.
(2) 81 for the holes.
(3) 13 for the crags.

The species were recorded separately in a shrub-, a field- and a bottom-layer. Crustaceous lichens and mushrooms were usually excluded. Only two species belong to the shrub layer: *Betula pubescens* and *Salix phylicifolia*. Dwarf shrubs are included in the field layer owing to their small size. In most cases a sample of bryophytes and lichens was taken from the plots for further identification of the species. All these specimens are preserved in the author’s herbarium.

The cover of the plant species was estimated according to the five degree scale of Hult-Sernander-Du Rietz (Du Rietz 1921): 1 ≤ 1/16, 2 = 1/16 – 1/8, 3 = 1/8 – 1/4, 4 = 1/4 – 1/2 and 5 ≥ 1/2.

4.3 Division into three environments and environmental factors

Both the macro- and microtopography of lava fields is extremely uneven. Even at a glance it is obvious that their vegetation is very heterogeneous and complex in relation to this irregularity. To cope with the irregularity some kind of division into more homogeneous environments is needed. The local type of variation of vegetation depends on the variation in abiotic and biotic factors. At each site the following abiotic factors were recorded:

a. The irregularity of the topography (I). The irregularity is based on the proportions of crags according to the division into the topographic features: main surface, holes, and crags (see further 5.1).

b. The age of the lava field (A). Information on the age of the lava fields is mainly according to Thorarinsson (1967). In some cases where the circumstances indicate some uncertainty, as in Lf 1766, the studies were deliberately restricted.

c. The elevation (E). The altitude above sea level was derived from the maps compiled by Thorarinsson (1967, 1970).

d. The number of deposited tephra falls (N). Each tephra fall has a great influence on the succession of vegetation. Therefore, it was considered that the structure of the plant cover depends on the number of tephra falls. The distribution and thickness of the tephra layers are often irregular around the volcanic vent itself in these rough lava fields. Therefore, the same number of tephra layers does not occur in all soil profiles at each site; the highest total number of layers was recorded.

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e. The quantity of deposited aeolian material between the tephra layers (Q). An estimation of the quantity of accumulated aeolian material, originating from wide open spaces in the vicinity, was recorded at each site. The estimations are based on the relative thickness of the accumulated aeolian material between the dated tephra layers and the tephra layers of more than 15 cm in thickness; the age of the lava fields was also taken into account (scale 1-5).

f. In addition to the cover of the plants, the cover of tephra (T) was estimated within each plot using the same scale.

g. The surface roughness was judged for every plot: 1 ≥ 2/3 even and unbroken surface, 2 = 1/3 - 2/3 even and unbroken surface and 3 ≤ 1/3 even and unbroken surface (R).

Moreover, for the study of colonization of plants in Lf 1947 and Lf 1970, it was useful to record (a) the position within the layer of clinkers (P), (b) the microsurface (texture) of the scoria (S) and the age of the lava field when the analyses were carried out (AE).

The position within the layers of clinkers on the lava fields was divided into three relative categories: 1. bottom of the clinker layer, 2. middle part of the clinker layer and 3. top of the clinker layer.

It was found sufficient to determine the general features of the microsurface (cf. Einarsson, T 1949) using three distinct forms with a few subdivisions: A. dense surface (a. smooth, glossy surface and b. vesicles); B. spongy surface (a. somewhat spongy, b. moderately spongy and c. very spongy with many sharp points) and C. conglomerate. ‘Red-brown conglomerates’ are present in all the lava fields but are not common and were therefore excluded. This classification was only used a few times in order to obtain a general survey (see 8.2.2).

In summary, the following environmental factors were used for synecological analyses: (a) tephra cover (T) and surface roughness (R), between each vegetation analysis, (b) irregularity of the topography (I), elevation (E), number of deposited tephra falls (N) and quantity of deposited aeolian material (Q), between sites and (c) age of the lava field (A), between lava fields.

4.4 Soil analysis and microclimatic measurements

In 1972 soil samples were taken from some sites in seven lava fields. These were collected close to each plot. The samples were taken in the uppermost 5 cm of the demarcated soil layer. The dominant grain size was estimated in the field. Measurements of pH and loss on ignition were carried out at the Agricultural Research Institute in Reykjavík.

A few soil profiles were described both on and close to some older lava fields. On many of the youngest lava fields no soil has yet developed and at higher altitudes the soil consists of thick accumulated tephra.

Most often only the total thickness of the soil was determined, but also the soil thickness beneath the oldest tephra layer and the accumulation of deposits, especially above the 2 or 3 youngest tephra layers. In most cases the profiles were compared in the field with the profile description by Thorarinsson (1967).

Local temperature climate conditions were measured in two lava fields in 1972. A ‘Grant multipoint temperature recorder’ (model D) was used for the recordings. The instrument enabled temperatures from 28 thermistor probes to be recorded automatically within 3 minutes at intervals of one hour, with an accuracy of ±0.2°C. The probes used were equipped with radiation shelters of aluminum foil during the measuring series.

4.5 Multivariate analysis of vegetation and environmental factors

The analyses from the main surface of the 11 oldest lava fields were treated with the clustering and relocation program TABORD (van der Maarel et al. 1978, van der Maarel 1979) and with Canonical Correspondence Analysis (CCA, CANOCO program; ter Braak 1986, 1987, Jongman et al. 1987). Altogether there are 1,312 analyses, distributed within the lava fields as follows:

| Lf 1766: | 103 |
| Lf 1766: | 103 |
| Su 1300: | 199 |
| Su 1300: | 199 |
| No 1389: | 232 |
| No 1389: | 232 |
| Pa 1554: | 108 |
| Pa 1554: | 108 |
| Lf 1693: | 52 |
| Lf 1693: | 52 |
| Tr 1725: | 25 |
| Tr 1725: | 25 |

The 254 analyses from Lf 1970 and Lf 1980/81 have been excluded from this treatment.

The options chosen in the TABORD program were: (a) clustering with weighted-pair-group agglomerative clustering with the similarity ratio SR as a measure of resemblance; (b) clustering was stopped at the fusion limit 0.50; (c) a threshold value of 0.30 was adopted to remove outlier analyses from clusters; (d) the resulting cluster structure was arranged in an ordered phyto-
sociological table (TABOP) using a frequency limit for characterizing species of 0.60.

The primary clusters obtained in this way were found realistic and considered as local types and named after the constant dominating species (one or two).

The 72 primary clusters from the 11 lava fields were treated again with TABORD (two-step analysis, cf. van der Maarel et al. 1987) and CANOCO. Eleven second-order clusters were obtained; eight primary clusters were considered either as vegetation fragments or initial stages. The 11 second-order clusters were arranged in a synoptical table and compared with existing typologies of lava vegetation. In this way a final classification of clusters was obtained. The final clusters were given the rank of community or variant, as will be explained in Chapter 7.

Canonical correspondence analysis, a special form of reciprocal averaging, presents a simultaneous ordination of sample and species scores along the ordination axes as well as vectors (drawn as arrows) indicating the direction and strength of correlation between vectors of floristic variation and the environmental vectors.

The CANOCO outputs (axes 1 and 2) of each lava field were used to check whether the second-order clusters occupied continuous sectors of the diagram. If there were clear subsectors in the diagram, which moreover clearly corresponded to a subgroup of analyses within a primary cluster, local variants were distinguished and named after one differentiating species.

The direction of each arrow shows the direction of increasing or decreasing influence of a certain factor, e.g., for tephra: increase of cover; position: from the bottom to the top within the clinker surface; irregularity: increasing percentage of crags; age: from young to old.
5 Topographic classification, soil and microclimate

5.1 Topographical habitat classification

Most authors (i.a. Jónsson 1901, 1906a, 1906b, Hesselbo 1916, Grønlund 1884 and Ostenfeld 1899) have pointed out the irregularity of the lava fields, but their systematical categories were vaguely defined and in most cases the age was unknown to them. In Jónsson’s survey (1901), for example, he enumerated only the species in different habitats (craggs, herb-cavities, fissures, holes) and vegetation community types (Grimmia heath, shrub heath, birchwood, bloom mats and grasslands) in some lava fields in Snæfellsnes, West Iceland. Steindórsson’s (1964) classification into: ‘bruni’, ‘mosaemblea’, ‘mórendi’ and ‘hraungjóta’ has the drawback that it is a combination of different characteristics; a bare patch (bruni), vegetation type (mosaemblea, mórendi) and topography (hraungjóta). Therefore, terms had to be based on uniformity, which was easily distinguishable (see 3.2, Table 3).

The following categories were considered adequate for most lava fields with a pronounced topographical structure. The occurrence of these categories was estimated at each site by inspection from a higher hillock.

I Main surface: The more or less flat parts of the lava field, ranging from shallow depressions to small hillocks with more or less continuous plant cover, usually including a moss carpet.

II Hole: A depression with steeply sloping walls, or a crevice.

III Crag: Perpendicular outcrop, often jagged.

The differences between main surface, holes and crags are generally well demarcated (Fig. 12). On a new lava field, however, no main surface can be distinguished, until, in most cases, Racemitrium lanuginosum forms a continuous moss carpet. In Lf 1970 and Lf 1980/81 the categories II and III occur in roughly equal proportions. The main surface can also be demarcated by other species, e.g. Stereocaulon vesuvianum, or by very heavy tephra deposits. Table 3 (see 3.2) gives the sizes (%) of the categories in the lava fields at each site.

This division has been used as a frame of reference in the Hekla area, where the lavas are all of the apalhraun type. It is possible to use this classification in the helluhraun as well, where the wide, more or less bare, smooth and ropy lava forms the main surface. A more detailed subdivision is possible, which should be linked to characteristics of the vegetation.

The proportion of the topographical categories is given in Table 3. The difference between the lava fields is mainly linked to the development of a field, which generally depends on the growth of R. lanuginosum or the amount of accumulated aeolian material. There is a weak relation between the age and the proportion of the main surface, except for the youngest lava fields. The original feature of the lavas (topography of the clinker layer and the size and shape of each clinker) is also a relevant factor but there no documentation or measurements are available. It must be stressed that the estimation of the main surface is not equivalent to the cover value of, e.g., R. lanuginosum.

5.1.1 Main surface

The main surface occupies the largest part of the older lava fields; here some land use is possible, mainly sheep grazing. Usually, the main surface develops as follows: small tussocks of R. lanuginosum grow together to form a continuous cover of moss, sometimes as a more or less continuous thick carpet or as bolsters and it may become up to 40 cm thick. The field layer is often poorly developed. The carpet may gradually grow over all the holes; the underlying clinkers may sometimes be very loose and mobile for a period of many years. The Icelandic name for such a moss carpet is ‘mosaemblea’, meaning inflated moss. The moss cover mosaemblea was considered the second step in the development of vegetation on lava fields (Jónsson 1906a).

In some depressions, R. lanuginosum tends to become replaced by R. caesescens, Drepanocladus uncinatus and/or Hylocomium splendens and also vascular plants become more scattered. In some places the main surface consists of sand or tephra flats. At higher
5.1.2 Holes

The Icelandic word ‘gjóta’ means a more or less deep, irregular hollow or hole in a lava field, mainly made up of many surrounding, loose, pebbles. The holes differ in many respects from the caves and vesicular cavities which are common in the hellsaur. They are much more irregular in shape, usually less deep and wide. The border of the opening is less distinct and has no real kind of roof but can partly be covered by protruding stones. The holes are usually narrow and oriented more or less vertically with many ledges along their sides. In older lava fields some of the holes have a sandy bottom, as in the cavities, but in others the bottom cannot be traced. Most of the holes are 20 - 100 cm deep but much deeper holes occur too, at least 4 m. The deepest holes have not been included in this investigation as they are most difficult to explore due to narrowness and loose pebbles.

Generally speaking, in a new apalhraun there are cavities around each boulder, and therefore no two holes are alike. With the progressive development of the main surface, either by accumulation of aeolian material or by the growth of R. lanuginosum, the frequency of the holes decreases. The holes are feared by people and prevent them from crossing the lava fields.

The holes are the most sheltered places, where the influence of wind, water and environmental disturbances (e.g. grazing and trampling) is minimised. The duration of the snow cover is perhaps two to three weeks longer, on average. The living space for the species is physically restricted to a narrow ledge and they have to compete for light and space.

5.1.3 Crags

The Icelandic word ‘drangi’ means a more or less free-standing, often ‘barren’ crag. The crags are often prominent and appear frequently in a lava field. In this investigation all massive outcrops of lava rocks, which rise 0.5 - 3.0 m above the main surface, are treated as crags. They are highly differentiated as to surface and shape, ranging from vertical, smooth surfaces to horizontal small furrows and rock ledges, altogether providing a very rich variety of environmental conditions.

The moss carpets of R. lanuginosum are often ruptured at the crag base. The formation of the ‘barren’ zone depends on water runoff or possibly in some cases on the idling of the sheep in poor weather. The width of the zone is highly variable, from a few centimeters to several decimeters. It is always leaning (20 - 15 %) and the soil is packed.

The top of some lower crags can often be regarded as the continuation of the main surface with the well-developed moss carpet of R. lanuginosum. Such tops are excluded here. On the other hand, bird mounds are included here although their vegetation is somewhat different.

5.2 The soil

5.2.1 Soil formation

All definitions of soil are mostly limited. The widest definition is “the material in which plants root” (Etherington 1975) or “a dynamic, three-dimensional piece of landscape that supports plants” (Kellogg & Nygård 1951). According to common definition (e.g., Daubenmire 1948) there is no ‘soil’ in a barren lava field. Perhaps it is more realistic to talk about substrate than soil.

The first stage in the developing process, which leads to formation of soil, has been discussed by several authors (i.a. Crocker & Major 1955, Cooper & Rudolph 1953, Jacksons 1965, Tagawa 1964, Atkinson 1969).
The raw material for soil formation is the result of physical and chemical weathering of the bare lava surface. Further development is an interaction of biological, climatic and topographic factors. The importance of each factor depends on the environmental conditions in a certain place.

According to Tagawa (1964), the formation of soil in the lava fields can take place in three ways: (a) accumulation of volcanic ash and small pieces of pumice gravel, (b) physical and chemical weathering of lava, and (c) addition of humus from organisms. He pointed out that the accumulation takes place more rapidly than other processes, and he agrees with Cooper & Rudolph (1953) that the role of lichens in soil formation in an early stage of plant succession has been exaggerated by many authors.

In a young apalhraun the scoria blocks on the surface are very loose and unstable. This is most obvious where the boulders are between 20 and 50 cm in diameter. The scoria blocks are irregularly arranged on the central massive part and it certainly takes about 40 to 80 years or more before they become fairly stabilized. In the oldest lava field, Ef 1158, there are still some unstable areas and Lf 1947 and younger ones are almost inaccessible for the same reason. Even when the surface is completely covered by a moss carpet, considerable movements may occur.

The weathering process of the lavas is of particular importance during the first stage of colonization of plants but has only a small influence on further soil formation. The spinous surface parts of the scoria are very fragile and small amounts of cracked fragments are accumulated in small ledges, crevices and vesicles. This is most obvious in the early years, when the pioneer plants colonize the bare lava. The broken pieces of the scoria blocks can hardly be separated from primary lava, which is also present in most new lavas.

In the older lava fields, the soil is almost exclusively volcanic loess formed by surface redeposits of tephra. The main bulk of the volcanic loess originates from the black tephra. Although the silicic (dacitic, rhyolitic) tephra layers may be of importance for the formation of soil in some places, it is of limited value for the formation of soil in the historical lava fields. The ‘Selsund pumice’ has accumulated in a small tongue of Su 1300, but most of that part has been omitted in this study.

The decomposition of the organic fraction is very slow. The growth rate of the main plant species, Racomitrium lanuginosum, is low but nevertheless the organic matter in the soil (% of dry matter) is relatively high. In 10 randomized samples in soils of some depressions from three lava fields (Ef 1158, Su 1300 and No 1389) with little to moderate accumulation, organic matter amounted to 16.4 - 49.6% (average 34.2%). Jónsdóttir Svane (1964) reported from Þingvallahraun and its vicinity equally high values of organic matter (31.75 - 51.15 %, average 43.58%) in a R. lanuginosum heathland.

The decomposition of R. lanuginosum seems to depend on the habitat and also on the quantity of accumulated aeolian material. In depressions which are moister than the hillocks there is a higher activity of soil bacteria. In a moss carpet of R. lanuginosum, with small or no deposits of aeolian material, it is difficult to define the limit between R. lanuginosum and the soil. In contrast, where some accumulation occurs there is a distinct sand layer 3 - 15 cm below the surface of the R. lanuginosum carpet. The decomposition of R. lanuginosum produces infertile raw humus.

The structure of the volcanic loess or silt loams is weakly expressed, with very slight plastic properties and very weak cohesive forces. The soil between the tephra layers is coarse, mostly sandy to fine-sandy, rarely silty (fractions 2 - 0.02 mm), with extremely low or no clay fraction. Therefore, the soil is unproductive and hardly reaches any kind of equilibrium, being always in a process of changes due to the permanent accumulation of aeolian material. Lava fields with a poor field layer are of very small value for livestock grazing. A soil profile with clearly differentiated horizons has not been documented but may exist only in the

![Fig. 13. Sketches of soil profiles measured in five lava fields. All these profiles are from depressions, therefore, the thickness of the soil is the maximum one. Not all tephra layers have been dated.](image)
surface layer of organic matter in some depressions of the oldest fields (Ef 1158, Su 1300 and No 1389).

5.2.2 Soil profiles

Outside the lava fields, soil profiles are mostly in accordance with each other. On the fields themselves, some dissimilarities were noticed, partly because of the difficulties in getting perfect profiles in such a rough area. Level surfaces on flat areas for tephrachronological studies are not always available in the Hekla area.

The soil of the lava fields may be almost absent on barren lava but in other places the thickness may reach up to almost one meter, with the profile intersected by various numbers of demarcated tephra layers (Fig. 13). In the soil profiles, some tephra layers originate from eruptions in other parts of the country; the most prominent are the tephra layers originating from the Katla eruptions in 1721 and 1918.

The soil profiles are much thicker off than on the lava fields. This difference is much less prominent close to the edge of a lava field than further away. In the region west of Mt. Hekla, depths of 50 - 80 cm down to the tephra layer of 1845 and 150 - 250 cm down to the tephra layer of 1510 can frequently be measured. On the lava fields the corresponding figures are 5 - 12 cm and 40 - 70 cm, respectively.

The reason is that many of the lava fields are sheltered from northeasterly winds and large tephra flats. Furthermore, considerable quantities of deposits are needed to fill up the scoria, because where the surface is rough, aeolian sand/tephra disappears into cavities. On the other hand, it should be noted that deposited tephra layers are usually thicker on than off the lava fields. In a 70 cm thick soil profile in Su 1300, 53 % consisted of demarcated tephra layers but in a rofabard outside the lava field there was only 27%.

5.2.3 The rate of increment

By measuring the thickness of the soil between separate and dated tephra layers in soil profiles it is possible to get a figure of the rate of increment and to some degree also information on the rate of erosion in the vicinity.

In several soil profiles outside the lava fields the thickness of the soil was measured between a number of dated tephra layers. From these figures the annual average rate of increment (mm/year) was calculated:

<table>
<thead>
<tr>
<th>year interval</th>
<th>average rate of increment (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000-1300</td>
<td>0.8</td>
</tr>
<tr>
<td>1300-1341</td>
<td>1.1</td>
</tr>
<tr>
<td>1341-1510</td>
<td>0.8</td>
</tr>
<tr>
<td>1510-1693</td>
<td>1.7</td>
</tr>
<tr>
<td>1693-1766</td>
<td>2.2</td>
</tr>
<tr>
<td>1766-1947</td>
<td>3.8</td>
</tr>
</tbody>
</table>

From these measurements of soil profiles the conclusion can be drawn that the threatening erosion in the area of Hekla became noticeable in about 1510 or even somewhat later. During the eruption of Hekla in 1510, 215 million m³ of tephra fell on land, covering at least 3,000 km² (Thorarinsson 1967). Together with agricultural practices and other human interferences, this was probably the main reason for soil erosion starting in the Hekla area. The thickening rate of the volcanic loess depends mainly on eroded soil-covered areas and the availability of sandy flats in the vicinity. The sandy flats are extremely unstable during dry conditions. The sand/tephra begins to move already at a wind force of 0.5 - 1.0 m/sec. In heavy storms it is quite impossible to stay outdoors in these areas as the fine dust penetrates clothes and all equipment. In addition, the landscape and prevailing dry wind must be considered.

5.2.4 pH values

The slightly acid soil had an average of pH 6.5 (5.7 - 6.9). The highest and lowest values were found in the same lava field and within one plant community. There was no significant difference between the lava fields. The following results from the pH-measurements were obtained:

<table>
<thead>
<tr>
<th>pH</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ef 1158</td>
<td>6.5</td>
</tr>
<tr>
<td>Su 1300-I</td>
<td>6.6</td>
</tr>
<tr>
<td>No 1389-I</td>
<td>6.4</td>
</tr>
<tr>
<td>Lf 1693</td>
<td>6.5</td>
</tr>
</tbody>
</table>

For comparison, Mølholm Hansen (1930) reported pH values of 6.2 - 6.5 in 'mosapæmba' on Lyngdalsheiði and Jónsdóttir Svane (1964) 5.2 - 6.0 (average 5.8) in Racomitrium vegetation in Óingvallahraun. Gunnlaugsdóttir (1985) reported pH values of 5.2 - 6.4 in the soil of uneroded heathland and 6.2 - 7.6 in soils of the deflated heathland vegetation near the farm Gunnarsholt, about 15 km south of the Hekla area.

According to Jóhannesson (1960), the pH value of the surface layer of silty loam in South Iceland is 6.2 (± 0.4). He stated that there are two major factors that
influence the soil pH: “the amount of mineral surface deposits and the amount of precipitation. Increased mineral deposits tend to increase the pH; increased precipitation, or increased leaching, has the opposite effect.”

5.3 Microclimatic conditions

Several important investigations have dealt with microclimate in special habitats and plant communities in Iceland. Nevertheless, no measurements have been carried out in lava fields, except for some thermal areas of Surtsey (Sjögren 1974). A few temperature recordings were carried out in La 1913 and No 1389 in August 1972 in cooperation with Dr. E. Sjögren. The aim was mainly to study the presumed large fluctuations of temperatures in some habitats as compared to nearby habitats with much more stable temperature conditions. These temperature conditions, naturally related to widely different humidity conditions, are of course, important for the colonization of various plant species. As an example, the temperature variations from La 1913 are discussed below.

The measurements were carried out on 8 - 9 August from 16.00 h to 15.00 h. The weather conditions were characterized by cloudiness of 50% but no rain, and weak northerly winds (ca. 5 m/sec). These conditions perhaps did not give the most pronounced differences in the series of temperatures obtained at different points, as overcast weather tends to reduce the temperature variation (Sjögren 1973).

A total of 16 probes were placed at different sites, of which 8 will be presented (Fig. 14: A - C).

- A. Three of the probes were located in the middle of the main surface, two at the ground (a and b) and one in a tuft of *R. lanuginosum* (c):
  a: max. 28.0, min. − 1.0, mean 8.4 °C  
  b: max. 14.1, min. 1.3, mean 7.4 °C  
  c: max. 20.6, min. 2.3, mean 7.5 °C

- B. Four probes were located at different sites at the bottom of a 20 cm deep and relatively broad hole, one at the border where the vertical cliff above faced south (a) the second in the middle of the hole (b) the third at the border, where the vertical cliff above faced north (c) and the fourth in a shelter, protected against exposure (d):
  a: max. 9.8, min. 3.4, mean 4.5 °C  
  b: max. 18.8, min. 2.0, mean 7.3 °C  
  c: max. 13.5, min. 2.5, mean 6.9 °C  
  d: max. 10.7, min. 3.7, mean 6.6 °C

Fig. 14. A-C. Temperatures recorded with 8 thermistor probes in Lambafljotshraun lava field from the 1913 eruption. The position of the probes is described in the text (section 5.3).
- C. Finally, one was located in the bottom of a narrow (ca. 10 cm) and 50 cm deep fissure

\[ \text{a: max. 5.2, min. 4.6, mean 4.9 °C} \]

The highest and lowest air temperatures were recorded on bare ground in the middle of the main surface with an amplitude of 29.0 °C. The mean temperature was also higher there than in other habitats (8.4 °C) where recordings were made (A:a). The series of temperatures from the hole show a lower mean value and temperatures within a smaller amplitude. The greatest variation inside the hole was in the middle, 16.8 °C, as could be expected, and the smallest was in the shelter, 7.0 °C. The hole differs, moreover, from the surface by its higher night temperature and lower day temperature. In the narrow fissure the temperature range was only 0.6 °C and the mean only 5.4 °C.

The minimum temperature in the main surface occurred at 06.00 h in the morning, and in the hole it was not delayed more than 1 hour, except for B:a (facing south), where it occurred at 12.00 h. In the fissure the minimum temperature, 4.6 °C, remained unchanged between 10.00 - 12.00 h.

The maximum temperature in the main surface and the hole occurred at 15.00 h, except in B:d (in the shelter), where it occurred 5 hours earlier. In the fissure the maximum temperature, 5.2 °C, remained unchanged from 16.00 - 21.00 h.

One of the general features of the temperature sequences within the measuring area was the wide range in the main surface and the levelling effect of the hole and fissure. The temperature extreme was found where the exposure was strongest, in the main habitat of *R. lanuginosum*, suggesting that the species is not particularly sensitive to temperature variations (cf. Kallio & Heinonen 1973). The vegetation in a hole or fissure is subject to different microclimatic conditions, which results in a clearly different plant cover. Probably, the main microclimatic features described are characteristic in a lava field, but supplementary measurements are naturally required within the microsites during different seasons of the year in order to permit a more detailed description of the microclimatic conditions.
6 Floristic Notes

6.1 Vascular plants

The nomenclature used for vascular species is according to Lid (1985), except for a few taxa which occur in Iceland but not in Fennoscandia. For those (Epilobium latifolium, Platanthera hyperborea and Salix callicarpa) Flora Europaea has been followed. Voucher specimens of critical species are deposited in the author's herbarium. The total number of vascular species in Iceland amounts to about 470 (Bjarnason, A.H. 1983) of which 93 (20 %) are known from the lava fields. In the investigation of the main surface, 81 vascular species are included (71 in Tables). The other species are either rare there (e.g., I. unipe rus communis, Cassiope hypnoides, Lathyrus japonicus) or mostly confined to holes or crags, mainly the barren zone. They occur only occasionally on the main surface (e.g., Saxifraga cernua, Sibbalda procumbens, Rhodiola rosea). Twelve species were recorded in holes and 38 on crags.

All recorded species are fairly common elsewhere in Iceland. Most of the vascular species, which form the luxurious vegetation in clefts (cf. gja-vegetation, Grøntved 1942) belonging to ground-flora of woods and scrubs, do not occur in the Hekla area. Variants were not taken into account but several species are represented with shade forms (cf. Strømfelt 1884, Jónsson, H. 1901) of low taxonomical value.

6.2 Bryophytes

A large number of cryptogams was recorded in this study. Their identification has naturally met several taxonomic problems. For example, one of the problems has been the rich morphological variation of many species according to habitat. For this reason, the following comments on a small selection of species have to be made.

The bryophyte nomenclature follows Corley et al. (1981) and Grolle (1983), except for Anthelia julacea, which includes A. juratzkana. The total number of bryophyte species in Iceland amounts to 416 mosses and 146 liverworts (Jóhannsson 1983), of which 83 (20 %) and 42 (29 %) species respectively were recorded in the lava fields. In the investigation of the main surface, a total of 59 mosses and 37 liverworts was found. Among bryophyte species recorded in holes, 50 were mosses and 27 were liverworts, whereas on crags the corresponding figures were 56 and 22, respectively. These figures are interesting when considering the large areas occupied by the main surface as compared to the crags and holes. The difference does not seem to be large but, as pointed out by Hesselbo (1918 p. 618), in a lava field "species occurring on rocks and on the ground are always found both on the walls and also on, and among, the blocks”.

Regarding the Racomitrium canescens group, the taxonomical division according to Frisvoll (1983) has not been followed. According to Jóhannsson (1984), R. ericoides is the most common member of this group in Iceland. R. canescens is most common in the northern and eastern parts but is also found elsewhere. Both species occur in the Hekla area.

The species Encalypta brevipes Schljak. was only recorded in No 1389 and Næ 1845 but may be more widespread. The reason is that the identification was not possible before the paper of Horton (1980). The species seems to have a continuous but restricted southwesterly distribution in Iceland (Jóhannsson 1984).

Asexual diaspores (propagules or gemmae) do not seem to be more frequent in the lava fields than in other habitats. About 10 % of the mosses in the lava fields frequently produce asexual diaspores. In the taxonomic literature the gemmae of Dichodontium pellucidum are rarely mentioned. In Lf 1947 and Lf 1970 the species are highly gemmiferous.

The relatively large number of liverworts was expected due to the numerous microhabitats. Their determination has involved several difficulties, mainly due to the fact that they are scattered and rarely occur in big mats. They are often damaged by tephra. Many species are highly variable, such as Lophozia sudetica and Tritomaria quinque dentata. No attempt has been made to evaluate the taxonomic status of the variants.
6.3 Lichens

Altogether 43 lichen species were identified and the nomenclature is the same as used by Santesson (1984), except for the genus Stereocaulon (Kristinsson 1982). The lichens were less intensively studied than the vascular species and the bryophytes, except for the genus Stereocaulon (see below). The number of recorded species is, therefore, less reliable. One new species for Iceland was recorded: Lobaria laetevirens. It was collected from the lower part of a crag, facing south in Lf 1913. The material was identified by Prof. Rolf Santesson in Uppsala (Bjamason, Å.H. 1985).

A total of 13 species of the genus Stereocaulon has been recorded in Iceland (Kristinsson 1983). The following species were found in the lava fields: S. vesuvianum, S. botryosum, S. arcticum, S. vanoyei, S. depressum, S. rivulorum, S. alpinum and S. capitellatum. The dominating species is S. vesuvianum. It is not always well distinguished from S. arcticum. The distinguishing character, Stigonema algae in the cephalodia of S. vesuvianum and Nostoc in those of S. arcticum, is probably not reliable. Both species can grow on bare rock. In a thick carpet the pseudopodia of both species will die off at the base and they become gradually earth-lichens. According to Gallée (1920) this is a form intermediate between an earth-lichen-association and a rock-lichen-association, which is related to the influence of aeolian material. Other Stereocaulon species occur only scattered on protruding stones (S. botryosum, S. depressum) or in the carpet of R. lanuginosum and on sandy flats (S. alpinum, S. rivulorum). S. capitellatum was only found in Lf 1947 and Lf 1970.
7 The vegetation of the eleven older lava fields

7.1 Introduction

This chapter deals with the plant communities distinguished on 11 historical lava fields in the Hekla area. These local community types will be compared with earlier descriptions of similar Icelandic vegetation. The main emphasis will be on vegetation dominated by the moss species *Racomitrium lanuginosum*, which is well represented in Iceland as well as widely throughout the world (Kallio & Heinonen 1973). Sites dominated by this striking vegetation, easily recognized even at a distance, are named ‘heioar’ (pl. heioa) in Icelandic, which means highland, low, open elevation or uncultivated tussocky ground (equivalent to heath in English; Heide in German; hed in Swedish; closely related to heathen, perhaps a translation of Latin pagus, countryman).

Naturally, these heioar have attracted the attention of earlier Icelandic botanists. In section 7.2 a survey of vegetation types described earlier is presented. The vegetation typology of the 11 historical lava fields will be introduced in a general section, 7.3, where the more important communities and variants will be described more formally. There is also an enumeration of all the lava fields where each community in question is represented. Communities and variants occurring on only one lava field will be described in a subsequent section dealing with individual lava fields. Table 4 is a survey of the plant communities with their variants as distinguished in the 11 historical lava fields, arranged in physiognomical groups (dom. = dominant species; subdom. = subdominant species; diff. = differentiating species; var. = variant; sl = shrub layer; fl = field layer; bl = bottom layer). Table 5 presents the floristic composition of the majority of primary clusters as arranged within the communities and variants distinguished (second-order clusters). The community numbers in this table are the same as in Table 4. Also, each cluster has got a number, which has also been included in the synoptic tables and in the ordination diagrams presented for each lava field. Several primary clusters could not be easily placed in this system as the species composition includes only very few species, usually with low cover values. Some of them, from *Lf* 1947, have been named ‘initial stage’ as far as they could be interpreted as such. Other clusters of that kind could not even be interpreted because they are remnants of highly damaged communities. They have been omitted from the final description but their floristic composition can be derived from the synoptic tables for each lava field (vegetation fragments). For each community type the characteristic species are indicated: dominants with a cover value ≥ 3 either in the field layer or in the bottom layer, differentiating species, restricted to the type or to a few types and occurring with high constancy. The variants are characterized by subdominance of at least one species with a cover value of ≥ 2.

In sections 7.3 - 7.14 the composition of these communities, variants as well as local facies will be described and interpreted for each of the lava fields included in this study, starting with the oldest field. The synoptic tables (Tables 6 - 16) include mainly the species with distinctive characters. The species occurring in only one or two clusters with synoptic value of only 1 have been deleted from the tables, unless they are considered characteristic species, differentiating the cluster(s) from others. These additional species are mentioned below each synoptic table. Some ecological remarks illustrating the relations between the plant communities distinguished and the main environmental factors within each lava field are also included (Fig. 19 - 29). In sections 7.15 and 7.16, the vegetation in holes and on crags will be discussed. Finally, Chapter 11 will be devoted to a discussion of the synecological and syndynamical relationships between the various communities in relation to the age of the fields, altitude and local substrate characteristics.

7.2 Survey of plant communities described earlier

During recent decades a large number of Icelandic plant communities have been described by many au-
Table 4. Survey of plant communities with their variants distinguished in the 11 historical lava fields, arranged in physiognomical groups. dom. = dominant; subdom. = sub-dominant; diff. = constant, differentiating species; var. = variant; sl = shrub layer; fl = field; layer; bl = bottom layer. Each group has a special number which refers to the ordination diagrams presented for each lava field (Figs. 19 - 29).

<table>
<thead>
<tr>
<th>Number</th>
<th>Group Description</th>
<th>Species Mentioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Salix var. subdom.</td>
<td>S. herbacea fl</td>
</tr>
<tr>
<td>2.2</td>
<td>Emptetrum var. subdom.</td>
<td>E. nigrum fl</td>
</tr>
<tr>
<td>2.3</td>
<td>Stereocaulon var. subdom.</td>
<td>S. vesuvianum bl</td>
</tr>
<tr>
<td>2.4</td>
<td>Racomitrium canescens comm.</td>
<td>diff. Anthelia julacea bl</td>
</tr>
</tbody>
</table>
| 2.5    | D. flexuosa diff. | Arnoglossum virginicum
| 2.6    | Salix var. subdom. | S. herbacea fl    |
| 2.7    | Emptetrum var. subdom. | E. nigrum fl    |
| 2.8    | Stereocaulon vesuvianum comm. | diff. Solorina crocea bl |
| 2.9    | Racomitrium lanuginosum comm. | diff. Anthelia julacea bl |
| 2.10   | D. uncinatus diff. | Cerastium fontanum
| 2.11   | A. stolonifera diff. | Thalictrum alpinum
| 2.12   | A. vinealis diff. | Hylocomium var. subdom. H. splendens bl |
| 2.13   | S. phylicifolia diff. | Rhytidocalphus squarrosus bl |
| 2.14   | S. vesuvianum diff. | Empetrum nigrum - Racomitrium lanuginosum |
| 2.15   | S. phylicifolia diff. | P. drummondii bl |
| 2.16   | S. phylicifolia diff. | Solorina crocea bl |
| 2.17   | S. vesuvianum diff. | Thalictrum alpinum
| 2.18   | S. phylicifolia diff. | Hylocomium var. subdom. H. splendens bl |
| 2.19   | S. vesuvianum diff. | Rhytidocalphus squarrosus bl |
| 2.20   | S. vesuvianum diff. | Empetrum nigrum - Racomitrium lanuginosum |
| 2.21   | S. vesuvianum diff. | P. drummondii bl |
| 2.22   | S. vesuvianum diff. | Solorina crocea bl |
| 2.23   | S. vesuvianum diff. | Thalictrum alpinum
| 2.24   | S. vesuvianum diff. | Hylocomium var. subdom. H. splendens bl |
| 2.25   | S. vesuvianum diff. | Rhytidocalphus squarrosus bl |
| 2.26   | S. vesuvianum diff. | Empetrum nigrum - Racomitrium lanuginosum |
| 2.27   | S. vesuvianum diff. | P. drummondii bl |
| 2.28   | S. vesuvianum diff. | Solorina crocea bl |
| 2.29   | S. vesuvianum diff. | Thalictrum alpinum
| 2.30   | S. vesuvianum diff. | Hylocomium var. subdom. H. splendens bl |
| 2.31   | S. vesuvianum diff. | Rhytidocalphus squarrosus bl |
| 2.32   | S. vesuvianum diff. | Empetrum nigrum - Racomitrium lanuginosum |
| 2.33   | S. vesuvianum diff. | P. drummondii bl |
| 2.34   | S. vesuvianum diff. | Solorina crocea bl |
| 2.35   | S. vesuvianum diff. | Thalictrum alpinum
| 2.36   | S. vesuvianum diff. | Hylocomium var. subdom. H. splendens bl |
| 2.37   | S. vesuvianum diff. | Rhytidocalphus squarrosus bl |

7.2.1 Main surface

Racomitrium heaths and a special landscape of dwarf shrubs, with *R. lanuginosum* in the bottom layer, occur especially in rainy and exposed sites, from southeast to west Iceland and in the northeast. They are rare in the driest parts of the east, north, and northwest parts (Steindórrsson 1964). According to Jónsdóttir Svane (1964), the main factor, influencing the distribution of well-developed heaths is the number of months (max. 4) with a mean temperature below 0 °C, high annual rainfall and short duration of a thin snow-cover. In these areas cold, short periods with temperatures below zero occur frequently during the growing season. Many vascular species, especially shrubs, become severely damaged and must regenerate from the roots. These cold spells may delay the establishment of vascular species and make it difficult for them to capture the habitats occupied by *R. lanuginosum*. Racomitrium heath (mosaṣemba) becomes most extensive and best developed on a lava field, which can be regarded as the type-locality for mosaṣemba vegetation (Fig. 15). According to Tallis (1958) the distribution of *Racomitrium* heaths in Scandinavia is chiefly governed by the absence of competition. However, in the Arctic it is determined mainly by a high annual rainfall.

Racomitrium heaths, notably with *R. lanuginosum*, have often been described from Iceland (under different names) and there are numerous references to them in literature, e.g., Jónsson (1895, 1901, 1906a, 1906b), Ostenfeld (1905), Hesselbo (1918), Molholm Hansen (1930), Steindórrsson (1930, 1936, 1945, 1966), McVean (1955), Jónsdóttir Svane (1964), Hadač (1972) and Gunnlaugsdóttir (1985). Most of the older publications only report species present in the *Racomitrium* heath, without any sociological description. In some cases it is also difficult to discern whether the substrate...
is a lava field or a hyaloclastic rock.

In depressions, on slopes and in late-snow patches, *R. lanuginosum* heath is replaced mainly by a vegetation type with *R. canescens*, often mixed with other species. Some authors relate the *R. canescens* community types also to the mosaibemba (Jónsdóttir Svane 1964, Steindórsson 1966, McVean 1964a). Others consider it as grassy heathland but emphasize the great affinity to the *R. lanuginosum* heaths (Gunnlaugsdóttir 1985). However, these two community types differ from each other both in environmental conditions and floristically, and they should not be united into one community. This conclusion is confirmed in the present study.

The treatment by some of the authors of Icelandic heath communities rich in *Racomitrium* can be summarized as follows:

**Jónsdóttir Svane (1964)**
- a) Rhacomitrium (=Racomitrium) lanuginosum ‘Heide’
  - Rhacomitrium type
  - Thalictrum alpinum - Rhacomitrium soc.
  - Carex bigelowii - Rhacomitrium soc.
  - Salix herbacea - Rhacomitrium soc.
- b) Rhacomitrium reiche ‘Zwergstrauchheide’
  - Empetrum hermaphroditum - Rhacomitrium canescens - Rhacomitrium lanuginosum soc.
  - Betula nana - Empetrum hermaphroditum - Rhacomitrium lanuginosum soc.
  - Empetrum hermaphroditum - Cladonia mitis - Rhacomitrium lanuginosum - canescens soc.
  - Empetrum hermaphroditum - Loiseleuria procumbens soc.
  - Cassiope hypnoides - Loiseleuria procumbens soc.
  - Betula nana - Vaccinium myrtillus soc.
  - Vaccinium uliginosum - Vaccinium myrtillus soc.
  - Vaccinium uliginosum - Rhacomitrium canescens soc.
- c) Rhacomitrium canescens ‘Heide’
  - Anthoxanthum odoratum - Deschampsia flexuosa soc.
  - Deschampsia flexuosa - Rhacomitrium canescens soc.
  - Deschampsia flexuosa - Rhacomitrium canescens - lanuginosum soc.
- d) Rhacomitrium canescens ‘Heide des Hochgebirges’
  - Sibbaldiopsis procumbens - Onaphalium supinum soc.
  - Salix herbacea - Cassiope hypnoides - Rhacomitrium canescens soc.
  - Salix herbacea - Rhacomitrium canescens soc.

**Steindórsson (1966)**
- Rhacomitrium (=Racomitrium) heath
  - Caricetum bigelowii Rhacomitriosum
  - Salicetum herbaceae Rhacomitriosum
  - Empetretum hermaphroditis Rhacomitriosum
  - Equisetum arvensis Rhacomitriosum

**Hadač (1972)**
- Rhacomitrio - Caricetum bigelowii comm.
  - subass. empetretosum hermaphroditic
  - subass. carietosum bigelowii

**Gunnlaugsdóttir (1985)**
- a) Rhacomitrium lanuginosum heaths
  - Rhacomitrio lanuginosi - Thalictretum alpini
  - Subass. galtoolosum normanii
  - Typical form
  - Peltigera leucophlebia form
  - Cerastium alpinum form
  - The inops (species poor) subass. (indicated for Su 1300)
  - Empetrum nigrum - Racomitrium lanuginosum comm.
  - (indicated for Su 1300)
- b) Grassy heathlands
  - Agrostio capillaris - Hylocomietum splendentis
  - Subass. inops
  - Subass. racmitrietosum canescensit
  - Typical variant
  - Typical form
  - Drepanocladus uncinatus form
  - Thymus arcticus variant
  - Festuca vivipara - Racomitrium canescens comm.
  - Racomitrio canescensit - Gentianetum nivalis

Fig. 15. Species-poor moss carpet of *Racomitrium lanuginosum* in the Pálsteinsbraun lava field from the 1554 eruption. - July 1980.

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Vegetation on lava fields

Fig. 16. *Empetrum nigrum - Racomitrium lanuginosum* community, partly dominated by *Salix phylicifolia* in the depression, in the Suðurhraun lava field from the 1300 eruption. *Salix herbacea* is visible in the moss carpet and *Salix lanata* in the middle of the slope. - August 1976.

The period of snow-cover in the Hekla area is relatively short, except for some areas at high altitudes, mainly northeast of Mt. Hekla. It is difficult to obtain an exact definition of a snow-bed within a sociological framework; snow-bed borderline vegetation as described by Gjerevoll (1956) is not found in this area. The snow-bed (patch) vegetation types from Iceland described earlier are rare (Mølholm Hansen 1930, Steindórsson 1945) and deviate from those in the lava fields, due to the preponderance of vascular species and the lack of cryptogams. Since the term snow-bed is usually used in a strict sense, one should rather speak of chionophilous communities when dealing with lava field vegetation in the Hekla area.

An important vegetation type on the main surface, but only occurring in the three oldest lava fields, is the dwarf-shrub heath (Fig. 16). This community type, *Empetrum nigrum - Racomitrium lanuginosum* comm., has a clear floristic similarity with the *Racomitrium* heaths and transitions occur frequently. The closest relationship that could be found is with several *Empetrum*-rich sociations in the ‘Racomitrium heath’ and the ‘dwarf-shrub vegetation’ (Steindórsson 1966, 1974), *Empetrum nigrum - Racomitrium lanuginosum* comm. (Gunnlaugsdóttir 1985) and some of the ‘Rhacomitrium reiche Zwergstrauchheide’ (Jónsdóttir Svane 1964). The vegetation is dominated by *Empetrum nigrum*; may occur with a lower cover value of *R. lanuginosum*, but is often replaced by *Hylocomium splendens* or *Drepanoclados uncinatus*. Other dwarf shrubs involved, viz., *Arctostaphylos uva-ursi*, *Vaccinium uliginosum* and *Salix phylicifolia*, can be used for the distinction of variants.

Only in a few places is the vegetation on the lava fields physiognomically dominated by graminoids. This grassy heathland vegetation, only found in Su 1300, includes a transition between meadow vegetation (frequent in the lowland) and open grassland vegetation, common in sandy areas both in the lowland and the highland. The grassy heathland, in the wide sense of the word, has been described by Jónsson (1901, 1906a), Mølholm Hansen (1930), Steindórsson (1936, 1964, 1966), Knauer (1966), Tüxen & Böttcher (1969) and Gunnlaugsdóttir (1985).

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Table 5. The floristic composition of the second-order clusters.

<table>
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<th>Community</th>
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<th>1.2</th>
<th>1.3</th>
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<th>2.2</th>
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<th>8</th>
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<td>1222456</td>
<td>445</td>
<td>10034566</td>
<td>36</td>
<td>566</td>
<td>66</td>
<td>56</td>
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<td>1</td>
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<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>5</td>
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<td>38</td>
<td>9</td>
<td>12</td>
<td>4578</td>
<td></td>
</tr>
</tbody>
</table>

The open field vegetation, from gravelly flats to vegetation on sand, is often characterized by graminoids. It is found in wind-exposed areas which are often influenced by large amounts of aeolian material from the surroundings, or in areas which have recently received a tephra fall. The vegetation is most often very sparse. The surface is often very unstable and dries out quickly. The vegetation has been described by Jónsson (1895, 1901), Mølholm Hansen (1930), Steindórsson (1945, 1968), Hadač (1972), Venzke (1982), Gunnlaugsdóttir (1985).

7.2.2 Holes

Previous descriptions of the vegetation in holes are rare. Jónsson (1901) listed 6 common bryophytes and 1 alga for holes, together with 7 other bryophytes, from prehistoric lava fields in West Iceland. The ‘Anthelia’ (Hesselbo 1918) in very deep and narrow lava clefts resembles the hole vegetation. In such places Anthelia julacea forms a damp carpet, mixed with Polytrichum sexangulare, Conostomum tetrogonum, Pohlia drummondii and P. wahlenbergii. The vegetation of narrow lava cavities in North Iceland (Blázková 1973), with 5 vascular species and 12 bryophytes, has few floristic similarities with the hole vegetation in the Hekla area.

Descriptions of caves, clefts and cavities, often with vegetation very rich in species (gja-vegetation, Grönlund 1884), refer to other types of lava formation, which are common on helluhraun.

7.2.3 Crags

Descriptions of crag vegetation are rare as well. Jónsson (1901) listed 2 vascular species, 21 bryophytes and 14 lichens (incl. 7 crustaceous species) from prehistoric lava fields in West Iceland. Others (e.g., Grönlund 1884, Hesselbo 1918, Gallóe 1920) stressed the species poverty of the vegetation on crags although they listed several species.

7.3 Plant communities on historical lava fields, a survey

The second-order clusters obtained with the program TABORD were compared with the vegetation types described in the literature, mainly from Icelandic lava fields (Table 5). In view of the phytosociologically incomplete floristic composition of many clusters it was considered unrealistic to assign them to any existing formal system of plant communities. Instead, an ad hoc typology was used with three hierarchical levels: communities, variants and facies.

Community is defined here as an ecological unit characterized by one or two dominating plant species. Variant is defined as an ecological unit that differs from the main community composition by the subdominance of one species and is spatially differentiated in the ordination diagrams. Facies is defined as a unit deviating from communities or variants on the basis of a locally higher abundance of one of the characteristic species. Both variants and facies are named after the species which has been chosen as characteristic.

For each community the characteristic species are indicated: dominants with a cover value ≥ 3 either in the field layer or in the bottom layer, differentiating species, restricted to the community exclusively or to a few other communities as well and occurring with constancy. According to the percentage of stands in which the species occur, the following terms have been used: constant (in 81 - 100%), frequent (in 61 - 80%), moderately frequent (in 41 - 60%), infrequent (in 21 - 40%) and rare (in less than 20%). The variants are characterized by subdominance of at least one species with a cover value ≥ 2.

7.3.1 Racomitrium lanuginosum comm.

(Table 5, comm. 1) Su 1300 cl. 6, No 1389 cl. 14, Lf 1693 cl. 28, Tr 1725 cl. 34, Lf 1766 cl. 37, 39, Næ 1845 cl. 41, Kr 1878 cl. 51, La 1913 cl. 58, Lf 1947 cl. 65, 72.

The R. lanuginosum comm., including the following variants, occupies large areas from 100 to at least 800 m a.s.l. and occurs in all the 11 lava fields. It reaches from depressions to hillocks and forms a more or less continuous moss carpet.

The field layer is usually poorly developed (0 - 20% cover). The species may be small and weather-beaten. The occurrence of vascular species depends on the density and thickness of the moss carpet. A few species, with low cover value, occur in a dense and thick carpet, e.g., Salix herbacea, Empetrum nigrum and Festuca rubra. If the moss carpet is looser, especially around protruding stones, in small ruptures and sandy patches, several other species may occur, e.g.,
Regarding this community, Lf 1947 differs from all other lava fields by the almost complete absence of vascular species, probably because of its young age. In the three oldest lava fields, Ef 1158, Su 1300 and No 1389, several vascular species which are missing or less common in the younger fields are found, e.g., Thymus praecox ssp. arcticus, Thalictrum alpinum, Rubus saxatilis and Potentilla crantzii.

*R. lanuginosum* is the only dominant species. The moss carpet may be continuous over a large area but may also be intermittent, as a consequence of protruding stones or with ruptures. These ruptures are developed by wind, frost or where the carpet is exposed to aeolian material. The physiognomy of the community varies with thickness of the moss carpet, amount of aeolian deposits and, where the carpet is thin, with the underlying either stony or sandy surface. The number of species in the bottom layer varies greatly. On the whole, it is poor in species. The main differentiating species are *Pogonatum urnigerum* and *Lophozia ventricosa*. *Polytrichum piliferum* and *Ochrolechia frigida* are confined to exposed places. The number of species is highest where the ground is stony or where the moss carpet is thin and split by small ruptures. It is lowest in denser moss carpets, where at least the uppermost 8 cm of the *R. lanuginosum* stems are vigorous.

Other species of the bottom layer occur: (a) intermingled in the thick moss carpet, such as *R. canescens*, *Polytrichum juniperinum*, *P. alpinum*, *Drepanocladus uncinatus* and a few liverworts, (b) on small protruding pebbles, such as *Ceratodon purpureus*, *Distichium capillaceum*, *Schistidium aparcum*, *Stereocaulon vesuvianum*, *Cladonia pyxidata* and *Placopsis gelida*, or (c) on bare sandy patches, such as *Anthelia julacea*, *Diphyscium foliosum*, *Pohlia drummondii*, *Gymnomitrion corallioides* and *Solorina crocea*.

*Salix herbacea* variant

(Table 5, comm. 1.1)

Ef 1158 cl. 4, Lf 1693 cl. 29, Lf 1766 cl. 40.

Regarding the field layer, the *S. herbacea* var. is distinguished from the main community by the higher abundance of *S. herbacea*, although this species is always low and creeping and never shrublike. Also *Emetrum nigrum* is locally abundant. *Juncus trifidus* and *Polygonum viviparum* are moderately frequent but Luzula spicata, Cerastium alpinum, Saxifraga cespitosa and *Oxyria digyna* are absent. Some species are restricted to the oldest lava field Ef 1158, viz. *Selaginella selaginoides* and *Huperzia selago*. The field layer is similar to that of the following *E. nigrum* variant. The *Salix herbacea* var. is probably more exposed to wind and is more tolerant to aeolian material.

The bottom layer, forming a moss carpet of varying thickness, is mixed with *Pogonatum urnigerum* and the frequent *Lophozia ventricosa*. Ruptures are, as in the main community, mainly colonized by *Diphyscium foliosum* and *Anthelia julacea*, while *Bartramia ittyphylla*, *Pohlia drummondii*, *Ceratodon purpureus*, *Stereocaulon vesuvianum* and *Cladonia ssp.* are found on the protruding stones. In shallow depressions, *R. canescens* is sometimes abundant while accompanied by *Drepanocladus uncinatus* and *Hylocomium splendens*. Compared with the main community, the occurrence of the liverworts, e.g., *Barbilophozia hatcheri*, *Tritomaria quinquedentata*, *Ptilidium ciliare* and *Nardia scalaris*, are important.

*Emetrum nigrum* variant

(Table 5, comm. 1.2)

Su 1300 cl. 11, Pá 1554 cl. 23, 24, 25, 26, Næ 1845 cl. 43, Kr 1878 cl. 53, La 1913 cl. 61.

This variant is differentiated from the main community by the abundance of *E. nigrum* in the field layer. *Vaccinium uliginosum* may be locally abundant too. Species, such as *Festuca rubra* and *S. herbacea*, are equally frequent here as in the main community but others, e.g., *Poa glauca*, *Luzula spicata* and *Cerastium alpinum* are lacking or sparse. Species such as *Galium pumilum* ssp. *normanii* and *Thymus praecox* ssp. *arcticus*, are more frequent; they indicate a transition to the *E. nigrum - R. lanuginosum* comm.

The bottom layer is most frequently a continuous mat of the dominant *R. lanuginosum*, with few other species occurring. *R. canescens* is moderately frequent and *Drepanocladus uncinatus* and *Pogonatum urinigerum* are rare. The scattered occurrence of *Hylocomium splendens* and *Rhytidadelphus squarrosum* indicates also the transition to the *E. nigrum - R. lanuginosum* comm. Due to the usually thick moss carpet (up to 35 cm thick) small acrocarpous mosses and most lichens are infrequent.

*Stereocaulon vesuvianum* variant

(Table 5, comm. 1.3)

Næ 1845 cl. 42, Kr 1878 cl. 49, La 1913 cl. 57.

In the field layer of the *S. vesuvianum* var., the occurrence of vascular species varies considerably. *Saxifraga*

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Cystopteris fragilis
Carex bigelowii
Trisetum spicatum
Juncus trifidus
Cardaminopsis petraea
Cystopteris fragilis
Silene acaulis
Cerastium alpinum
Luzula spicata
Oxyria digyna

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cespitosa, Oxyria digyna and Salix herbacea are favoured by the sandy ground. Galium pumilum ssp. normanii and Deschampsia alpina are more rare.

In the bottom layer, S. vesuvianum is abundant and forms small bolsters. R. lanuginosum is dominant and Pogonatum urnigerum and Drepanocladus uncinatus occur scattered. Some small liverworts, e.g., Anthelia julacea, Gymnomitrion corallioides and G. concinnum together with other mosses, indicate late snow cover.

7.3.2 Racomitrium canescens comm.
(Table 5, comm. 2) Ef 1158 cl. 5, Su 1300 cl. 9, Tr 1725 cl. 33, Lf 1766 cl. 36, Næ 1845 cl. 46, Kr 1878 cl. 50, La 1913 cl. 62, Lf 1947 cl. 66.

The R. canescens comm. is confined to slopes and depressions of various depth in the main surface. It occupies relatively small areas and occurs where snow gathers during winter time, indicated by the presence of, e.g., Conostomum tetragonum. The border of the community is distinct in the depressions but becomes progressively more diffuse towards the hillocks (Fig. 17). The ground is often stony with many ruptures. The community, including its variants, is very widespread in the area and occurs in all lava fields, except for No 1389 and På 1554.

The field layer is very variable in cover (0 - 40 %). In many respects the similarity to the R. lanuginosum comm. (incl. the variants) is great, but species abundances and frequencies may differ. The cover value and abundance of the dwarf shrubs Salix herbacea and Empetrum nigrum may be fairly high locally. Among species with lower frequency can be mentioned, e.g., Galium pumilum ssp. normanii, Kobresia myosuroides, Trisetum spicatum, Festuca vivipara and Juncus trifidus. A few herbs (e.g., Armeria maritima, Polygonum viviparum) and grasses (e.g., Agrostis stolonifera, Festuca rubra) are moderately frequent, while others occur more locally due to special circumstances (e.g., Phleum alpinum, Deschampsia flexuosa, D. alpina and Carex bigelowii). Thalictrum alpinum, Polygonum viviparum, Kobresia myosuroides and Galium pumilum ssp. normanii grow mainly in the moss carpet, but other vascular species are largely confined to small sandy patches (e.g., Silene acaulis and Cardaminopsis petraea), ruptures (e.g., Saxifraga cespitosa, S. oppositifolia and Armeria maritima) or small tephra patches (e.g., Oxyria digyna, Lychnis alpina and Silene maritima).

The community is physiognomically well demarcated due to the dominance of R. canescens in the bottom layer. R. lanuginosum is also constant and may even be abundant in some places. Drepanocladus uncinatus can also be abundant locally. Constant species include Anthelia julacea and Gymnomitrion corallioides. The number of cryptogams may be high, which can be related to the roughness of the surface.

Salix herbacea variant
(Table 5, comm. 2.1)
Lf 1766 cl. 38, La 1913 cl. 64.

The S. herbacea var. of the R. canescens comm. occurs only in two lava fields. Apart from the constant, S. herbacea, the variant differs from the main community by a relatively large number of species.
**Empetrum nigrum** variant (7/7)  
(Table 5, comm. 2.2)  
The *E. nigrum* var. of the *R. canescens* comm. has only been found in Su 1300, cl. 12 (see 7.5.2).

7.3.3 *Stereocaulon vesuvianum* comm.  
(Table 5, comm. 3) Kr 1878 cl. 55, La 1913 cl. 59, 60, Lf 1947 cl. 68.

The *S. vesuvianum* comm. is confined to Kr 1878 and La 1913 and Lf 1947 (Fig. 18). Its occurrence in Kr 1878 and La 1913 northeast of Mt. Hekla is presumably linked to the more continental climate there than in other parts of the area. In Lf 1947 the community occurs at high altitude and its occurrence may perhaps be explained by the absence of developed moss carpet of *R. lanuginosum*.

Vascular species are scarce, especially at high altitudes. In Lf 1947 the field layer is totally absent. In Kr 1878 and La 1913, there is a scattered occurrence of small herbs and grasses, such as *Armeria maritima* and *Poa glauca* respectively.

The bottom layer of this chionophilous community is dominated by *S. vesuvianum*, which forms a well-developed and continuous carpet, mixed with *R. lanuginosum* and *R. canescens*. *Placopsis gelida* and *Anthelia julacea* occur with high frequency and *Drepanocladus uncinatus* is locally abundant. Small mosses, other liverworts and lichens are scattered.

7.3.4 *Drepanocladus uncinatus - Carex bigelowii*  
comm.  
(Table 5, comm. 4)

The *D. uncinatus - C. bigelowii* comm. has only been found in depressions in Pá 1554, cl. 27 (see 7.7.2).

7.3.5 *Anthelia julacea - Pohlia drummondii* comm.  
(Table 5, comm. 5) Kr 1878 cl. 54, La 1913 cl. 63.

The *A. julacea - P. drummondii* comm. is confined to the area northeast of Mt. Hekla (Kr 1878 and La 1913). The community occurs in small patches, where the ground is sandy and stable. The moisture conditions are favourable, at least periodically. The field layer is absent or very scarce. The bottom layer of this community is more or less broken up by small protruding stones. *Anthelia julacea*, covering only a few cm², colours the patches in between whitish gray, mixed with small tufts of *R. lanuginosum*, *R. canescens* and

Fig. 18. *Stereocaulon vesuvianum* community predominating on a lava surface at 710 m a.s.l. in the Krakatindshraun lava field from the 1878 eruption. - July 1980.

**Stereocaulon vesuvianum**.

The community resembles the alliance Polytrichion norvegici (Gjæreblad 1956).

7.3.6 *Empetrum nigrum - Racemniitrum lanuginosum*  
comm.  
(Table 5, comm. 6)

The *E. nigrum - R. lanuginosum* comm. is confined to the lower parts of the three oldest lava fields (EF 1158, Su 1300-I and No 1389-I & II). It is represented by four different variants. The community occurs frequently on slopes facing south and southwest but also in open depressions. The community never covers large areas and is usually split up by the moss carpet of *R. lanuginosum*.

The structure of the community and the presence of *B. pubescens*, which forms the scattered shrub layer (locally with *S. phylicifolia*), make this community physiognomically easy to distinguish from others in the lava fields.

In the field layer, the carpet of dwarf shrubs is frequently continuous. It is composed of the dominant *E. nigrum*; *Arctostaphylos uva-ursi*, *Vaccinium uliginosum* and *Salix phylicifolia* may be fairly abundant and even physiognomically dominant as well. The number of herbs and grasses is large. Species with high frequency are *Festuca rubra*, *Polygonum viviparum*, *Carex bigelowii*, *Galium pumilum* ssp. *normanii*, *G. verum*, *Agrostis vinalis* and *Juncus trifidus*. The scattered occurrence of many more species, e.g., *Deschampsia flexuosa*, *Luzula multiflora*, *Corallorhiza trifida*, *Coleoglossum viride*, and *Erigeron borealis* gives this community a luxuriant appearance.

The bottom layer is mostly well-developed except in
the densest stands of dwarf shrubs. *R. lanuginosum* is
the frequent dominant but *R. canescens, Drepanoclados uncinitus* and *Hylocomium splendens* alternate as dominants or subdominants. Some companion species to *R. lanuginosum*, such as *Pogonatum urnigerum*, and other acrocarpous mosses, such as *Bartramia thyphillla* and *Distichium capillaceum*, have a low frequency. Among the liverworts, *Barbilophozia hatcheri* and *Ptilidium ciliare* are moderately frequent but, e.g., *Anthelia julacea* is rare. Lichens, except for *Peltigera* spp., occur only scattered.

Three of the variants are characterized by the dominance of dwarf shrubs (*Arctostaphylos uva-ursi, Vaccinium uliginosum* and *Salix phylicifolia*) and one by the dominance of the moss species *Hylocomium splendens* in the bottom layer.

*Arctostaphylos uva-ursi* variant

(Table 5, comm. 6.1)

Ef 1158 cl. 2, No cl. 15, 20.

The *A. uva-ursi* var. occurs in Ef 1158 and No 1389 in more exposed places than the other variants. The variant differs from the others by the abundance of *A. uva-ursi* and the local occurrence of *Calluna vulgaris, Agrostis stolonifera* and *Erigeron borealis*. In No 1389-IV the bottom layer has been severely damaged by aeolian material.

*Vaccinium uliginosum* variant

(Table 5, comm. 6.2)

Ef 1158 cl. 1, Su 1300 cl. 13, No 1389 cl. 16.

The *V. uliginosum* var. occurs in the three oldest lava fields. It is mainly confined to the middle part of slopes. The variant differs from the others by the abundance of *V. uliginosum* and the local occurrence of *Calluna vulgaris, Agrostis stolonifera* and *Erigeron borealis*. In No 1389-IV the bottom layer has been severely damaged by aeolian material.

*Salix phylicifolia* variant

(Table 5, comm. 6.3)

The *S. phylicifolia* var. of the *E. nigrum - R. lanuginosum* comm. has only been found in depressions in No 1389, cl. 17 (see 7.6.2).

*Hylocomium splendens* variant

(Table 5, comm. 6.4)

The *H. splendens* var. of the *E. nigrum - R. lanuginosum* comm. has only been found in Su 1300, cl. 7, 8. (see 7.5.3).

7.3.7 *Agrostis vinealis* - *Drepanoclados uncinitus* comm. (Table 5, comm. 7)

The *A. vinealis* - *D. uncinitus* comm., is only found in one place in Su 1300, cl. 10 (see 7.5.4).

7.3.8 *Luzula spicata* - *Festuca vivipara* comm.

(Table 5, comm. 8) No 1389 cl. 22.

The *L. spicata* - *F. vivipara* comm. (incl. the following variant) belongs to the open field vegetation (Steindörsson 1964) and is found on hillocks in two of the oldest lava fields (EF 1158, No 1389-III). It is mainly developed in places where there is wind erosion and seems to be an initial stage of a gravel flat vegetation with an open sward. It is not, or very little, influenced by aeolian deposits.

The field layer covers 10 - 50%. Besides the physiognomical dominants, some herbs and grasses occur scattered, e.g., *Minuartia rubella* and *Agrostis stolonifera*.

The bottom layer consists of *Bryum* spp., Ceratodon purpureus and/or scattered *R. lanuginosum*.

*Thymus praecox* ssp. *arcticus* variant

(Table 5, comm. 8.1) Ef 1158 cl. 3, No 1389 cl. 18.

The physiognomical dominance of *T. praecox* ssp. *arcticus* and the occurrence of the subdominant *Cerastium alpinum* in the field layer characterize the *Thymus praecox* ssp. *arcticus* var. The bottom layer covers ca. 10% with scattered occurrence of *R. lanuginosum* and *Pogonatum urnigerum*.

7.3.9 *Festuca rubra* - *Agrostis stolonifera* comm.

(Table 5, comm. 9)

The *F. rubra* - *A. stolonifera* comm. has only been found in No 1389-IV, cl. 19, 21 (see 7.6.4).

7.3.10 *Calamagrostis stricta* - *Festuca rubra* comm.

(Table 5, comm. 10)

The *C. stricta* - *F. rubra* comm. has only been found in Kr 1878, cl. 52 (see 7.12.5).
7.3.11 *Oxyria digyna* - *Silene maritima* comm.  
(Table 5, comm. 11)

The *O. digyna* - *S. maritima* comm. has only been found in Næ 1845-II, cl. 44, 45, 47, 48 (see 7.11.3).

7.4 Plant communities of Efraholfsbraun 1158  
(Table 6, clusters 1 - 5)

### 7.4.1 *Racomitrium lanuginosum* comm.

In this lava field, the oldest historical one, the *R. lanuginosum* heath is still predominating, as in the younger fields. The *R. lanuginosum* comm. is represented by its *Salix herbacea* var., which mainly occupies the uppermost part of the main surface.

*Salix herbacea* variant (cl. 4)

In the field layer *S. herbacea* is dominant. Other abundant and constant vascular species are *Emetrum nigrum* and *Festuca rubra*. *Polygonum viviparum* and *Juncus trifidus* are frequent and characteristic for the community. Except for scattered occurrence of, e.g., *Kobresia myosuroides* and *Trisetum spicatum*, the scarcity of vascular species is typical for this community here.

The bottom layer consists mainly of a thick moss carpet, totally dominated by *R. lanuginosum*. The variant is poor in species, two of which are constants: *Pogonatum urnigerum* and *Lophozia ventricosa*. There are small patches with, e.g., *Anthelia julacea*, *Gymnomitrium concinnatum*, *G. corallioides* and *Nardia scalaris* and protruding stones in the moss carpet, e.g., *Encalypta rhabdocarpa*, *Distichium capillaceum*, *Pohlia cruda* and *Stereocaulon spp.*, occurring sporadically.

In shallow depressions the *Hylocomium splendens* facies occurs with a more luxuriant appearance. A few vascular species are restricted to this facies, e.g., *Thalictrum alpinum*, *Selaginella selaginoides* and *Huperzia selago*, but they occur with low frequency. In the bottom layer there are, of course, some species, such as *Barbilophozia hatcheri* which usually occur more frequently in the *R. canescens* comm.

### 7.4.2 *Racomitrium canescens* comm. (cl. 5)

The *R. canescens* comm. is mainly restricted to depressions and the lowest part of slopes. It occupies only
small areas. In the field layer Polygonum viviparum is constant; Empetrum nigrum is abundant and Carex bigelovii is frequent while Salix herbacea and Festuca rubra are moderately frequent.

The bottom layer is unusually poor in species and physiognomically dominated by R. canescens, mixed with R. lanuginosum and Drepanocladus uncinitus.

### 7.4.3 Empetrum nigrum - Racomitrium lanuginosum comm.

The E. nigrum - R. lanuginosum comm. is found in and around the birchwood on the south- to west-facing slopes and down the shallow depressions. It is represented with its two variants; the Vaccinium uliginosum var. and Arctostaphylos uva-ursi var. In a shallow depression, some Salix phylicifolia shrubs appear, not very high (35 - 40 cm) and creeping. No analyses are presented here.

Vaccinium uliginosum variant (cl. 1)
The V. uliginosum var. is common and has a wide distribution. It is unusually rich in species. Scattered occurrence of Betula pubescens forms an open shrub layer. V. uliginosum is abundant. It is a constant species in the field layer as well as Empetrum nigrum and Festuca vivipara. Salix herbacea, S. callicarpea, Galiumpumilum ssp. normanii, Polygonum viviparum and Carex bigelovii are frequent. A few other species occur sporadically but are still characteristic for the community: Arctostaphylos uva-ursi, Deschampsia flexuosa, Juncus trifidus, Galium verum, Luzula multiflora and Thymus praecox ssp. arcticus.

The bottom layer is rich in species and mainly dominated by the constants R. canescens, R. lanuginosum. Drepanocladus uncinitus is frequent, Hylocomium splendens, and Lophozia ventricosa occur moderately frequently. Some liverworts occur sporadically, such as Anthelia julacea, Barbilophozia hatcheri and Pitlidium ciliare. Arctostaphylos uva-ursi variant (cl. 2) The A. uva-ursi var. forms a distinct zone uppermost in the slopes and merges gradually into the R. lanuginosum comm. The variant has a certain resemblance with the above-mentioned variant regarding both field and bottom layer. The main difference is the high abundance of A. uva-ursi and Empetrum nigrum, and the absence of some vascular species such as Carex bigelovii, Luzula multiflora, Thalictrum alpinum and Galium verum.

### 7.4.4 Luzula spicata - Festuca vivipara comm.

The L. spicata - F. vivipara comm. is only represented by its fragmentarily developed variant on wind-eroded hillocks. All mentioned species are typical for the gravel beds in Iceland which are permanently exposed to wind (Steindórsson 1964).

Thymus praecox ssp. arcticus variant (cl. 3)
The physiognomy of this variant is dominated by T. praecox ssp. arcticus in the field layer. Subdominants are Luzula spicata, Festuca vivipara, Agrostis stolonifera, Poa glauca and Trisetum spicatum. Other recorded species are Polygonum viviparum, Cerasium alpinum and Juncus trifidus. The bottom layer is open with small cushions of R. lanuginosum, mixed with Pogonatum urnigerum.

### 7.4.5 Ecological remarks

The result of the CCA on the material for Ef 1158 can be summarized as follows:

<table>
<thead>
<tr>
<th>Axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>67.1</td>
<td>32.9</td>
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<td>0</td>
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<tr>
<td>Biplot scores of environmental variables:</td>
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<tr>
<td>Surface roughness</td>
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<td>-115</td>
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<td>0</td>
</tr>
<tr>
<td>Tephra cover</td>
<td>142</td>
<td>255</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Two environmental factors have been included in the
CCA of this material of Ef 1158 (Fig. 19). The main differentiation along axis 1, which is related to roughness, is expressed by the concentration of *R. lanuginosum* stands to the left, where the surface is even, versus the occurrence of the *E. nigrum - R. lanuginosum* stands and *R. canescens* stands to the right, where the surface is rough. In fact, this contrast is originally one between the upper parts of the main surface and depressions, dominated by *R. lanuginosum* and *R. canescens* respectively. Secondly, *R. lanuginosum* develops a thick carpet, which has a strongly levelling effect.

The *V. uliginosum* var. of the *E. nigrum - R. lanuginosum* comm. occurs mainly on slopes between the upper parts of the main surface and depressions. Here, surface roughness is more pronounced because *R. lanuginosum* has not developed that well; it is in fact partly overgrown by the heath species. Moreover, the soil is moister than in the main type. Within the *R. canescens* comm., little differentiation occurs.

Although the *R. lanuginosum* comm. has a wide amplitude, stretching from hillocks to shallow depressions, the abundance of its species does not vary to the extent that separate facies should be distinguished, except for a *Hylocomium splendens* facies. In the *R. lanuginosum* comm., the tephra deposit of 1970 disappeared relatively fast under the moss carpet, or was blown away, i.e., from small hillocks.

Barren and stony ground occurs sporadically on the top of wind-exposed small hills. The habitat seems to be the initial stage of a gravel ground. The *L. spicata - F. vivipara* comm. is distinct from other communities. Its position in Fig. 20 to the extreme right of axis 1, suggests that it is maximally different from the *R. lanuginosum* comm.

The proportion of the three main types mentioned, the *Racomitrium* heath (*R. lanuginosum* and *R. canescens*), dwarf shrubs and shrubs (*Betula pubescens*) occupy 60, 40 and 20 % respectively. The occurrence of *B. pubescens* is confined to the *V. uliginosum* var. of the *E. nigrum - R. lanuginosum* comm.

The *R. lanuginosum* comm. is widely distributed and generally characterized by the scarcity of vascular species. Its *E. nigrum* var., occurring in less exposed places, is usually richer in species.

*Festuca rubra* is frequent while *Empetrum nigrum*, *Salix herbacea* and *Carex bigelowii* may be fairly abundant in the field layer. *Polygonum viviparum*, *Agrostis vinealis, Potentilla crantzii, Thymus praecox ssp. arcticus*, *Galium pumilum ssp. normanii* and *Thalictrum alpinum* are scattered where the moss carpet is less dense.

The bottom layer is mostly poor in moderately frequent species. In some places *R. canescens* is subdominant, hence a facies of this species has been distinguished with *Galium boreale* as a constant in the field layer. The bottom layer of the facies is mixed with *Hylocomium splendens* and *Rhytidiadelphus squarosus* and is characterized by a higher frequency of other mosses, liverworts and lichens.

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**7.5 Plant communities of Suðurhraun 1300**

(Table 7, clusters 6-13)

**7.5.1 *Racomitrium lanuginosum* comm.**

The *R. lanuginosum* comm. is widely distributed and generally characterized by the scarcity of vascular species. Its *E. nigrum* var., occurring in less exposed places, is usually richer in species.

*Empetrum nigrum* variant (cl. 11)

*E. nigrum* is a constant species of the *E. nigrum* var. and *Salix herbacea* is frequent in the field layer. Some vascular species occur scattered, such as *Polygonum viviparum* and *Festuca rubra*, and the others are rare, e.g., *Salix phylicifolia, Arcostaphylos uva-ursi* and *Galium pumilum ssp. normanii*.

*R. lanuginosum* is dominating in the bottom layer. Due to the many ruptures the number of species is...
Table 7. Synoptic table for the eight community groups in the Suðurhraun lava field from 1300.

<table>
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<tr>
<th>Cluster size</th>
<th>Clusters</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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<td>Cluster 9: Raconitrum canescens comm.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster 10: Agrostis vinealis - Drepanocladus uncinatus comm.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster 11: Raconitrum lanuginosum comm. - Empernum nigrum var.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster 12: Raconitrum canescens comm. - Empernum nigrum var.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cluster 13: Empernum nigrum - Raconitrum lanuginosum comm.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaccinium uliginosum</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional species, occurring with a synoptic score <1, or with 1 but in only 1 or 2 clusters (cluster number between brackets).

Alchemilla alpina 1(7); Amphidium mougeotii 1(11,12); Armeria maritima 1(10); Barbilophozia hatcheri 1(12,13); Barisia alpina 1(8); Beomyces rufus 1(13); Bryum sp. 1(11,12); Calluna vulgaris 1(11); Cephalozia arctica 1(12,13); C. sp. 1(11,12); Coleogyne ramosissima 1(13); Coptopteris fragilis 1(11); Dichodontium pellucidum 1(12); Dicranum fusceans 1(12); Diaphyscum foliosum 1(8,11); Distichicum capillaceum 1(6,11); Dryas octopetala 1; Encalypta rhabdocarpa 1(8); Erigeron borealis 1(10); Festuca vivipara 1(9); Galium boreale 1(6,10); Gymnomitrion concinnatum 1(12); Hieracium sp. 1(13); Jungmannia spheuroporata 1; Lophozia bicornata 1(12); L. heteroceros 1(12); Luzula multiflora 1(7,13); L. scirta 1(8); Metzgeria furcata 1; Parnassia palustris 1; Peltigera leucophlebia 1(12); P. rufescens 1(13); P. venosa 1(12); P. sp. 1(16,7); Pleurozium schreberi 1; Poa glauca 1(11); Polytrichum alpinum 1(7,11); Potentilla crantzii 1(6); Pseudospora hynoptum 1(13); Raconitrum fasciculare 1; Salix lanata 1(13); Saxifraga nivalis 1(11); Scapania curta 1(12); Silene acaulis 1(12); Solonaria crocea 1(13); Stereocaulon sp. 1(9); Taraxacum sp. 1(6,9); Timmia australica 1(8,12); Tolotella pusilla 1(8); Umbilicaria sp. 1(13).

In the bottom layer, the E. nigrum variant dominates. The E. nigrum - R. lanuginosum comm. is moderately frequent and other mosses, such as Hylocomium splendens and Polytrichum juniperinum, occur scattered. Ptilidium ciliare is an infrequent liverwort.

**7.5.2 Raconitrum canescens comm. (cl. 9)**

The R. canescens comm. is rather poor in vascular species. In the field layer Saxix phylicifolia and Agrostis vinealis are constant and Festuca rubra is frequent. Species with lower frequency include Carex bigelowii, Thalictrum alpinum, Thymus praecox ssp. arcticus and Festuca vivipara.

In the bottom layer, R. canescens is dominant and R. lanuginosum subdominant. Drepanocladus uncinatus is moderately frequent, and other mosses, such as Hylocomium splendens and Polytrichum juniperinum, occur scattered. Ptilidium ciliare is an infrequent liverwort.

**Empernum nigrum variant (cl. 12)**

The field layer of the E. nigrum var. is dominated by E. nigrum, but S. phylicifolia is absent. Constants are Carex bigelowii (often abundant), Festuca rubra, Kobresia myosuroides and Polygonum viviparum. Other vascular species are scattered, such as Galium pumilum ssp. normanii and Saxix herbacea.

The bottom layer is rich in species. R. canescens is dominating and R. lanuginosum is abundant. Drepanocladus uncinatus is constant and may become abundant, while Hylocomium splendens is more scattered. These two species are often mixed with Timmia australica, Ptilidium ciliare, Tritomaria quinque dentata, Lophozia ventricosa and Peltigera leucophlebia.

The ground has many ruptures, indicated by the occurrence of Dichodontium pellucidum, Lophozia bicornata, Scapania curta, Gymnomitrion concinnatum and Solorina crocea. The stony ground is colonized by Bryum spp., Pohlia drummondii, Amphidium mougeotii and Stereocaulon vesuvianum.
Hylocomium splendens var. and the Vaccinium uliginosum var. The V. uliginosum var. is mainly restricted to steep slopes. The tops of these slopes end often abruptly at the base of crags. This may explain the absence of the Arctostaphyllos uva-ursi variant. The H. splendens var. occupies horizontal ground.

Hylocomium splendens variant (cl. 7 and 8)
In the field layer, the dwarf-shrubs Salix phyllicifolia, V. uliginosum and Empetrum nigrum are dominating in the H. splendens var. Salix herbacea may locally be fairly abundant, in places where Bartsia alpina, Luzula spicata and Tofieldia pusilla are frequent. Festuca rubra is constant and Polygonum viviparum frequent. Thalictrum alpinum is moderately frequent but other species are rare, such as Alchemilla alpina, Agrostis vinealis, Thymus praecox ssp. arcticus, Galium pusillum ssp. normanii and G. verum.

In the bottom layer, H. splendens dominates in shallow and wide depressions, often mixed with R. lanuginosum, R. canescens, Drepanocladus uncinatus and Rhytidiadelphus triquetrus are scattered. Lophozia ventricosa, Pitilidium ciliare and Tritomaria quinquentata are the most common liverworts. Occurrences of other species (e.g., Polytrichum alpinum, Peltigera rufescens and Stereocaulon vesuvianum) are linked to local environmental characteristics such as exposure, sward density and the frequency of rock ledges. Pleurozium schreberi, Timmia austriaca and Diphysicum foliosum are found in a more open bottom layer.

Vaccinium uliginosum variant (cl. 13)
In the field layer of the V. uliginosum var., V. uliginosum and Empetrum nigrum dominate. Arctostaphyllos uva-ursi is often abundant. Constant species are also Festuca rubra, Galium pusillum ssp. normanii and Polygonum viviparum. Agrostis vinealis and Kobresia myosuroides are infrequent and Coleglossum viride, Luzula multiflora and Juncus trifidus are rare. Salix phyllicifolia and S. herbacea are absent.

In the bottom layer, H. splendens is replaced by Drepanocladus uncinatus and the frequency and abundance of R. lanuginosum and R. canescens is much higher. Among rare species can be mentioned Pitilidium ciliare, Peltigera rufescens, Polytrichum juniperinum and Barbilophozia hatheri.

7.5.4 Agrostis vinealis - Drepanocladus uncinatus comm. (cl. 10)
Although grass heathland is common in Iceland it is rare in the alpilhraun. Jónsson (1906a) stressed that it may not even be found there until the lava field is totally leveled by soil. The community belongs to the grassy heathland vegetation type (Steindórsson 1966).

The field layer of the A. vinealis - D. uncinatus comm. is dominated by grasses, notably Agrostis vinealis, A. capillaris and Festuca rubra. The occurrence of Erigeron borealis, Galiun boreale, Armeria maritima, Cerastium alpinum, and C. fontanum is very characteristic, where the community is influenced by sheep-grazing.

The bottom layer is dominated by D. uncinatus whereas Hylocomium splendens and Rhytidiadelphus squarrosus are subdominants. The total absence of Racemitrium spp. is notable.

The community occurs in shallow depressions less exposed than the environment of the R. lanuginosum heath. The soil is deep (>30 cm), silty to fine sandy, and nutrient poor. The grass-rich heath may be regarded as intermediate between the nutrient-richer grasslands (vallendi) in Iceland and the vegetation types of the R. lanuginosum heath (Gunnlaugsdóttir 1985). The community is most similar to the Drepanocladus uncinatus dominated form of the subass. racemitrietsosum canescents of the Agrostio capillaris-Hylocomietum splendentis (Gunnlaugsdóttir 1985).

7.5.5 Ecological remarks
The result of the CCA on the material for Su 1300 can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>46.2</td>
<td>23.5</td>
<td>14.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Biplot scores of environmental variables:
- surface roughness: -63 -94 9 190
- tephra cover: -97 127 211 25
- elevation: -212 212 180 -82
- no. of tephra falls: -213 -28 -233 109
- quantity of acc. mat.: 421 161 -12 9

Five environmental factors have been included in the CCA of this material of Su 1300 (Fig. 20). The two environmental factors explaining most of the floristical variation are quantity of deposits, which runs parallel to axis 1, and altitude, which runs diagonally upwards to the left together with tephra cover. The main differentiation along axis 1, is related to the quantity of accumulated material, and is negatively correlated with the number of tephra layers. This shows that the lava field has been influenced by deposits of other origin than tephra falls. The two variants of the E. nigrum
7.6 Plant communities of Norðurhráun 1389
(See Table 8, clusters 14 - 22)

7.6.1 Racotritium lanuginosum comm. (cl. 14)

The *R. lanuginosum* comm. has a wide distribution, especially in No 1389-III. In the field layer, *Emetrum nigrum*, *Festuca rubra* and *Galium pubescens* ssp. *normanii* are constant species. *Salix herbacea*, *Polygonum viviparum* and *Carex bigelowii*are moderately frequent. *Vaccinium uliginosum* and *Arctostaphylos uva-ursi* are locally abundant. Other species are rare, such as *Agrostis vinealis*, *Festuca vivipara* and *Rhytidiodendron squarrosum*.

Table 8. Synoptic table for the nine community groups in the Norðurhráun lava field from 1389.

<table>
<thead>
<tr>
<th>Cluster no.</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster size</td>
<td>92</td>
<td>16</td>
<td>74</td>
<td>40</td>
<td>10</td>
<td>8</td>
<td>16</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

Cluster 14: Racotritium lanuginosum comm.
Cluster 15: *Emetrum nigrum* - Racotritium lanuginosum comm.
Cluster 16: *Emetrum nigrum* - Racotritium lanuginosum comm. *Vaccinium uliginosum* var.
Cluster 17: *Emetrum nigrum* - Racotritium lanuginosum comm. *Salix herbacea* var.
Cluster 19: *Festuca rubra* - *Agrostis stolonifera* comm.
Cluster 21: *Festuca rubra* - *Agrostis stolonifera* comm.

Additional species, occurring with a synoptic score <1, or with 1 but in only 1 or 2 clusters (cluster number between brackets).

*Alchemilla alpina* <1; *Armeria maritima* <1(19); *Boraginaceae floerkei* <1(15); *B. hatcheri* <1(16, 15); *Betula pubescens* <1(15); *Bryum sp.* <1(18, 20); *Cardaminopsis petraea* <1(18); *Carex maritima* <1(19); *Cerastium alpinum* <1(14, 18); *Ceratodon purpureus* <1(18, 20); *Cephaloziinae trifida* <1(15); *Chadonia ecnocyna* <1(15); *Deschampsia flexuosa* <1(16); *Dicranum scoparium* <1(18); *Dicyonodontium spinulosum* <1(15); *Dichondra spictata* <1(14, 15); *E. nigrum* <1(17); *E. schafta* <1(17); *Erigeron borealis* <1(15); *Festuca rubra* - *Agrostis stolonifera* comm.

*Additional species, occurring with a synoptic score <1, or with 1 but in only 1 or 2 clusters (cluster number between brackets).*

*Alchemilla alpina* <1; *Armeria maritima* <1(19); *Boraginaceae floerkei* <1(15); *B. hatcheri* <1(16, 15); *Betula pubescens* <1(15); *Bryum sp.* <1(18, 20); *Cardaminopsis petraea* <1(18); *Carex maritima* <1(19); *Cerastium alpinum* <1(14, 18); *Ceratodon purpureus* <1(18, 20); *Cephaloziinae trifida* <1(15); *Chadonia ecnocyna* <1(15); *Deschampsia flexuosa* <1(16); *Dicranum scoparium* <1(18); *Dicyonodontium spinulosum* <1(15); *Dichondra spictata* <1(14, 15); *E. nigrum* <1(17); *E. schafta* <1(17); *Erigeron borealis* <1(15); *Festuca rubra* - *Agrostis stolonifera* comm.

*Additional species, occurring with a synoptic score <1, or with 1 but in only 1 or 2 clusters (cluster number between brackets).*

*Alchemilla alpina* <1; *Armeria maritima* <1(19); *Boraginaceae floerkei* <1(15); *B. hatcheri* <1(16, 15); *Betula pubescens* <1(15); *Bryum sp.* <1(18, 20); *Cardaminopsis petraea* <1(18); *Carex maritima* <1(19); *Cerastium alpinum* <1(14, 18); *Ceratodon purpureus* <1(18, 20); *Cephaloziinae trifida* <1(15); *Chadonia ecnocyna* <1(15); *Deschampsia flexuosa* <1(16); *Dicranum scoparium* <1(18); *Dicyonodontium spinulosum* <1(15); *Dichondra spictata* <1(14, 15); *E. nigrum* <1(17); *E. schafta* <1(17); *Erigeron borealis* <1(15); *Festuca rubra* - *Agrostis stolonifera* comm.
Kobresia myosuroides, Carex capitata, Dryas octopetala, Poa pratensis, Parnassia palustris and Gentiana nivalis.

R. lanuginosum dominates in the thick pure bottom layer. Pogonatum urnigerum and Lophozia ventricosa are frequent. Hylocomium splendens, Polytrichum juniperinum, Peligeraleucolephelia and S. vesuvianum are only present sporadically.

In some places many ruptures occur in the moss carpet. These patches are small, generally sparsely vegetated with a number of species worth mentioning, e.g., R. canescens, Drepanocladus uncinatus, Polytrichum alpinum, P. piliferum, Nardia scalaris, Gymnomitrium concinnatum and Ptilidium ciliare. In other places, small stones are exposed and colonized, e.g., by Stereocaulon botryosum, Racomitrium fasciculare, Grimmia torquata, Dicranella subulata, Amphidium trichum alpinum, P. pillferum, Nardia sea/m-is, Gymnomitrium concinnatum and Ptilidium ciliare. These patches are small, generally sparsely vegetated, with a number of species worth mentioning, e.g., Thymus praecox ssp. arcticus, Carex bigelowii, Luzula multiflora, and Agrostis capillaris, Thymus praecox ssp. arcticus.

7.6.2 Empetrum nigrum - Racomitrium lanuginosum comm.

The E. nigrum - R. lanuginosum comm. occurs especially on south- to southwest-facing slopes and on small hillocks. The total number of plant species is high and the vegetation is often luxuriant. Betula pubescens often forms the shrub layer. The community is represented with its three variants: Salix phylicifolia var. (mainly depressions) Vaccinium uliginosum var. (slopes) and Arctostaphylos uva-ursi var. (the uppermost part of slopes).

Salix phylicifolia variant (cl. 17)
The S. phylicifolia var. is closely related to the V. uliginosum var. In the field layer, S. phylicifolia is physiognomically dominating and Empetrum nigrum subdominant. Festuca vivipara is constant, Thymus praecox ssp. arcticus is moderately frequent but Juncus trifidus, Galium verum, Carex bigelowii, Luzula multiflora and Agrostis capillaris occur sporadically.

In the bottom layer, R. canescens and Hylocomium splendens dominate alternatively. R. lanuginosum is constantly present but with low cover and Polytrichum juniperinum is scattered. Bare patches with Distichium capillaceum occur sporadically.

Vaccinium uliginosum variant (cl. 16)
The field layer of the V. uliginosum var. is characterized by the dominant E. nigrum and V. uliginosum occurs as subdominant. Polygongnum viviparum, Festuca vivipara, F. rubra and Agrostis vinealis are frequent but Galium pumilum ssp. normanii, Hieracium sp., Deschampsia flexuosa and Luzula multiflora occur scattered. Some species, such as Arctostaphylos uva-ursi, Salix phylicifolia, S. lanata and Carex bigelovii, are locally abundant. The number of species here is much lower compared with other variants.

The bottom layer is dominated by R. lanuginosum, Hylocomium splendens and Drepanocladus uncinatus. Polytrichum juniperinum and R. canescens are moderately frequent and Rhytidiadelphus squarrosus is rare. In several places the vegetation is rich in some liverworts, such as Barbi lophozia hatcheri and Ptilidium ciliare. Lichens are not common.

Arctostaphylos uva-ursi variant (cl. 15 and 20)The field layer of the A. uva-ursi var. is dominated by A. uva-ursi, whereas E. nigrum and V. uliginosum are constant subdominants. Festuca vivipara and Polygongnum viviparum are frequent. Agrostis capillaris, Calluna vulgaris, Thymus praecox ssp. arcticus and Luzula multiflora are frequent.

The bottom layer is very rich in species compared with other communities. It is dominated by R. lanuginosum but Hylocomium splendens, R. canescens, Drepanocladus uncinatus and Rhytidiadelphus squarrosus are moderately frequent. Liverworts, such as Trichomaria quinquedentata, Bar bilophozia hatcheri and B. floerkei are rare. The lichens Peltigera canina and P. leucolephelia are moderately frequent but P. malacea, S. vesuvianum and Cladonia ecnocyna are rare.

In No 1389-IV this variant is highly influenced by accumulation of sand. There it is very poor in species, with the constants Agrostis stolonifera and Salix phylicifolia. The bottom layer is completely drowned by sand, only with accidental presence of Bryum spp. and Ceratodon purpureus on protruding lava blocks.

7.6.3 Luzula spicata - Festuca vivipara comm. (cl. 22)
The L. spicata - F. vivipara comm. occurs on top of some hillocks. The field layer is poor in species and the bottom layer almost absent. The community is highly influenced by sheep grazing.

Thymus praecox ssp. arcticus variant (cl. 18)The field layer is physiognomically characterized by T. praecox ssp. arcticus and L. spicata as dominants, with scattered presence of Festuca vivipara, Agrostis stolonifera, Minuartiarubella, Cardaminopsis petraea

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and Juncus trifidus. Cerastium alpinum may be abundant.

The abundance of cryptogams in the open sward, exposed to wind and with a minimum cover of snow, is low. R. lanuginosum has a low cover value but is frequent. Ceratodon purpureus, Dicranoweisia crispula and Bryum spp. are infrequent although they are at least locally characteristic for the community.

### 7.6.4 Festuca rubra - Agrostis stolonifera comm.

(cl. 19)

The F. rubra - A. stolonifera comm. is characterized by a few vascular species and a devastated bottom layer, so the concept of plant community with variants can hardly be used. It is highly influenced by drifting sand/tephra (No 1389-IV).

In the field layer, grasses and herbs occur only scattered, such as Juncus trifidus, Kobresia myosuroides, Luzula spicata and Galium verum. On the other hand, Salix herbacea, Armeria maritima, Carex maritima and Silene maritima are regular species. The field layer covers less than 20%.

The bottom layer has only small remnants of moss carpet of R. lanuginosum and R. canescens.

### 7.6.5 Ecological remarks

The result of the CCA on the material for this lava field can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>32.1</td>
<td>21.7</td>
<td>18.0</td>
<td>16.2</td>
</tr>
</tbody>
</table>

The six environmental factors have been included in the CCA of this material of No 1389 (Fig. 21). The main differentiation along axis 1 is related to tephra or sand cover in No 1389-IV. Along axis 2, the uppermost communities are the three variants of the E. nigrum - R. lanuginosum comm. Their position is mainly related to the increasing accumulation of aeolian material. Tephra deposits from many tephra falls have leveled the topography. The topography is similar to that of Ef 1158, with small hills and shallow, open depressions. Here the most luxuriant vegetation occurs. The occurrence of Betula pubescens is confined to these variants. The R. lanuginosum comm. is concentrated at the lower end but extends upward.

At the lower end of axis 2 we find the L. spicata - F. vivipara comm. and its T. praecox ssp. arcticus variant. It is related to the top of the crags or increasing irregularity.

In No 1389-IV, towards the right, the circumstances are quite different; there accumulation of sand is still in progress. Formerly this was a typical lava field but it has become gradually subject to heavy accumulation of sand. This accumulation started probably not more than 60 years ago. The devastation has begun earlier at the edge of the lava and has successively subdued the field. Now, more than 85% of the main surface consists mainly of barren sandy soil, extending in a fairly broad zone along the mountain Botnafjall.

Regarding the vegetation in No 1389-IV, which is scattered, the area can be divided into three categories: a. Pure sandy soil (no analyses). A few species are only found here in the lava fields, such as Leymus arenarius and Lathyrus japonicus. b. Hard-packed sand with Arctostaphylos uva-ursi, Salix lanata, Oxyria digyna, Carex maritima, C. bigelowii, Agrostis stolonifera, Festuca rubra, Silene maritima and Thymus praecox ssp. arcticus. c. Sandy, sheltered places under big stones and in wide clefts with Galium verum, Rhi-
nanthus minor, Rubus saxatilis and Platanthera hyperborea. Amongst the species mentioned here are several maritime species, which are not confined to seashores in Iceland. L. japonicus is mostly found in the coastal areas in Iceland (except in the east) but in South Iceland it also occurs at a great distance from the sea. C. maritima, as well as the other species, are recorded from many localities in the central highlands. Many species of the first substrate category (a) are very typical for cold deserts elsewhere in Iceland (Steindórsson 1964).

The sandy soil is very unstable. It quickly dries up because the soil is well-drained. Consequently, the bottom layer is very scattered or lacking altogether. In some places viable plants of *R. lanuginosum* are covered by sand, which shows that the accumulation has taken place fairly recently. Birchwood has a very patchy occurrence but in one cleft there was an old unique specimen, 2.5 m high and 19 cm in diameter, surrounded by a high sand dune.

### 7.7 Plant communities of Pálsssteinshraun 1554 (Table 9, clusters 23 - 27)

#### 7.7.1 *Racomitrium lanuginosum* comm.

The *R. lanuginosum* comm. is less damaged and more continuous in Pá 1554 than elsewhere. The extensive distribution of the community is mainly due to the uniform feature of the lava field. *R. lanuginosum* has formed an unusually dense and thick moss carpet, especially in the middle of the main surface. The upper 8 - 15 cm of the shoots of *R. lanuginosum* are vital; below there is a thick, brown, decayed layer of mosses, almost without mineral deposits except for the well-demarcated tephra layer of 1947. The *R. lanuginosum* comm. is represented by the following variant.

**Empetrum nigrum** variant (cl. 23, 24, 25 & 26)

The field layer is sparse, except for the constant *Empetrum nigrum*, which is nearly the only species over a large area. *Salix herbacea*, *Juncus trifidus* and *Galium pumilum ssp. normanii* are infrequent while other species such as *Festuca rubra* and *F. vivipara* are rare.

The bottom layer consists mostly of *R. lanuginosum*, which is locally mixed with *Pogonatum urnigerum*.

**R. canescens** and *Drepanoclados uncinitus* are only locally moderately frequent and therefore *Stereocaulon alpinum* may be abundant. Protruding stones or small ruptures occur occasionally in the thick moss carpet and therefore *S. vesuvianum*, *Cladonia* spp. and small acrocarpous mosses are rare or absent. One patch where the wind has blown away the moss carpet is described in section 9.3. Separate facies can be recognized and should be mentioned.

The *Vaccinium uliginosum* facies distinguished within this variant is characterized by the constant *V. uliginosum*, absence of grasses and herbs and a not so dense bottom layer. It contains a slightly larger number of species in the bottom layer, where *Hylocomium splendens* may be abundant. Other species, e.g., *Drepanoclados uncinitus*, *R. canescens*, *Rhytididiades squarrosus* and *Peltigera polydactyla*, occur rarely.

The *Racomitrium canescens* facies occurs in open depressions with a high cover of *Agrostis vinealis* and *Festuca rubra*. *Kobresia myosuroides* and *Galium*
pumilum ssp. normanii also occur. The bottom layer is thin and mixed with Plagiochila porelloides, Lophozia ventricosa and Stereocaulon alpinum. There are also small protruding stones with Cladonia spp., S. vesuvianum and Parmelia saxatilis.

The Drepanocladus uncinatus facies occurs in somewhat deeper depressions than the R. canescens facies. The field layer has several additional vascular species such as Alchemilla alpina, Thymus praecox ssp. arcticus and Salix phylicifolia. S. herbacea is sometimes abundant. The bottom layer differs only by the higher cover of Drepanocladus uncinatus.

7.7.2 Drepanocladus uncinatus - Carex bigelowii comm. (cl. 27)

The D. uncinatus - C. bigelowii comm. differs from the Drepanocladus uncinatus facies of the R. lanuginosum comm. by the dominance of D. uncinatus, the lower cover value of R. lanuginosum and presence of the constant and fairly abundant Carex bigelowii. Festuca rubra is frequent but Galium pumilum ssp. normanii and Empetrum nigrum are rare. The absence of several vascular species is notable. The compact subterranean stolons of Carex bigelowii make it difficult for other vascular species to compete. Apart from the dominant in the bottom layer, R. canescens may sporadically be abundant while R. lanuginosum is infrequent.

7.7.3 Ecological remarks

The result of the CCA on the material for this lava field can be summarized as follows: Since only one factor was involved all variance is explained on axis 1.

biplot scores of environmental variables:

<table>
<thead>
<tr>
<th>Factor</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>axis</td>
<td>1</td>
</tr>
<tr>
<td>surface roughness</td>
<td>414</td>
</tr>
</tbody>
</table>

One environmental factor has been included in the CCA of this material of Pá 1554 (Fig. 22). The main differentiation along axis 1, with the only correlated environmental factor, surface roughness, is between three facies of the E. nigrum var. of the R. lanuginosum comm., i.e., the V. uliginosum facies, the D. uncinatus facies and the R. canescens facies.

The V. uliginosum facies, situated to the left, is very poor in species in comparison with other stands of this type and its occurrence can be considered as the first step in the colonization of the moss carpet. In the middle we find the D. uncinatus facies, while the stands at the right of axis 1 belong to the R. canescens facies. Here the moss carpet is thinnest and the protruding stones are most frequent. Consequently, the largest number of cryptogams is found here.

The D. uncinatus - C. bigelowii comm. is situated at the top of axis 2, expressing the maximum difference between this community and the R. lanuginosum comm. Pá 1554 is entirely surrounded by other lava fields and, therefore, mostly sheltered against deposits of aeolian material.

7.8 Plant community of Lava field 1693

(Table 10, 28 - 32)

7.8.1 Racotnium lanuginosum comm. (cl. 28)

Lf 1693 is a small lava field and here only the R. lanuginosum comm. with its S. herbacea var. has been distinguished. The main reason is the situation of the lava field on a gentle slope, frequently affected by tephra deposits from different eruptions. The R. lanuginosum comm. has not developed into a continuous, thick carpet. A separate facies, rich in Empetrum nigrum, indicates a weak influence of drifting sand/tephra. S. herbacea and Polygonum viviparum are frequent. Galium pumilum ssp. normanii and Kobresia myosuroides are also found with moderate frequency.
In the bottom layer of the community the moss carpet is interrupted and mixed with, e.g., *Polytrichum juniperinum*, *Bartramia ithyphylla*, *Barbilophozia hatcheri*, *B. barbata* and *B. floerkei*. *R. canescens* may be frequent and fairly abundant. Consequently, it is justified to separate a *R. canescens* facies.

**Table 10. Synoptic table for the five community groups in the lava field from the 1693 eruption.**

<table>
<thead>
<tr>
<th>Cluster no.</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster size</td>
<td>26</td>
<td>18</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Racomitrium lanuginosum</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Empetrum nigrum</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Racomitrium canescens</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Salix herbacea</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Lophozia sudetica</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diphyscium foliosum</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Festuca vivipara</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stereocaulon vesuvianum</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pogonatum urnigerum</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polytrichum juniperinum</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthelia julacea</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartramia ithyphylla</td>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nardia scalaris</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polhia drummondii</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tritomaria unguendentata</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lophozia heterocolpos</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Juncus trifidus</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drepanochus uncinatus</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Polygonum viviparum</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polytrichum piliferum</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicranum fuscescens</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ochrolechia frigida</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cluster 28: Racomitrium lanuginosum comm. (Empetrum and *R. canescens* facies)
Cluster 29: Racomitrium lanuginosum comm. Salix herbacea var.
Cluster 30: vegetation fragment
Cluster 31: vegetation fragment
Cluster 32: vegetation fragment

Additional species, occurring with a synoptic score ≤ 1 or with 1 but in only 1 or 2 clusters (cluster number between brackets).
- *Amphidium mougeoti* (29); *Bryum sp.* (1, 28); *Barbilophoziafloerkei* (31); *B. hatcheri* (31); *Cephaloziella arctica* (28); *Cladonia cervicornis* (28, 29); *C. chlorophaea* (28, 29); *Cladonia coccifera* (28, 29); *C. furcata* (<1); *C. sp.* (1, 30); *Cystocoleus niger* (29); *Dicranella sp.* (28, 29); *D. crispula* (28, 30); *Galium pumilum* ssp. (28, 31); *Hylcomium splendens* (1, 31, 32); *Kobresia myosuroides* (1, 28); *Leptariopsis sp.* (29); *L. sp.* (28, 29); *Luzula multiflora* (28); *Mnium stellare* (<1); *M. thomsonii* (28, 29); *Nardia geoscyphus* (29); *Parmelia saxatilis* (30); *Peperiera venosa* (1, 28); *Placopsis gelida* (28, 29); *Plagiochila pereoides* (28, 30); *Pinus alpina* (28, 32); *Polhia cruda* (28, 32); *Polytrichum alpinum* (1, 28, 29); *Psoroma hypnorum* (1, 28); *Salix callicarpea* (29); *Silene acaulis* (1, 31); *Solorina crocea* (28); *Sternula minutus* (<1); *Stereoaulon alpinum* (1, 31); *Timmia austriaca* (28, 29); *Umbilicaria sp.* (1, 30).

**7.8.2 Ecological remarks**

The result of the CCA on the material for this lava field can be summarized as follows:

- **axis:** 1 2 3 4
- **% variance explained:** 69.7 30.3 0 0
- **biplot scores of environmental variables:**
  - surface roughness: 55 303 0 0
  - tephra cover: 479 67 0 0

Two environmental factors have been included in the CCA of this material of Lf 1693 (Fig. 23). The differentiation along axis 1 is related to tephra cover. The diagram suggests that the *S. herbacea* var. of the *R. lanuginosum* comm. is tolerant towards tephra deposits. The *E. nigrum* facies of the *R. lanuginosum* comm. is located at the opposite end of the axis, where the influence of tephra deposition is less pronounced.

The main differentiation along axis 2, which is related to surface roughness, is expressed by the concentration of the *E. nigrum* facies of the *R. lanuginosum* comm. at the lower end, where the substrate is even, against the occurrence of the *R. canescens* facies upward, where the substrate is more rough.

Where the deposit of tephra is thickest, towards the left, degenerated stages of the *R. lanuginosum* comm. occur and the vegetation is heterogeneous. Remnants of some communities are almost totally buried by tephra/sand; they are not described here.

On the other hand, the number of species in the...
Fig. 23. CCA ordination diagram, axes 1 and 2: lava flow from the 1693 eruption. - 1 = *Racomitrium lanuginosum* comm. (cl. 28); 1.1 = ibid., *Salix herbacea* variant (cl. 29); v = vegetation fragment.

bottom layer is unusually rich. The many sheltered places, ledges and small hollows are suitable habitats for many species. Three categories have been distinguished with the following species composition:

(a) In the moss carpet of *R. lanuginosum*, characteristic species are:

*Racomitrium canescens*  
*Pogonatum urnigerum*  
*Lophozia ventricosa*

(b) In sandy patches and ruptures; characteristic species are:

*Polytrichum piliferum*  
*P. alpinum*  
*Anthelia julacea*  
*Barbiplophozia kunzeana*  
*Stereocaulon alpinum*  
*Mnium stellare*  
*Lophozia heterocolpos*  
*Timmia austriaca*

(c) On stones (with accumulation of sand in the vesicles):

*Placopsis gelida*  
*Bartramia ithyphylla*  
*Mnium thomsonii*  
*Pohlia drummondi*  
*Ochrolechia frigida*  
*Drepanocladus uncinatus*  
*Lophozia ventricosa*  
*Conostomum tetragonum*  
*Pohlia drummondi*  
*Polytrichum juniperinum*  
*Polytrichum piliferum*  
*Anthelia julacea*  
*Gymnomitrium corallioides*  
*Gymnomitrium concinnatum*  
*Nardia scalaris*  
*Peltigera venosa*  
*Peltigera occidentalis*  
*Cladonia ecmocyna*  
*Cladonia sp.*  
*Stereocaulon vesuvianum*

Table 11. Synoptic table for the three community groups in the Trippafjallahraun lava field from 1725.

<table>
<thead>
<tr>
<th>Cluster no.</th>
<th>33</th>
<th>34</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster size</td>
<td>5</td>
<td>19</td>
<td>1</td>
</tr>
</tbody>
</table>

- *Racomitrium canescens*  
- *Drepanocladus uncinatus*  
- *Racomitrium lanuginosum*  
- *Polygonum viviparum*  
- *Lophozia ventricosa*  
- *Conostomum tetragonum*  
- *Pohlia drummondi*  
- *Polytrichum juniperinum*  
- *Polytrichum piliferum*  
- *Anthelia julacea*  
- *Gymnomitrium corallioides*  
- *Gymnomitrium concinnatum*  
- *Nardia scalaris*  
- *Peltigera venosa*  
- *Peltigera occidentalis*  
- *Cladonia ecmocyna*  
- *Cladonia sp.*  
- *Stereocaulon vesuvianum*

Additional species, occurring with a synoptic score <1 or with 1 but in only 1 or 2 clusters (cluster number between brackets):

- *Barbilophozia hatcheri* 1(33); *Bryum sp.* 1(34); *Encalypta ciliata* 1(34); *Juncus trifidus* 1(33); *Jungermannia sp.* 1(33); *Lophozia sudetica* 1(34); *Peltigera canina* 1(33); *P. sp.* 1(34,35); *Phleum alpinum* 1(33); *Physcia caesia* 1(33); *Poa alpina* 1(34), *P. glauca* 1(33); *Pogonatum urnigerum* 1(34); *Pohlia cruda* 1(33); *Salix herbacea* 1(34); *Stereocaulon vesuvianum* 1(33); *Umbilicaria torrefacta* 1(33).

7.9 Plant communities of Trippafjallahraun 1725

(Table 11, clusters 33 - 35)

7.9.1 *Racomitrium lanuginosum* comm. (cl. 34)

The field layer of the *R. lanuginosum* comm. is poor in vascular species due to the highly damaged vegetation. *Salix herbacea* is constant with moderate cover while *Polygonum viviparum* and *Poa alpina* are infrequent. Physiognomically, *R. lanuginosum* is the only dominant, mixed with *Pogonatum urnigerum*, *Lophozia ventricosa*, *Anthelia julacea* and some other species with low frequency. On the other hand, the barren patches are colonized by small mosses, liverworts and lichens, often frequent. The barren patches are of two types: (a) A sandy tephra ground with small pebbles, with *Polytrichum piliferum*, *P. juniperinum*, *Pohlia drummondi*, *Encalypta ciliata*, *Lophozia sudetica*, *Acta Phytogeogr. Suec. 77*
Stereocaulon alpinum, S. vesuvianum, Solorina croceae and (b) brown, decaying remnants of R. lanuginosum with Bryum spp., Anthelia julacea, Gymnomitrium coralliioides, G. concinnatum, Nardia scalaris, Peltigera occidentalis, P. venosa and Cladonia spp. (cf. C. pyxidata and C. chlorophaea).

7.9.2 Racomitrium canescens comm. (cl. 33)

The field layer of the R. canescens comm. is poor. Polygonum viviparum and Phleum alpinum are the only moderately frequent species, while Poa glauca and Juncus trifidus are rare.

The bottom layer is dominated by R. canescens but Drepanocladus uncinatus is a co-dominant. Gymnomitrium concinnatum is frequent. Among moderately frequent species are R. lanuginosum, Polytrichum juniperinum, Anthelia julacea, Barbilophozia hatcheri and Nardia scalaris.

7.9.3 Ecological remarks

The result of the CCA on the material for this lava field can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>81.6</td>
<td>18.4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>biplot scores of environmental variables:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface roughness</td>
<td>390</td>
<td>194</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>tephra cover</td>
<td>-383</td>
<td>199</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Two environmental factors have been included in the CCA of this material of Tr 1725 (Fig. 24). The two main axes are roughly equal in importance and the two environmental factors run more or less diagonally. The main differentiation along axis 1 is related to roughness. The R. lanuginosum comm. is situated to the left where the substrate is even, versus the occurrence of the R. canescens comm. to the right, where the substrate is rough (with a larger number of species). The differentiation within the R. canescens comm. is not clear. This community is restricted to sheltered places in some fissures, since deep depressions are rare or absent. These fissures are 0.5 - 1 m wide and 0.3 - 1.0 m deep. They extend from northeast - southwest and the soil is a hard-packed sand.

Along axis 2, the tephra cover increase upwards. The differentiation within the community is related to variance in tephra cover. In the uppermost stands the cover value of R. lanuginosum decreases gradually.

This differentiation resembles that in Lf 1693. There is a difference, though, especially in the occurrence of the small patches of barren decaying remnants of R. lanuginosum that have occurred as a result of wind.

The moss carpet of R. lanuginosum is broken, ca. 40% has been blown away. This is caused by the northeastern wind. On the main surface, R. lanuginosum is 3 - 8 cm thick, filled with aeolian material and with small barren patches here and there. When the tephra deposits become thick and continuously flat, the vegetation is very sparse. In such places, Polygonum viviparum and Polytrichum piliferum reach a moderate frequency.

Most vascular species are rare in the moss carpet but grow frequently on eroded, decaying moss carpet, sandy patches or stony ground. The following list shows the vascular species composition in different habitats:

(a) Moss carpet:

<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polygonum viviparum</td>
<td></td>
</tr>
<tr>
<td>Empetrum nigrum</td>
<td></td>
</tr>
<tr>
<td>Galium pusillum ssp. normani</td>
<td></td>
</tr>
<tr>
<td>Kobresia myosuroides</td>
<td></td>
</tr>
<tr>
<td>Salix herbacea</td>
<td></td>
</tr>
<tr>
<td>Festuca rubra</td>
<td></td>
</tr>
<tr>
<td>Cerastium alpinum</td>
<td></td>
</tr>
<tr>
<td>Silene acaulis</td>
<td></td>
</tr>
<tr>
<td>Cardaminopsis petraea</td>
<td></td>
</tr>
<tr>
<td>Juncus trifidus</td>
<td></td>
</tr>
<tr>
<td>Salix herbacea</td>
<td></td>
</tr>
<tr>
<td>Oxyria digyna</td>
<td></td>
</tr>
<tr>
<td>Polygonum viviparum,</td>
<td></td>
</tr>
<tr>
<td>Salix herbacea</td>
<td></td>
</tr>
<tr>
<td>Cerastium alpinum</td>
<td></td>
</tr>
<tr>
<td>Salix lanata</td>
<td></td>
</tr>
</tbody>
</table>

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7.10 Plant communities of Lava fields 1766 (Austurhraun and Hringlandahraun) (Table 12, clusters 36 - 40)

7.10.1 Racomitrium lanuginosum comm. (cl. 37 & 39)

In the poor field layer of the *R. lanuginosum* comm., *Salix herbacea* is frequent and may sometimes occur locally abundant. *Festuca vivipara* is a constant species while *Thymus praecox* ssp. *arcticus*, *Salix phylicifolia*, *Cerastium alpinum*, *Trisetum spicatum* and *Kobresia myosuroides* occur only scattered. The only other locally abundant species is *Carex bigelowii*, which is rare elsewhere. Consequently, a *C. bigelowii* facies can be recognized. It is very poor in species and resembles the *C. bigelowii* - *S. herbacea* soc. in the *Racomitrium* heath (Steindórsson 1974). Other vascular species are scattered there, such as *Polygonum viviparum*, *Luzula spicata* and *Empetrum nigrum*.

The bottom layer is very homogenous and is dominated by a dense carpet of *R. lanuginosum* with relatively few companion species. Some species, like *Pogonatum urnigerum*, *Polytrichum piliferum*, *Lophozia ventricosa* and *Stereocaulon vesuvianum*, are only scattered.

*Salix herbacea* variant (cl. 40)
The *S. herbacea* var. of the *R. lanuginosum* comm. resembles the *Salix herbacea* - *Anthelia soc.* in the snowpatch vegetation (Steindórsson 1974). *S. herbacea* is abundant but other vascular species are only *Polygonum viviparum* and *Poa glauca*.

The tephric bottom layer is composed of *R. lanuginosum* and *Anthelia julacea* in addition to *R. canescens* and *Pogonatum urnigerum*, which are fairly abundant. The occurrences of both *Conostomum tetragonum* and *Scapania curtata* indicate the presence of late snow areas while *Diancowaesia crispa* and *Ceratodon purpureus* indicate protruding pebbles. (The lichens *Psoroma hypnorum* and *Beomyces rufus* were very striking in some parts of the moss carpet but not where the analyses were made.)

7.10.2 Racomitrium canescens comm. (cl. 36)

In the field layer of the *R. canescens* comm., the abundant *Agrostis stolonifera* and frequent *Armeria...
maritima, Silene maritima and Oxyria digyna indicate that the soil is sandy. Among infrequent species can be mentioned Polygonum viviparum, Luzula spicata, Trisetum spicatum, Festuca rubra, Salix herbacea, S. lanata and Gnaphalium supinum.

The bottom layer is dominated by R. canescens and R. lanuginosum is a subdominant. Conostomum tetragonum, Saelania glaucescens and Jungermannia pumila indicate a late snow cover. Anthelia julacea may locally become frequent. The number of species is smaller than in the following variant described. In this community the following species were only recorded in Lf 1766-I: Solorina crocea, S. bispora, Ptilidium ciliare, Saxifraga oppositifolia, Poa alpina, Oxyria digyna, and Cystopteris fragilis.

Salix herbacea variant (cl. 38)
The field layer of the S. herbacea var. is dominated by S. herbacea. Poa glauca is moderately frequent but Kobresia myosuroides is absent. Additional species are Botrychium lunaria, Silene acaulis, Saxifraga nivalis and S. cespitosa.

The bottom layer is very rich in species, with R. canescens as dominant, covering 70 - 80 %, and R. lanuginosum as subdominant. An explanation of this richness might be the stony character (mostly 10-25 cm big) of the slope on which the variant occurs, together with its surface roughness and amount of sheltered places. The slope is covered by a loose and thin moss carpet, which is to some extent influenced by aeolian material. Some species worth mentioning occur mixed in the carpet, e.g.:

Drepanocladus uncinatus, Pogonatum urnigerum, Timmia austriaca, Dicranum fuscescens

Several species are found on ‘bare’ sandy soil, e.g.:

Conostomum tetragonum, Amblystegium jungermannoides, Isopterygium pulchellum, Kieria glacialis, Cephaloziella divaricata

Several species that are Botrychium lunaria, Silene acaulis, Saxifraga oppositifolia, Poa alpina, Oxyria digyna, and Cystopteris fragilis.

7.10.3 Ecological remarks

The result of the CCA on the material for this lava field can be summarized as follows:

\[
\begin{array}{cccc}
\text{axis} & 1 & 2 & 3 & 4 \\
\% \text{ variance explained} & 44.7 & 34.1 & 21.2 & 0 \\
\end{array}
\]

\text{biplot scores of environmental variables:}

\begin{tabular}{cccccc}
\text{surface roughness} & 62 & -73 & 281 & 0 \\
\text{tephra cover} & 167 & 323 & 7 & 0 \\
\text{elevation} & -306 & 199 & 88 & 0 \\
\end{tabular}

Three environmental factors have been included in the CCA of this material of Lf 1766 (Fig. 25). The two main vectors in the diagram, altitude and tephra cover, are roughly equal in importance and run more or less diagonally.

The main R. lanuginosum comm. is located to the left: found at higher altitudes. Its C. bigelowii facies at the lower end indicates a low tephra cover. Up to the right, related to high tephra cover, is the S. herbacea var. of the community. The same variant but of the R. canescens comm. is also related to high tephra cover.

Down to the right is the stand of the R. canescens comm., which is related to slightly more surface roughness, lower tephra cover and lower altitude. The community is mainly found in Lf 1766-II on the northwest slope of Mt. Hekla at a lower elevation(400 m) than Lf 1766-I (650 m), which faces south. Moreover, depressions are rare at higher altitudes in Lf 1766-I close to the fissure of Mt. Hekla, due to heavy tephra deposits, which have leveled the topography to a greater extent than further away.

Some other differences between the vegetation in Lf 1766-II and Lf 1766-I were noticed. Festuca rubra is much more common in the R. lanuginosum comm. of Lf 1766-I while F. vivipara occurs only in Lf 1766-II. In Lf 1766-II the moss carpet was almost continuous without any ruptures and, therefore, the number of companion species was very low.
7.11 Plant communities of Næfurholtsbraun 1845
(Table 13, clusters 41 - 48)

7.11.1 *Racomitrium lanuginosum* comm. (cl. 41)

The field layer of the main *R. lanuginosum* comm. is poorly developed with scattered occurrences of several species. *Salix herbacea*, *Empetrum nigrum*, *Galium pumilum* ssp. *normanii*, *Luzula spicata*, *Festuca rubra* and *Poa glauca* are the most common species, although they are infrequent. Some species are rare, such as *Trietum spicatum* and *Cerastium alpinum*. The presence of *Cardaminopsis petraea*, *Oxyrya digyna* and *Cystopteris fragilis* indicates ‘bare’ patches or small ledges.

The bottom layer is a more or less continuous and dense moss carpet of *R. lanuginosum*, with scattered occurrences of companion species. *Pogonatum urtigerum* and *Lophozia sudetica*, *Distichium capillaceum* and *S. vesuvianum* are all moderately frequent, while other species, such as *Pohlia cruda*, *Ceratodon purpureus* and *Peltigera canina*, are rare.

*Empetrum nigrum* variant (cl. 43)
The *E. nigrum* var. differs from the main community in the dominance of *E. nigrum* and the constancy of *Salix herbacea*. In spite of the high cover of *E. nigrum*, few other species are prominent, although *Festuca rubra* may become fairly abundant. Other species are infrequent, such as *Agrostis capillaris*, *Festuca vivipara*, *Thymus praecox*, *Salix lanata*, *Cerastium alpinum*, *Gymnomitrium coerulescens* and *Cerastium nigrum*.

The bottom layer is a thick moss carpet dominated by *R. lanuginosum*. The extreme scarcity of companion species can be explained as an effect of the powerful growth of *R. lanuginosum* in Næ 1845-1.

*Stereocaulon vesuvianum* variant (cl. 42)
Floristically, the field layer of the *S. vesuvianum* var. closely resembles the main *R. lanuginosum* comm., *Salix herbacea* can be abundant but *Empetrum nigrum* is totally absent. *Poa glauca* is frequent and *Cerastium alpinum* is moderately frequent. The addition of *Deschampsia alpina* and *Poa alpina*, which occur scattered, is not unexpected at the higher altitudes.

*R. lanuginosum* and *S. vesuvianum* dominate the bottom layer. *Pogonatum urinigerum* and *Anthelia julacea* are constant, while other species are moder-
The S. vesuvianum var. is probably a transition between the R. lanuginosum comm. and the S. vesuvianum comm. (see 7.12.3 and 7.13.3).

7.11.2 Racomitrium canescens comm. (cl. 46)

The field layer of the R. canescens comm. is relatively sparse (10-30%). The only frequent species is Agrostis vinealis, and Salix herbacea is moderately frequent, rarely abundant. Poa alpina, Carex bigelowii and Silene maritima are infrequent.

In the bottom layer, R. canescens is dominant with co-dominance of Anthelia julacea, which is constant and abundant. Pohlia drummondii, Lophozia sudetica and Gymnomitrion corallioides are moderately frequent, but R. lanuginosum is rare. The occurrence of Conostomum tetragonum, Cephalozia arctica, Scapania hyperborea and Peltigera occidentalis, indicates a long-lasting snow cover.

7.11.3 Oxyria digyna - Silene maritima comm. (cl. 44, 45, 47 & 48)

The field layer of the O. digyna - S. maritima comm. is sparse (2-5% in 1980) and O. digyna is the only species, which is almost constant. Some species are only locally moderately frequent, such as Silene maritima, Agrostis stolonifera, Cerastium alpinum and Salix herbacea.

The bottom layer consists of remnants of a moss carpet, growing between protruding stones or a bare tephra ground. Consequently, the bottom layer is of no differentiating value. For further discussion about the influence of the tephra fall in 1970, see section 10.4.

7.11.4 Ecological remarks

The result of the CCA on the material for this lava field can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>51.7</td>
<td>27.3</td>
<td>11.0</td>
<td>2.5</td>
</tr>
<tr>
<td>biplot scores of environmental variables:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface roughness</td>
<td>423 -106</td>
<td>2 -16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tephra cover</td>
<td>16 -237 -69</td>
<td>168</td>
<td></td>
<td></td>
</tr>
<tr>
<td>elevation</td>
<td>473 -66</td>
<td>-1</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>no. of tephra falls</td>
<td>139 -117</td>
<td>205</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td>quantity of acc. mat.</td>
<td>451</td>
<td>121</td>
<td>-6</td>
<td>22</td>
</tr>
</tbody>
</table>

Five environmental factors have been included in the CCA of this material of Næ 1845 (Fig. 26). Along axis 1, three vectors run almost horizontally: altitude, roughness and the number of tephra falls. Tephra cover is related to axis 2 and the quantity of deposits runs diagonally upward to the right.

The R. lanuginosum comm. occupies the largest part of the diagram and shows a high differentiation. Its E. nigrum var. occurs to the left at the lower end; it is linked to low quantities of deposits and small tephra cover.

The Stereocaulon vesuvianum var. is found in places where there are large quantities of deposits. This may partly be due to the fact that former tops of the crags now belong to the main surface. Highly damaged vegetation types occur at the highly tephra-influenced areas (Næ 1845-II and III). There is only a scattered occurrence of a few species. The bottom layer consists almost entirely of bare patches.

The R. canescens comm. is situated to the right; it is related to high elevation and increasing roughness in areas which were influenced by tephra deposition in 1970. The Oxyria digyna - Silene maritima comm. occurs towards the top, along axis 2; having developed after the great tephra fall of 1970.

Kjartansson (1946) stated that the surface of the lava field had grown more level during the last 100 years, as thick tussocks of grayish moss have covered a large part of the clinkers, particularly in shallow depressions. Empetrum nigrum can be found, together with
The field layer of the main *R. lanuginosum* comm. is extremely poor in vascular species. *Festuca rubra*, *Salix herbacea*, *Empetrum nigrum*, *Oxyria digyna* and *Luzula spicata* are all infrequent.

*R. lanuginosum* is the dominant species; the bottom layer is mixed with several species. *R. canescens* is moderately frequent and may locally be abundant. The liverworts *Antheila julacea*, *Gymnomitrium corallioides*, *G. concinnatum* and *Lophozia sudetica* are moderately frequent, but the mosses *Bartramia ithyphylla*, *Polytrichum piliferum*, *Pohlia drummondii*, *Mnium thomsonii* and the lichens *S. vesuvianum* and *Peltigera venosa* are all infrequent.

**Empetrum nigrum** variant (cl. 53)

The *E. nigrum* var. is very sparsely represented. It is also very poor in species. It differs from the main community in the abundance and constancy of *E. nigrum* in the field layer. *Salix herbacea* is the only other vascular species observed here.

The bottom layer is not dense, and the cover value of *R. lanuginosum* is lower than in the main community. *R. canescens* and *Mnium thomsonii* are moderately frequent. Due to the low cover value of *R. lanuginosum* several species occur in this variant, such as *Hylocomium splendens*, *Dicranoweisia crispula*, *Polytrichum piliferum*, *Isotrichum piliferum*, *Lophozia sudetica*, *Cephalozia rubella*, although they are mainly infrequent. The late snow cover in the area is indicated by the presence of, e.g., *Antheila julacea*, *Cephalozia arctica*, *Pleurocladula albasces* and *Peltigera occidentalis*.

**Stereocaulon vesuvianum** variant (cl. 49)

The field layer of the *S. vesuvianum* var. is richer in vascular species than the main community and the *E. nigrum* var. The explanation is probably that several of the vascular species are favoured by a thinner and not so dense moss carpet. *Cerastium alpina* is constant and *Salix herbacea* and *Luzula spicata* are frequent.

Physiognomically, *R. lanuginosum* is dominant but the constant *S. vesuvianum* is fairly abundant. *Conostomum tetragonum* and *Antheila julacea* are frequent. With very few exceptions all previously

### Table 14. Synoptic table for the seven community groups in the Krakatindshraun lava field from 1878.

<table>
<thead>
<tr>
<th>Cluster no.</th>
<th>49</th>
<th>50</th>
<th>51</th>
<th>52</th>
<th>53</th>
<th>54</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster size</td>
<td>11</td>
<td>12</td>
<td>20</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>21</td>
</tr>
</tbody>
</table>

---

**Racotritium lanuginosum** (cl. 51)

**Racotritium lanuginosum** is the dominant species; the bottom layer is mixed with several species. *R. canescens* is moderately frequent and may locally be abundant. The liverworts *Antheila julacea*, *Gymnomitrium corallioides*, *G. concinnatum* and *Lophozia sudetica* are moderately frequent, but the mosses *Bartramia ithyphylla*, *Polytrichum piliferum*, *Pohlia drummondii*, *Mnium thomsonii* and the lichens *S. vesuvianum* and *Peltigera venosa* are all infrequent.

**Empetrum nigrum** variant (cl. 53)

The *E. nigrum* var. is very sparsely represented. It is also very poor in species. It differs from the main community in the abundance and constancy of *E. nigrum* in the field layer. *Salix herbacea* is the only other vascular species observed here.

The bottom layer is not dense, and the cover value of *R. lanuginosum* is lower than in the main community. *R. canescens* and *Mnium thomsonii* are moderately frequent. Due to the low cover value of *R. lanuginosum* several species occur in this variant, such as *Hylocomium splendens*, *Dicranoweisia crispula*, *Polytrichum piliferum*, *Isotrichum piliferum*, *Lophozia sudetica*, *Cephalozia rubella*, although they are mainly infrequent. The late snow cover in the area is indicated by the presence of, e.g., *Antheila julacea*, *Cephalozia arctica*, *Pleurocladula albasces* and *Peltigera occidentalis*.

**Stereocaulon vesuvianum** variant (cl. 49)

The field layer of the *S. vesuvianum* var. is richer in vascular species than the main community and the *E. nigrum* var. The explanation is probably that several of the vascular species are favoured by a thinner and not so dense moss carpet. *Cerastium alpina* is constant and *Salix herbacea* and *Luzula spicata* are frequent.

Physiognomically, *R. lanuginosum* is dominant but the constant *S. vesuvianum* is fairly abundant. *Conostomum tetragonum* and *Antheila julacea* are frequent. With very few exceptions all previously
mentioned cryptogams are present. The most important additional species are, e.g., *Brachythecium glaucum, Ditrichum flexicaule, Cephalozia bicuspidata, Lophozia excisa* and *L. heterocolpos*. One of the most characteristic species for the *S. vesuvianum* comm., *Placopsis gelida*, is absent, probably due to the dominance of *R. lanuginosum*.

The *S. vesuvianum* var. is found in isolated places inside the *R. lanuginosum* comm. Perhaps the variant is a remnant of earlier stages of succession, as in Næ 1845 and La 1913.

### 7.12.2 *Racomitrium canescens* comm. (cl. 50)

The field layer of the *R. canescens* comm. is poor in vascular species. Moreover, the species in this community occur with low frequency, e.g., *Empetrum nigrum, Sagina intermedia, Salix herbacea, Luzula spicata* and *Poa glauca*.

*R. canescens* is dominant in the bottom layer. *R. lanuginosum* is frequent and very abundant. *Hylocomium splendens, Tritomaria quinquedentata, Bartramia itsphylla* and *Gymnomitrium corallioides* are infrequent. *Jungermannia atrovirens* and *Pleurocladula ablescens* indicate bare soil and a late snow cover. The presence of *Lophozia collaris* marks the northern aspect of this community (Shuster 1969).

### 7.12.3 *Stereocaulon vesuvianum* comm. (cl. 55)

The field layer of the *S. vesuvianum* comm. is absent in this habitat. The reason is the dense carpet of the dominant *S. vesuvianum*. Between the bolsters, outside the analyses, we find, e.g., *Poa alpina, P. glauca, Salix herbacea, Saxifraga nivalis* and *Silene acaulis*.

In the bottom layer, *S. vesuvianum* is the dominant species. *R. lanuginosum* and *R. canescens* are moderately frequent and may be abundant. Other species which occur moderately frequently are, e.g., *Polytrichum piliferum, Anthelia julacea, Lophozia spp., Tritomaria quinquedentata, Gymnomitrium concinnum, Cephaloziella arctica* and *Placopsis gelida*. Many species are infrequent, nevertheless indicating the aspect of the community, e.g., the liverworts *Cephaloziella rubella, Jungermannia subelliptica* and the lichens *Peltigera occidentalis, P. venosa, P. spuria, Solorina crocea* and *S. bispora*.

The *S. vesuvianum* comm. is widespread at Kr 1878-II at 710 m a.s.l. The species is well developed and forms a very compact, up to 12 cm thick, carpet.

### 7.12.4 *Anthelia julacea - Pohlia drummondii* comm. (cl. 54)

The only vascular species present in the field layer of the *A. julacea - P. drummondii* comm. are *Empetrum nigrum* and *Silene acaulis*.

The sandy bottom layer is coloured by *Anthelia julacea*, interspersed with single tufts of *R. lanuginosum*. The patches are more or less broken up by small pebbles and small holes, sparsely colonized by species, such as *Isothecium myosuroides, Eurhynchium pulchellum, Tritomaria quinquedentata, Cephaloziella pleniceps* and *Blepharostoma trichophyllum*, and the lichen *S. vesuvianum*.

### 7.12.5 *Calamagrostis stricta - Festuca rubra* comm. (cl. 52)

The *C. stricta - F. rubra* comm. is extremely poor in species, due to the unstable substrate. *C. stricta* dominates and gives the area a distinctive purple-coloured appearance from early August onwards. It is the best characteristic species of the community. Another constant species is *Festuca rubra* but *Luzula spicata* and *Cerastium alpinum* are only moderately frequent.

The bottom layer is of negligible importance due to the intensive influence of drifting sand. Only small tufts of *R. lanuginosum* and *R. canescens*, mixed with *Pogonatum urnigerum*, may be found.

### 7.12.6 Ecological remarks

The result of the CCA on the material for Kr 1878 can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>53.3</td>
<td>32.7</td>
<td>14.0</td>
<td>0</td>
</tr>
<tr>
<td>biplot scores of environmental variables:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface roughness</td>
<td>105</td>
<td>24</td>
<td>297</td>
<td>0</td>
</tr>
<tr>
<td>tephra cover</td>
<td>-177</td>
<td>-398</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>elevation</td>
<td>486</td>
<td>38</td>
<td>-12</td>
<td>0</td>
</tr>
</tbody>
</table>

Three environmental factors have been included in the CCA of this material of Kr 1878 (Fig. 27). The main environmental differentiation along axis 1 is due to the interrelated factors surface roughness and altitude. The *S. vesuvianum* comm. occurs at the highest elevation (Kr 1878-II), to the right of axis 1. The fact that roughness increases with elevation may be explained by the minimal leveling effect of the scanty moss carpet.
The 

The 

7.13 Plant communities of Lambafitjarhraun 1913

7.13.1 Racomitrium lanuginosum comm. (cl. 58)

In the poor field layer of the main R. lanuginosum comm. Festuca rubra and Salix herbacea are moderately frequent. Species such as Saxifraga nivalis, Cardaminopsis petraea and Agrostis stolonifera occur only accidentally in the moss carpet and many species growing on ledges or in ruptures do not invade the carpet of R. lanuginosum in the younger lava fields.

The dense and dominating moss carpet of R. lanuginosum in the bottom layer is also poor in species. S. vesuvianum is the only frequent species on protruding pebbles. Its high frequency indicates the roughness of the underlying substrate, although the moss carpet has developed into thick tussocks during 60 years. R. canescens is frequent but not abundant and the companion species, Pogonatum urnigerum and Lophozia ventricosa, are moderately frequent. Drepanoclados uncinatus, Polytrichum piliferum, P. juniperinum, Peltigera spp., and Stereocaulon alpinum are infrequent. The lack of Hylocomium splendens is remarkable. It was recorded in some holes but never in the moss carpet.

Empetrum nigrum variant (cl. 61)

The Empetrum nigrum variant has a great resemblance to the main community. It can only be distinguished by the presence of E. nigrum and a slightly lower number of cryptogams.

Stereocaulon vesuvianum variant (cl. 57)

The S. vesuvianum var. differs in many respects from the main community, because the ground is both very

Helgi Jónsson (1906a) visited Kr 1878 in 1901 and reported on plant colonization. He found 16 species (12 bryophytes, 3 lichens and 1 alga). The lichens Stereocaulon alpinum (probably vesuvianum) and Placopsis gelida occurred scattered only in few places. The bryophytes grew in small tussocks in vesicles or furrows. The most common species was Dicranoweisia crispula; other species mentioned were Bartramia ithyphylla, Racomitrium canescens v. ericoïdes, R. lanuginosum, Bryum sp., Ceratodon purpureus, Pohlia drummondii, P. cruda, Drepanoclados uncinnatus, Bryum pallescens, Lophozia sudetica, Scapania curta and Leucidea alpestris.

Kjartansson (1946) visited Kr 1878 twice in 1930 and 1945. He said that the pale colour of the lava field depended on the dense cover of a light-gray fruticose lichen (presumably Stereocaulon vesuvianum). When he compared his observations from these two visits, he thought he could notice the difference that some moss (presumably R. lanuginosum) had increased, and the lichen had become reduced and that the lava field did not seem equally pale as before.
Table 15. Synoptic table for the nine community groups in the Lambafitjarhraun lava field from 1913.

<table>
<thead>
<tr>
<th>Cluster no.</th>
<th>Cluster size</th>
<th>56</th>
<th>57</th>
<th>58</th>
<th>59</th>
<th>60</th>
<th>61</th>
<th>62</th>
<th>63</th>
<th>64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racemotrium lanuginosum</td>
<td>1</td>
<td>2</td>
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<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Stereocaulon vesuvianum</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>Empetrum nigrum</td>
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<td>1</td>
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<td>1</td>
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<td>1</td>
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</tr>
<tr>
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<td>1</td>
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</tr>
<tr>
<td>Anthelia julacea</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pohlia drummondii</td>
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<td>1</td>
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<td>1</td>
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<tr>
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<tr>
<td>Placopsis gelida</td>
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<tr>
<td>Stereocaulon alpinum</td>
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<tr>
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<td>Bartramia ithyphylla</td>
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<tr>
<td>Distichium capillaceum</td>
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<td>Pogonatum umigerum</td>
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<tr>
<td>Polytrichum piliferum</td>
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</tr>
<tr>
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<td>1</td>
<td>1</td>
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<tr>
<td>Polytrichum piliferum</td>
<td>1</td>
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<tr>
<td>Distichium capillaceum</td>
<td>1</td>
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<td>1</td>
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<tr>
<td>Bartramia ithyphylla</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>Distichium capillaceum</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>


Additional species, occurring with a synoptic score <1, or with 1 in only 1 or 2 clusters (cluster number between brackets).

Agrostis vinealis (<1) 1(64,57); Armeria maritima 1(60,57); Barbilophozia kunceana (<1); Beomyces rufus (<1); Bryum sp. 1(56); Cephaloziapleniceps 1(57); Cladonia cernuca (<1); Deschampsia alpina 1(64); Didymodon 1madophillus (<1); Eurychnium pulchellum 1(62); Festuca vivipara 1(62,64); Galium pumilum 1(59,64); G. corallioides 1(59,64); Lophozia heterocolpos (<1); L. sp. 1(62,63); L. arcuata (<1); L. spicata 1(62,57); Marsupella spuria (<1); P. sexangularare 1(62); Peltigera canina 1(61); Polytrichum juniperinum 1(59,61); P. sativum 1(59,64); P. occidentalis. Eurhynchium pulchellum grows on sandy pebbles together with Distichium capillaceum, Pohlia drummondii, Scapania spicata and Drepanoecladus uncinitus.

Fig. 28. CCA ordination diagram, axes 1 and 2: Lambafitjarhraun lava field from 1913. 1 = Racemotrium lanuginosum comm. (cl. 58); 2 = ibid., Empetrum nigrum variant (cl. 61); 3 = ibid., Stereocaulon vesuvianum variant (cl. 57); 4 = Racemotrium canescens comm. (cl. 62); 5 = Anthelia julacea - Pohlia drummondii comm. (cl. 63); v = vegetation fragment (cl. 56).

7.13.2 Racemotrium canescens comm. (cl. 62)

The field layer of the R. canescens comm. is, as usual, poor in vascular species. Festuca vivipara, Trisetum spicatum and Oxypa digyna are infrequent. Species such as Silene maritima, Saxifraga cespitosa and Luzula spicata occur only sporadically.

The bottom layer is dominated by R. canescens and does not differ appreciably from other places with this community. R. lanuginosum is frequent and may be abundant, as is also the case with S. vesuvianum. Anthelia julacea is also locally highly abundant and may almost be justified as a facies. Some infrequent species indicate late snow cover, such as Polytrichum sexangularare, Peltigera venosa and P. occidentalis. Euryhynchium pulchellum grows on sandy pebbles together with Distichium capillaceum, Pohlia drummondii, Scapania spp. and Drepanoecladus uncinitus.

Salix herbaea variant (cl. 64) The S. herbaea var. is characterized by the constant Salix herbaea and also by a higher frequency of other vascular species. Festuca vivipara is frequent and F. rubra, Luzula spicata, Deschampsia alpina and Agrostis vinealis are moderately frequent. Among rare species can be mentioned, e.g., Salix lanata, S. phyllicifolia, Oxypa digyna, Luzula arcuata and Trisetum

Stony and sandy. In the field layer, Poa glauca is frequent and among moderately frequent species are Agrostis vinealis and Saxifraga cespitosa. Species such as Galium pumilum ssp. normanii, Armeria maritima, Cardaminopsis petraea and Agrostis stomonifera, are infrequent.

In the bottom layer the co-dominating species, R. lanuginosum and S. vesuvianum, are equally distributed mixed with R. canescens, Pogonatum umigerum, Anthelia julacea and Lophozia sudetica. Bartramia ithyphylla and Distichium capillaceum are moderately frequent on pebbles.

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The bottom layer is quite similar to that of the main community.

7.13.3 Stereocaulon vesuvianum comm. (cl. 59 & 60)

The field layer of the S. vesuvianum comm. is very poor in vascular species. Several species (Salix herbacea, Armeriamaritima, Cardaminopsis petraea, Cerastium alpinum, Poa glauca and Poa alpina) occur in the gaps between the Stereocaulon carpet.

S. vesuvianum dominates in the stony bottom layer. The lichen is 4-10 cm high with 1-4 cm of the lower part brownish. Scattered sandy patches between the lichen are poorly vegetated with, e.g., Anthelia julacea, R. lanuginosum, R. canescens, Marsupella spp., Lophozia sudetica, Gymnomitrion concinnatum, G. corallioides and Philonotis sp. Drepanoclados uncinatus may be locally abundant.

7.13.4 Anthelia julacea - Pohlia drummondii comm. (cl. 63)

There is no field layer in the A. julacea - P. drummondii comm.

The bottom layer is covered with unstable sand (15 - 40%), but Anthelia julacea colours the other part. Small tufts of R. lanuginosum and R. canescens are moderately frequently mixed with scattered occurrences of Pohlia drummondii, Distichium capillaceum, Lophozia spp. and Stereocaulon alpinum. On protruding stones, S. vesuvianum and Schistidium apocularum are also found. Outside the analyzed plots, Peltigera occidentalis, P. venosa and Cladonia ecmocyna were present.

7.13.5 Ecological remarks

The result of the CCA on the material for this lava field can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>68.2</td>
<td>31.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>biplot scores of environmental variables:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface roughness</td>
<td>278</td>
<td>284</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>tephra cover</td>
<td>424</td>
<td>-147</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Two environmental factors have been included in the CCA of this material of La 1913 (Fig. 28). The environmental differentiation along axis 1 is mainly related to tephra/sand-cover. The main R. lanuginosum comm. and its two variants occur over the entire length of axis 1 but only at the lower end of axis 2. The thickness of the carpet varies but is, on average, 5 - 10 cm, broken by protruding stones. The E. nigrum var. occurs in sheltered places related to low tephra cover to the extreme left, then follows the main R. lanuginosum comm., but in the middle and to the extreme right of axis 1, the S. vesuvianum var. is situated, highly influenced by aeolian material. The Anthelia julacea - Pohlia drummondii comm. occurs in sandy patches. The tephra/sand-cover in this field is mainly derived from the large area of sand along the river Helliskvísl. No species grew within the analyzed plots, but outside them in a similar habitat the following ones were recorded: Poa alpina, Silene acaulis, Cardaminopsis petraea, Cerastium alpinum, Pinguicula vulgaris and Sagina saginoides.

The S. vesuvianum comm. is at the top right of the diagram; it is found on rough surfaces and is partly influenced by the aeolian material. It covers ca. 20% of the main surface. The R. canescens comm. is more confined to depressions and slopes.

Björnsson (1943) described that the lava field was completely without vegetation in 1931. Kjartansson (1946) said that from afar the appearance was very dark and it was easily distinguishable in the landscape. On the other hand, it had become much more light-coloured since he saw it for the first time in 1930, due to the same lichen that coloured Kr 1878.

7.14 Plant communities of Lava field 1947

(Table 16, clusters 65 - 72)

7.14.1 Racomitrium lanuginosum comm. (cl. 65 & 72)

The field layer of the R. lanuginosum comm. is absent, which is probably due to the young age of the lava field. The bottom layer is dominated by R. lanuginosum. S. vesuvianum (often only the phyllocladias) is frequent in almost all gaps in the moss carpet of R. lanuginosum. Relatively few species are moderately frequent, such as R. canescens and Pogonatum urnigerum. However, many species occur scattered in this community, as in other ones.

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7.14.3 Stereocaulon vesuvianum comm. (cl. 67)

The field layer of the S. vesuvianum comm. is usually very poor in all the lava fields. Here it is totally absent due to the young age of the field.

In the bottom layer, S. vesuvianum is dominant. Placopsis gelida and R. lanuginosum are frequent, but R. canescens is rare. Several accidental species occur in the community, which is mainly confined to depressions (e.g., with Timmia austriaca) and to the upper part of the main surface (e.g., with Racomitrium fusciculare). Crustaceous lichens are moderately frequent. The reason may be that this community occupies larger areas of even surfaces than other communities.

7.14.4 Initial stages

In the relatively young Lf 1947 there are many vegetation fragments, which can hardly be treated as communities. However, by studying the colonization of species from the start and following the course of events it might be possible to attribute these fragments to various successional stages. On the other hand, the colonization and the establishment of the species characteristic of a community in a lava field, do not proceed simultaneously.

Many of the initial stages in Lf 1947 occupy microsites where R. lanuginosum and S. vesuvianum are almost absent, for different reasons. Most microsites available are small tephra-covered patches or glossy surfaces. Except for many undefined initial stages, which occur only scattered (see section 7.14.5), some fragments can roughly be grouped as follows:

I. In more or less deep depressions, including holes:

A. Drepanocladius uncinatus - Peltigera spuria initial stage

Both species colonize the lava fields early and have wide ecological amplitudes. The habitat includes sandy/tephric depressions in the centre of the main surface. The substrate is relatively unstable. Bartramia ithyphylla, Pogonatum urnigerum, R. canescens, Pohlia proligerà, Bryum pallescens and Lophozia ventricosa are intermingled in the mats. All these species are characteristic for almost bare, sandy soil, most often in shady habitats (Mårtensson 1955, 1956). Stereocaulon

7.14.2 Racomitrium canescens comm. (cl. 66)

Both the Racomitrium canescens comm. and the previous community (7.14.1) are characterized by lack of vascular species in the field layer.

The bottom layer is dominated by R. canescens. Of other mosses only R. lanuginosum may be fairly abundant locally. Some species occur with low frequency, such as Pohlia drummondii, S. vesuvianum and Placopsis gelida. Other more scattered species will be discussed below (see 7.14.5).
capitellatum is also found on protruding, very scorious and fragile clinkers in the upper part of the depressions.

B. Bartramia ithyphylla - Polytrichum juniperinum initial stage
Both species have wide ecological amplitudes. A few small dots of the phyllocladia of S. vesuvianum can be found on pebbles around the dry, packed, sandy/tephric patches with firm substrate. 3 - 5 specimens of Pogonatum urnigerum and Polytrichum piliferum also occur.

C. Hylocomium splendens initial stage (cl. 71)
H. splendens was relatively early to invade Lf 1947. It has become abundant on poor, moist, sandy/tephric substrate in depressions, growing in pure mats. Probably, H. splendens is dependent on a supply of mineral nutrients, leached out by dripping water. Racomitrium species are totally absent. Other frequent species are S. vesuvianum on pebbles and Ceratodon purpureus.

II. In the middle of the main surface:

A. Racomitrium lanuginosum initial stage
R. lanuginosum is the primary colonist and grows in the whole area except for high crags and deep depressions. The thin and split-up carpet, less than ca. 2 cm thick, can include several other species, such as Bartramia ithyphylla, Distichium capillaceum and Amphidium mougeotii in small patches of loose material.

B. Racomitrium lanuginosum - Ceratodon purpureus initial stage
The colonization of R. lanuginosum has led to a more developed and continuous carpet, more than 3 cm thick. The loose material becomes overgrown by the species and the frequency of many of the primary colonists decreases. The only constant species is Ceratodon purpureus, which is the most successful species to colonize every possible microsite and “using every opportunity to grow” (Mårtensson 1956 p. 50). The only moderately frequent species are Bartramia ithyphylla, Dicranoweisia crispula and Lophozia ventricosa.

C. Racomitrium lanuginosum - Bryum spp. initial stage
This stage resembles the above-mentioned one (B), although it is more sheltered as indicated by the occurrence of Timmia austriaca. The cover value of R. lanuginosum is lower, in other respects it is similar.

III On exposed boulders:

A. Umbilicaria torrefacta initial stage (cl. 69)
On glossy surfaces Umbilicaria torrefacta, U. spp. (U. cf. cylindrica and U. cf. proboscidea), S. vesuvianum and crustaceous lichens, e.g., Placopsis gelida, are constant. The longest specimen of S. vesuvianum was 8 mm. Most likely it will be carried away by wind or water when it gets taller due to poor attachment to the surface. Other species recorded, Racomitrium fasciculare, R. lanuginosum, Bryum sp. and Bartramia ithyphylla, are only represented by single specimens.

B. Stereocaulon vesuvianum initial stage (cl. 70)
Exposed boulders are often without vegetation, although the surface is very rough. Small specimens of S. vesuvianum and Cladonia sp. were recorded at the most exposed sites facing north. Further development of this initial stage is uncertain. Probably, the rocks will remain totally bare in the future due to the weathering process and wind force.

7.14.5 Ecological remarks
The result of the CCA on the material for this lava field can be summarized as follows:

<table>
<thead>
<tr>
<th>axis</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% variance explained</td>
<td>30.5</td>
<td>23.5</td>
<td>16.3</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Biplot scores of environmental variables:

| surface roughness | -1 | -109 | 29 | -16 |
| tephra cover | 7 | -57 | 297 | -39 |
| age of analyses | 173 | -278 | -49 | 91 |
| elevation | -220 | -216 | 19 | -143 |
| irregularity | -249 | 226 | 40 | -57 |
| position | -235 | 87 | 86 | 65 |

Six environmental factors have been included in the CCA of this material of Lf 1947 (Fig. 29). Due to the complex environmental situation the ordination diagram cannot easily be interpreted.

The main floristic variation is determined along axis 1 by the contrast between Umbilicaria stands (left top), which are related to high irregularity and the top of the clinker layer (position) and the Hylocomium splendens stands (right middle), which are related to the bottom of the clinker layer.

The environmental differentiation along axis 2 is weakly related to surface roughness and tephra cover, which run downward along axis 2. Two vectors run more or less diagonally: elevation downward to the left
and increased age of the analyses downward to the right. Initial stages occur scattered, especially those of *S. vesuvianum*, but with a clear tendency to appear at the lower end of axis 2, suggesting a relation to more varying microhabitats and especially to increasing elevation. The main *R. lanuginosum* comm. occurs over some length of axis 2 and almost in the middle of axis 1.

The *R. canescens* comm. and the *Drepanocladus uncinatus - Peltigera spuria* initial stage and *Hylocomium splendens* initial stage are situated along axis 1 to the right; they are related to the bottom of the cinder layer.

In all communities and initial stages, except for the initial stages of *Hylocomium splendens*, *Stereocaulon* and *Umbilicaria*, many accidental species occur scattered. These species are most frequent in the initial stage of *R. lanuginosum* and in the undefined initial stage. There is no significant difference between the three main communities. The number of species is highest in the *R. lanuginosum* comm. but lowest in the initial stage of *S. vesuvianum*, 38 and 2 species, respectively.

The investigation by Jóhannsson and Kristinsson produced a preliminary (unpublished) list of altogether 43 recorded species; 16 were mosses, 3-4 liverworts and 22 lichens (incl. 12 crustaceous). Their observations can be grouped into: (a) depressions and (b) ridges. A summary of their material provides the following cover values (%) of the most common species in plots of 100 cm²:

<table>
<thead>
<tr>
<th>Species</th>
<th>Depressions</th>
<th>Ridges</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Racomitrium lanuginosum</em></td>
<td>77.0</td>
<td>13.6</td>
</tr>
<tr>
<td><em>Racomitrium canescens</em></td>
<td>5.4</td>
<td>0.2</td>
</tr>
<tr>
<td><em>Stereocaulon vesuvianum</em></td>
<td>2.7</td>
<td>2.0</td>
</tr>
<tr>
<td><em>Placopsis gelida</em></td>
<td>0.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

All other species have considerably lower cover values. The largest number of species in a plot is 15 (12 bryophytes, 3 lichens) in a depression and 16 species (2 bryophytes, 14 lichens) on a ridge.

The preliminary results by Jóhannsson and Kristinsson are confirmed by the present results:

1. *S. vesuvianum* colonizes nearly the whole of the lava field in the beginning, from depressions (except deep holes) to crags and
2. *R. lanuginosum* and *R. canescens* occur more scattered on ridges than in the middle or lower part of the main surface.

The development of the moss carpet of *R. lanuginosum* was very irregular, starting from suitable places and then expanding. In 1970, *R. lanuginosum* was already established and the initial phase of primary colonization was at its end. The tephra fall in 1970 created a situation when several species could start a new colonization on tephra. There was a pronounced increase in number of species during the first years but then only a few more were added during a period of years, finally reaching an equilibrium in number of species in about 1985.

The increase of vascular species shows a similar tendency. In 1968 no vascular species grew in Lf 1947 (Kristinsson pers. comm.). The first three species were found in 1970, in 1972 the number was doubled, but from 1973 to 1987 the number had only increased by four species. The total number of vascular species amounted to ten in 1987. Among these species were one fern, three grasses and six herbs. There were less than twenty specimens of each species each year. Most of the species grew in a coarse, loose material on rock ledges in the middle part of the main surface, two were found in accumulated sand. One species (*Empetrum nigrum*) grew on top of a 1.5 m high crag. It was the only one growing in a thin moss carpet. Droppings of Ptarmigan (*Lagopus mutus*) were pressed into the moss carpet.
7.15 Holes

The analyses of the hole vegetation could not be carried out in a standardized manner. The small patches of the vegetation on the small rock ledges or bottom were collected and numbered on a sketch. The width of the openings and the depth of each ledge (stand) were measured and an attempt was made to sketch a profile of each hole. Exposure was described in a qualitative way. Measurements of essential factors, such as light and moisture combined with soil conditions have not been possible to carry out, except for a few temperature measurements (see 5.3). These measurements indicate some variation within the hole, due to different exposure.

Habitat conditions prevailing in the holes are of a special nature. The available space for each plant species is physically restricted to the narrow ledges and the sandy bottom. The difference between summer and winter temperature is presumably small and even the summer temperature may be slightly lower. The explanation is found in the cooling effect of percolating water. During spring and summer the snow becomes drenched by thaw and rain. The melting water, in addition to precipitation, percolates into the layer of clinkers until it begins to snow in the autumn. This water is cold, especially in the spring when it is just above freezing-point, as it derives mainly from thawing snow. Air humidity in spaces between the clinkers is probably maintained at a very high level during most of the year, although there is no standing water. Obviously, most of the annual precipitation percolates during half of the year. In contrast, this water flow is very small during the winter.

The differences along the gradient of light intensity become more distinctly revealed by the cover of species than the species composition (Blažková 1973). Nevertheless, the light intensity is correlated to the width and depth of a hole and to the shape and number of ledges jutting out from the sides. On the other hand, reflection of light from snowdrifts and rock surfaces in the holes may influence the growth of some species, but this suggestion needs further investigation (cf. Creveld 1981).

Although the holes are sheltered places the influence of dripping water is often obvious: it flushes along small ledges. The moisture conditions also depend on the width and the depth of the hole. The relative humidity is apparently higher in narrow and deep holes than in wide and shallow ones.

The holes are located in the uppermost layer of clinkers, which may be up to several meters in thickness. The occurrence of holes decreases continuously along the age gradient of the lava fields due to the progressive development of the main surface (accumulation of aeolian material or a moss carpet, Fig. 30). In Ef 1158 to Lf 1766 the percentages of the holes are 2–10 %, in Ne 1845 to La 1913 they are 15–30 % and in Lf 1947 and in younger lava fields the percentages are 40–50 %.

In the present investigation, totally 81 holes were recorded. The total number of recorded taxa in the hole vegetation was 91 (7 vascular species, 48 mosses, 23 liverworts and 8 lichens). A few other species not included in these numbers (e.g., Saxifraga cernua) were also listed from scattered holes, which were not completely examined. The largest number of species in one hole was 18 (Pá 1554), and the lowest was only 2 (Lf 1947 & Lf 1970). On average, the numbers of species increases continuously along the age gradient (Fig. 30).

None of the species recorded in the holes is restricted to this habitat type but several species apparently grow there with a clear preference, such as Mnium stellare, Pohlia cruda, Isopterygium pulchellum, Oligotrichum hercynicum, Blepharostoma trichophyllum and Nardia geoscyphus. Most of the species occur also scattered on the crags, such as Saxifraga nivalis, Encalypta ciliata, Plagiothecium cavifolium, Diplphyllum albinans, Lophozia gillmanii and Cystocoleus niger. Moreover, many of the species occur also in small ruptures in the main surface as well, e.g., Poa glauca, Dicranoweisia crispsula, Diplphysicum foliosum, Pohlia drummondii, Cephaloziella divaricata and Solorina crocea.

The species composition in the holes does not vary

Fig. 30. a. Correlation between the number of species in each hole and different lava fields. b. Correlation between the frequency of holes and different lava fields.
much in most of the lava fields older than Lf 1947, where *Distichium capillaceum* is a constant species and *Amphidium mougeotii* and *Bartramia ithyphylla* occur frequently. Characteristic species for chionophilous vegetation, such as *Catoscopium nigritum* and *Saella glaucescens*, are rare. It is possible to compare the descriptions of habitats given by Mårtensson (1955, 1956) for the species in common. Most of these species characteristically grow on ‘bare’ soil (poor substrate) in shady but not too wet crevices and caves. Near the openings of the holes, *Racomitrium lanuginosum* and *Stereocaulon vesuvianum* usually occur abundantly but, e.g., *Andreaea rupestris* and *Schistidium apocarpum* are infrequent. The rock ledges of the uppermost 10 - 30 cm of the holes are richest in species but in the moistest places on the sandy bottom, at a depth of 40 - 60 cm, small patches of liverworts occur mixed with a few other species, e.g., *Bartramia ithyphylla* and *Plagiochila porelloides*. In shallow and wide holes an additional number of species occur also in the bottom, e.g., *Timmia austriaca*, *Polytrichium juniperinum*, *Brachythecium albicans* and *Rhytidiales squarrosus*.

Fig. 31 A - D present some features characterizing the hole vegetation.

7.16 Crags

Several analyses of the crag vegetation were carried out but they have not been elaborated because of insufficient measurements of physical factors. Plant species were recorded on 38 crags in all lava fields. However, the following presentation is based mainly on observations from 13 crags in the following lava fields: Ef 1158 (2), Su 1300-1 (4), No 1389-II (4) and Næ 1845-I (3). Consequently the description is only a generalized overview.

The crags are steep or almost vertical, but often with many flat rock ledges, vesicles and furrows. Soil is rarely completely absent due to the irregularity of the surface. No soil is found on vertical, smooth surfaces. Also, as previously mentioned, small cushions of vegetation always accumulate aeolian material. The exposed crag vegetation is influenced by the microstructure of the surface and the state of weathering (cf. Sjögren 1964). It is also related to prevailing strong winds, mainly northeastern to southeastern (ca. 30 %, cf. Einarsson, M.Á. 1976), intense rain storms and to microclimatic conditions related to relief and exposure. Snow cover is absent, except on the lowest parts

and on ledges, but is still thin and with short duration, often as glare ice.

The occurrence of crags varies between the lava fields and cannot be easily related to their age. Generally, they rather reflect the originally irregular topography of each lava field and the quantities of accumulated deposits. The lowest proportion of crags (8%) occurs in highly deposited areas: Ef 1158, No 1389-III, Lf 1766-II. Some exceptions from this rule are Su 1300-I with 20% of crags, in spite of high age and considerable quantities of deposits, and På 1554 with very small amounts of deposits but only 10% of crags.

The total number of species on each crag may be very high. The habitat richness motivates a much more varied species composition than elsewhere. It must be pointed out that crag vegetation deviates from typical rock vegetation due to the many ledges which carry small tussocks, and the ‘barren zone’ (see 5.1.3). Only one species was restricted to this crag habitat, namely, Woodsia ilvensis, but 15-20 vascular species show a clear preference to choose this habitat, although they may occasionally occur in the main surface (mainly in other communities than the R. lanuginosum comm.). The most important are:

- Armeria maritima
- Bartsia alpina
- Botrychium lunaria
- Cystopteris fragilis
- Draba incana
- Euphrasia figida
- Gentiana nivalis
- Minuartia rubella
- Parnassia palustris
- Pinguicula vulgaris
- Platanthera hyperborea
- Rhodiola rosea
- Sagina procumbens

The same may be valid for bryophytes, although there is of course a risk that some species remained overlooked when bearing in mind the extremely rough crag substrate. The bryovegetation on crags is rich in species, in relation to their extent and exposure, due to the great variety of substrates. Fissidens bryoides, Enca lyptta brevipes, Amphi dium lapponicum, Aneura pinguis and Blasia pusilla have only been recorded on crags. Several species show a clear preference to grow on the steep rock surfaces, such as: Anoectangium aestivum, Dicranoweisia crispula, Grimmia funalis, G. torquata, G. donniana, Racomitrium heterostichum and Schistidium apocarpum. These species accumulate fine-grained aeolian material and form convex cushions on the rocks. When these ‘dust bolsters’ reach a height of ca. 4 cm they become unstable and are often carried away by wind. Small remaining shoots at the periphery of the former cushions start the development of new ‘dust bolsters’.

Fig. 31 B-D.
No lichen species are restricted to the crags. Several species such as *Leptogium lichenoides*, *L. sinuatum*, *Physcia caesia* and *Cladonia* spp. occur in the small tussocks on ledges as well as in the main surfaces. *Cystocoleus niger*, *Sphaerophorus fragilis* and *Parmelia saxatilis* are somewhat more frequent on crags than in other habitats. In addition, the crustaceous lichens, *Dermatocarpon miniatum* and several species of *Umbilicaria*, grow on the smooth surfaces.

The crag vegetation is very scattered and its occurrence is related to substrate texture and exposure. Shaded and somewhat sheltered places facing northeast to southeast, at the lower parts of the crags, are usually especially rich in species. The photophilous community with *Parmelia saxatilis*, *Hypnum cupressiforme*, *Homalothecium sericeum*, *Tortula ruralis* and *T. subulata* highly influenced by bird droppings, is found in more exposed places on the crags (Fig. 32).

A real zonation of vegetation is rarely found due to the irregularity of rocks. An accumulation of aeolian material at the lower part of the crags promotes higher moisture for a longer period than in the middle part. The barren zone is richest in vascular species when facing southwest. In moist places on the lower part of crags, species such as *Sagina procumbens*, *Drepanoclados uncinatus*, *Bartramia ithyphylla*, *Antheria julacea* and *Cystocoleus niger*, occur. In the middle part of the crags are found scattered species such as *Grimmiatorquata*, *Amphidium lapponicum*, *Andreaea rupestris*, *Dicranoweisia crispa*, *Schistidium apocarpum* and *Bryum inclinatum*. The uppermost part is usually richer in vascular species (e.g., *Poa glauca* and *Draba incana*), growing together with, e.g., *Encalypta brevipes*, *E. ciliata*, *Tortella tortuosa*, *Lophozia obtusa* and *Scapania curta*.

**Fig. 32.** Crag in the Norðurhraun lava field from the 1389 eruption. a. July 1970. *Parmelia saxatilis* dominates with scattered occurrence of *Poa glauca*, *Cardaminopsis petraea*, *Homalothecium sericeum* (in the middle) and *Hypnum cupressiforme*, *Schistidium apocarpum* and *Tortula ruralis* and *T. subulata* (especially in the uppermost part). b. August 1980. *P. saxatilis* has grown and covers more continuous patches. *Homalothecium sericeum* has increased in the middle. *Hypnum cupressiforme* in the uppermost part has also increased.
8 The vegetation of the younger lava fields

8.1 Introduction

The younger lava fields, Lf 1970 and Lf 1980/81, became available for colonization by plants 20 and 10 years ago, respectively. Owing to their young age and the unstable nature of the substrate, only indistinctive plant assemblages had been established when they were last investigated by the author (Lf 1970-I in 1979, Lf 1970-II in 1980 and Lf 1980/81 in 1981). As has been mentioned previously, most of Lf 1970 became covered with a thick deposit of tephra during the eruption of 1980/81. The following description provides only some information on the colonization of bryophytes and lichens.

8.2 Lava field 1970

The surface of the lava fields was divided into:
1. Bottom of the layer of clinkers, 2. Middle part of clinkers; and 3. Top of clinkers. Mainly two types of substrates occur within each category: (a) small primary tephra patches mixed with smashed pieces of clinkers and (b) rock surface with varying texture, from smooth and glossy to very spongy with many sharp, fragile points and microfurrows. The small tephra patches cover ca. 2 - 10 % of the clinker surfaces. They are somewhat more frequent at the bottom of clinkers than at the top, but the difference is small in a new lava field due to high irregularity, many microsites and a little weathering. Moreover, inside the vesicles and microfurrows there is generally some accumulated loose material.

Due to the complex environmental condition the ordination diagram is not easily interpreted. However, there is a weak indication that the lower parts of the clinkers are more favourable for the colonists than the tops. Also, the difference in elevation between Lf 1970-I and Lf 1970-II is not a decisive factor influencing the colonization in the area. For that reason Lf 1970-I and Lf 1970-II are treated together.

8.2.1 Colonization

In 1971, no plants were found upon the field itself, but Ceratodon purpureus and Racomitrium canescens grew on tumbled stones outside the border and small seedlings of grass species (Festuca rubra and Poa glauca) were found on accumulated sand at the edge. In 1972, several diminutive mosses appeared in the tephra patches, scattered from the top to the bottom. Ceratodon purpureus was the most frequent species together with Pohlia cruda, P. drummondii, P. filum, Bryum cf. pallens and B. cf. caespitices. The habitat preference of these species was small tephra patches on sheltered ledges. R. lanuginosum and R. canescens grew in more exposed microsites, in furrows and on more coarse material. At the bottom of the clinkers, on fine-grained material, Lophoziopsis spp. occurred with Cephaloziella divaricata and Dichodontium pellucidum and one single specimen of Peltigera cf. spuria. In 1975, this species was refound in 4 places with the folious thallus up to 6 mm in diameter. In 1976, it was difficult to determine the species of the genus Bryum but B. inclinatum had become the clearly most frequent species in the middle part of the clinkers. As expected, there was a clear dominance by acrocarpous mosses. In 1973, Schistidium apocarpum appeared in exposed habitats, and at the bottom of the clinkers Pogonatum urnigerum, Philonotis tomentella and the pleurocarpous species Drepanocladus uncinatus were found. The occurrences of the species were mainly confined to the first 100 - 200 m of the edge and thereafter they became rare.

The craters Öldugfeg and Hlifargfar in Lf 1970-I provide special habitat conditions. They are built up of tephra cones and no real lava occurs. Several species are much more frequent there, on fine-grained to coarse tephra, than on the lava rocks, such as (recorded in 1975) Racomitrium canescens, Bryum cf. pallens, Funaria hygrometrica, Dichodontium pellucidum, Ceratodon purpureus, Bryum arcticum and Didra- nella subulata.

Among the new colonists in 1975 was Blindia acuta. The presence of that species in this habitat is unexpected.
Fig. 33. The initial colonization occurred rapidly during the first ten years in the lava field from the 1970 eruption.

It has never been found either earlier or later in the lava fields. In Iceland, the species is very common on wet rocks in or close to rivers and waterfalls up to about 400 - 500 m a.s.l (Hesselbo 1918). Martensson (1956 p. 55) pointed out that B. acuta in the Tornetrask area of Sweden “occurs in fairly wet localities.... It grows mainly on stones in the flood zone of streams or on irrigated rock surfaces in steep slopes and cliffs”. B. acuta grew in sandy patches among Bartramia ithyphylla, Bryum spp. and Bryoerythrophyllum recurvirostrum, where water dripped in rainy weather. The precipitation that year was unusually high.

The juvenile stages of the phyllocdia of Stereocaulon vesuvianum (0.2 - 0.5 mm in diameter) became prominent in 1975 with numerous dots but the dark spot in the middle of the phyllocdia was first observed two years later.

In 1977, R. lanuginosum was locally abundant on rock surfaces and the occurrence of Bryum spp. and Ceratodon purpureus was most striking. Two lichens were recorded: Placopsis gelida (max. diam. 1.6 cm, mainly restricted to moist depressions with Conostomum tetragonum and Ditrichum flexicaule) and Stereocaulon cf. capitellatum (on spongy surface).

The following increase in number of species continued in such a way that already in 1979 it was almost possible to distinguish initial stages of plant communities. In that year, 1979, two liverworts occurred for the first time since 1972 (Anthelia julacea, Scapania cf. curta), as well as four mosses (Arctoa fulvella, Bryum stenotrichum, Encalyptaciliata, Pohlia proligerata) and two species of Peltigera (P. venosa and P. cf. canina).

In 1980, the following species were recorded in Lf 1970-II: Grimmiacsp. affinis, Racomitriumfasciculare, Didymodon rigidulus, Polytrichum alpinum, Nardia scalaris and Leptogium lichenoides (Fig. 33).

8.2.2 Remarks on the texture of the surface

Some measurements were made on the texture of the microsurfaces, especially regarding the colonization on Lf 1970. Very little has been published on this subject (Atkinson 1969, Wentworth & MacDonald 1953). Most authors have simply considered the difference implicit in the classification into apalhraun and helluhraun. Others only mention the bizarre features of the lava or vesicular cavities created in the molten lava by evaporating moisture of the substrate.

The following percentages (per 100 cm$^2$) of the listed categories of microsurface originate from 11 measurements in each of the three youngest lava fields (Lf 1980/81, Lf 1970 and Lf 1947), but there is no evidence that the texture was similar from the beginning:

<table>
<thead>
<tr>
<th>Lf 1980/81</th>
<th>-70</th>
<th>-47</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. dense surface:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. smooth, glossy surface</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>b. vesicles</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>II. spongy surface:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. slightly spongy</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>b. moderately spongy</td>
<td>43</td>
<td>35</td>
</tr>
<tr>
<td>c. very spongy, innumerable sharp points</td>
<td>25</td>
<td>20</td>
</tr>
</tbody>
</table>

Of course, these figures would become more interesting if compared with similar ones obtained in older lava fields, but such information is not easily obtained as such measurements are obstructed by the cover of mosses. Still, it is most likely that the percentages regarding vesicles will become more discernible as the weathering process proceeds.

The very spongy surface, with many sharp points, is very fragile. It crumbles easily, mostly during the actual movement of the material and during the first months after the eruption. The crushed pieces form small patches, often together with the primary tephra. The moderately to slightly spongy surface is much more stable. In Lf 1980/81 and Lf 1970 there was no indication that the texture was different at different heights but it was obvious that crags in the Lf 1947 were more weathered than lower-lying parts. No attempt
Vegetation on lava fields

Fig. 34. a. Clinker in the lava field of 1970. On the top is a glassy surface, the other part is spongy. On the ledge there is loose material (broken pieces) where *Racomitrium lanuginosum* grows. b. Very spongy lava surface with protruding points and microfurrows. *Pohlia filum* grows in the furrows.

was made to determine the rate of the weathering process.

The spongy and vesicular surface of the blocks significantly affects the colonization of barren lava fields. With its microholes and microfurrows, often filled with fine material, the rough surface provides excellent shelter and colonization facilities for several plants, especially mosses (Fig. 34).

The habitats, referred to categories of microsurface, listed above, are colonized in different ways. The smooth and glossy surfaces (dense surfaces) in Lf 1970 were quite barren. In Lf 1947 more or less horizontal surfaces of that sort were locally overgrown by a carpet of *R. lanuginosum*, but others, generally sloping steeply, were colonized by crustaceous lichens such as *Rhizocarpon geographicum* and *Lecidea* spp. A colonization by some patches of *Stereocaulon* sp. was also noticed, but never by fully developed specimens. It is probable that the specimens get blown away at a certain stage of development (Fig. 35).

A dense surface with many vesicles is often slightly uneven and becomes colonized by lichens such as *Placopsis gelida* and *Stereocaulon* spp. The vesicles are often filled with silty to sandy material. This material is not so coarse as on the spongy surfaces, where it is mixed with broken lava pieces. The vesicles are colonized, e.g., by *Dicranoweisia crispula*, *Bartramia ithyphylla* and *Distichium capillaceum*.

The spongy surface is the most suitable substrate for colonization. It is sufficiently rough for fragments of mosses, especially of *R. lanuginosum*, to get captured there. An accumulation of material occurs between the narrow, sharp and protruding points in the microfurrows, which offer suitable habitats for acrocarpous mosses,

Fig. 35. The boulders in the lava field from the 1947 eruption are covered with *Racomitrium lanuginosum*, except on the densest surface, where *Stereocaulon vesuvianum* and *Umbilicariatorrefacta* grow.

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e.g., *Bryum* spp., *Pohlia* spp., *Ceratodon purpureus* and *Dichodontium pellucidum*. Its coarseness varies from silty grains to tephra particles or broken lava pieces up to 2 mm or larger. *Stereocaulon vesuvianum* seems to colonize mostly the moderate to very spongy surfaces, but *S. capitellatum* seems to grow mostly on the top of the most fragile points. The folious lichens prefer the slightly spongy surface and the same seems to apply to *Cladonia* species.

**8.3 Lava field 1980/81**

In 1981 only two species, *R. lanuginosum* and *S. vesuvianum*, were found in one place at the first visit by the present author. The site is situated east of the mountain Selsundsfjall, at 450 m a.s.l. About 60 m inside the lava field and on the top of the raised lava field was a small amount of accumulated sand. Both species were with all certainty carried there by wind. They were embedded in the sand. Moreover, a few specimens of *R. lanuginosum* were loosely attached to the spongy surface. Two vigourous stems, 3 - 6 mm, were located in small vesicles, as is the normal situation. They were very loosely attached to the surface. It must be considered unlikely that the fragments of *S. vesuvianum* could become established from these fragile, up to 1 cm high, specimens. They were only attached to the accumulated sand with no connection to the lava surface, in which the species usually develops from tiny single phyllocladias.
9 The *Racomitrium lanuginosum* moss carpet

9.1 Introduction

The most characteristic biological feature of the lava fields is the development of a massive moss carpet of *Racomitrium*, mainly of *R. lanuginosum*. This moss species occupies vast areas of lava surface and lives under unique ecological conditions. It develops into a continuously covering carpet and consequently becomes the first stage in the primary succession on lava and other rock types, as is also known from Scandinavia (Nordhagen 1917, Du Rietz 1925). The special significance of *R. lanuginosum* in the vegetation succession on lava fields deserves a special chapter in this study.

9.2 Growth and development of *Racomitrium lanuginosum*

*R. lanuginosum* is very common all over Iceland on all kinds of substrates, except for damp habitats. As well as in other oceanic climatic regimes within the temperate zones and in Arctic regions, its lower altitudinal limit drops progressively northward and it may be abundant at sea level (Herzog 1926, Tallis 1958). *R. lanuginosum* is a clear dominant in many communities from the coast to high altitudes, and it seems to have a low substrate preference (cf. Mårtensson 1956). According to Tallis (1958, 1959), *R. lanuginosum* is not a true lithophyte and it apparently always needs some accumulation of humus. In the younger lava fields, especially Lf 1947 and Lf 1970, it was frequently found on bare rock surfaces, where it was largely confined to small vesicles and microfurrows. Such microsites usually have some accumulation of dust or fragile particles, due to the presence of aeolian material in the surroundings and to the fragile microtexture of the surface inside the lava vesicles. Moreover, any small established shoot of *R. lanuginosum* rapidly starts accumulating additional aeolian material. It is difficult to reach a definitive conclusion as to the substrate preference of the species. In conclusion, I would consider *R. lanuginosum* as a facultative lithophyte.

The colonization of new habitats by *R. lanuginosum* proceeds either with spores or decaying fragments of parent stems. According to Tallis (1959) there is only one documented case of development from spores in nature. Cooper (1931) confirmed colonization by sporelings of *Racomitrium* on barren glacial moraines in Alaska, but here it is not certain which species was involved, probably mainly *R. canescens*; Cooper mentioned “*R. canescens* (with some *R. lanuginosum*)." Several indications that *R. lanuginosum* has developed from spores have been found. The species has been frequently recorded on almost vertical rocks growing from microscopic vesicles and furrows, where the number of young plants amounts to hundreds within 0.25 m². It has not yet been possible to verify this presumption firmly. However, the few specimens which have been prepared have traces of rhizoids with no connection to parent stems, which may be interpreted as an indication of a juvenile stage.

Capsules have not been found frequently, but they are not as rare as is stated in taxonomic literature. An unusually high capsule production was recorded in 1972, perhaps due to the weather conditions during April and May of that year. The mean temperature was 0.8 °C above average and the precipitation was 26% higher (Veörättan 1972). Sex organs are formed in the spring (mid-May) and the fertilization is related to the uptake of water. Both sexes are mixed in the tufts. The high capsule production may also be related to the release of nutrients from tephra falling in 1970 into a biologically available form. The capsules were confined to the moderately exposed parts of the main surface.

Capsules were counted in 22 plots of 20 cm² in Lf 1947, Næ 1845 and No 1389. The following result was obtained:

<table>
<thead>
<tr>
<th>Location</th>
<th>Capsules/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lf 1947</td>
<td>63.5</td>
</tr>
<tr>
<td>Næ 1845</td>
<td>4.9</td>
</tr>
<tr>
<td>No 1389</td>
<td>3.8</td>
</tr>
</tbody>
</table>

The mean thicknesses of the moss carpet were, 2 cm in Lf 1947, 14.5 cm in Næ 1845 and 26.5 cm in No 1389. The reason for the highly different numbers of capsules in Lf 1947 versus Næ 1845 and No 1389, may be that the plants in Lf 1947 are subject to less favourable conditions.
Fig. 36. Racomitrium lanuginosum colonizing a boulder in the lava field of 1947. The most exposed places are sparsely colonized but later the moss carpet can overgrow these places.

Although the fragments are not equipped to colonize bare areas, they become easily established in the lava fields, especially in Lf 1947 and younger lavas. The surface of each scoriaceous clinker is always more or less spongy and, with its coarsely serrated leaves, R. lanuginosum gets sufficient anchorage. The present author has confirmed that, from a 5 mm long apical stem, a new main stem can easily develop from lateral branches; even apices ('buds'), of not more than 5 leaves, can form new branches in suitable habitats. The conclusion is that many specimens of R. lanuginosum originate from detached fragments.

R. lanuginosum was found to colonize substrates of all types of texture, except for smooth and glossy ones. The species is able to colonize both horizontal and steep surfaces (vertical to overhanging), provided there is sufficient light. Many boulders in Lf 1947 have become almost completely moss-covered. However, many plants on vertical rocks in the upper part of the main surface only reach a size of 1 - 2 cm before they get washed away, except in sheltered places, where weathering is less rapid (Fig. 36). The supply of rain water is the main factor determining the establishment and growth of R. lanuginosum, as in most cases of other bryophytes (Anderson & Bourdeau 1955), and the effects of desiccation are broadly correlated with conditions in their habitats (Dilks & Proctor 1976). Long-lasting dry periods may stop the growth, but the xerophytic characters of R. lanuginosum, such as thickness of the cell walls, development of a cuticle with marked papillae, the capacity to press the leaves towards the stems when dry, and the presence of hyaline leaf apexes may improve its capability to resist desiccation. R. lanuginosum has been found to be extraordinarily resistant to desiccation and it is still capable of rapid and virtually complete recovery after 239 days at only 32% relative humidity (Dilks & Proctor 1974). According to Kallio & Heinonen (1973), it has its optimum temperature for net photosynthesis at +5 °C with a minimum at −10 °C, which is one of the lowest values known for mosses; consequently it is 'preadapted' to wide temperature variation.

In the first four years the main stem is upright with few lateral branches developed. Thereafter, a further elongation starts and more lateral branches are formed with reduced elongation of the interfascicular zone. Later, the scattered tufts coalesce into a continuous mat, with a thickness of 4 - 6 cm; the moss carpet becomes really massive. Thus, the spreading of R. lanuginosum depends also on the surface roughness (Fig. 37). At this stage very few species enter the R. lanuginosum carpet, due to the immature substrate.
In contrast, *R. lanuginosum* may overgrow existing phylloclades of *Stereocaulon vesuvianum* and small acrocarpous mosses on small patches with loose material, which are often colonized by such species.

During the expanding growth of *R. lanuginosum* in Lf 1947 the frequency of *S. vesuvianum* decreased gradually, especially in the middle of the main surface. Under a moss carpet, up to 12 - 15 cm from its border, white dots of decaying phylloclades were still observed. The most resistant species is the rigid and erect *Pogonatum urnigerum*. Also *Lophozia ventricosa* can grow on *R. lanuginosum*. Presumably, some species which decrease in frequency during the initial stage are later able to invade the growing moss carpet, occupying another niche, when the moss carpet has accumulated aeolian material and small ruptures are formed. Examples are *Distichium capillaceum*, *Antheila julacea* and *Nardia scalaris*.

When *R. lanuginosum* reaches a height of 3 - 6 cm in a dense carpet, the lower parts of the stems start to decay. Accumulation of aeolian material, such as tephra, definitely speeds up the decaying process. The tephra fall of 1970 sunk down easily through the carpet and became accumulated close to the surface. Consequently, it may be fairly improbable that a tephra layer at 1 - 2 cm above the surface of a lava is only 30 - 40 years younger than the lava (cf. a tephra layer of 1341 in Su 1300, Thorarinsson 1968).

Further development of the moss carpet depends on the elevation and on its position in the lava field. The main growth patterns described by Tallis (1959), where most of the variation can be grouped around a 'central' growth-form, are all represented in the area. In the middle part of the main surface, below 350 - 400 m, the moss carpet reaches its best development, becoming up to 40 cm thick, occasionally intersected by one or two tephra layers. The main stems grow upright with little growth of lateral branches. In sheltered places they can reach an uninterrupted length of 35 cm, with a fully vigorous uppermost top of 15 cm but gradually decaying downward. In exposed sites and at higher elevation the branching pattern becomes more obscured. The specimens become typically asymmetric due to strong winds, which is also the case where they grow on slopes (cf. Tallis 1959).

The structure of the carpet varies in density, depending on the influence of aeolian material, shelter, etc. The carpet is very loose with very few or no companion species, where the deposit of aeolian material is very small and no tephra fall has occurred after 1947. In some places, where *R. lanuginosum* has completely leveled the lava field, it forms characteristic cones, a feature which is most likely related to the soil moisture regime (Fig. 38).
9.3 Succession of the *Racomitrium lanuginosum* carpet

Some observations on stands with a pure and thick *R. lanuginosum* carpet, which were carried out during up to 8 yrs (Su 1300-II and Pá 1554), have confirmed that such carpets may remain monospecific for a long period of time. This agrees with the observation that many vascular species are restricted to rock ledges. In other stands, also with a thick moss carpet still unaffected by aeolian material, small ruptures in the carpet have enabled some vascular species to become established there. These vascular species have prominent stolons in common (e.g., *Festuca rubra*) or prostrate shoots (e.g., *Empetrum nigrum* and *Salix herbacea*). In Pá 1554 quite vigorous, light green shoots of *F. rubra* extended 11 cm down in the loose moss carpet. Fig. 39 shows the changes in one stand of *R. lanuginosum* with *Empetrum nigrum* in No 1389 during a period of four years. The retrogression of *E. nigrum* and *F. rubra* within the analysis is clear. On the other hand, *Carex bigelovii* and *Polygonum viviparum* prefer a more densely packed moss carpet.

In three places some thick tussocks of *R. lanuginosum* were deliberately turned upside down by the author. Two years later, one of these tussocks, which contained some stolons of *Carex bigelovii*, had developed some fairly vigorous specimens of that species, but no other invasion into the tussock was observed. The two other tussocks remained totally unchanged. Only the borders had become more diffuse three years later, due to the growth of *R. lanuginosum* from the margin.

In areas with very little or no aeolian deposits, the moss carpet becomes damaged only in some places. This confirms its high resistance to wind force. On the other hand, when the moss carpet reaches the edge of a rock it becomes hanging. Such a suspended moss carpet is often peeled off in rainy and stormy weather (Lye 1967). Small ruptures, which are frequently observed around more or less big protruding stones, are of little importance. They are most often vegetated by small acrocarpous mosses and liverworts, e.g., *Bartramia ittyphylla*, *Anthelia julacea* and *Gymnomitrium concinnatum*.

Under certain conditions, wind can destroy the moss carpet (cf. Ostenfeld 1908), but in the areas with little deposits, damage is mostly confined to specimens on small hillocks. One such opening in Pá 1554 was mapped during 1972 - 1979. About 30 cm x 50 cm of the 10 - 15 cm thick carpet had blown away, most likely in 1972, leaving a 2 - 5 cm thick decaying moss layer. No plants were found on the surface, except for one specimen of *Poa glauca*, which may have occurred there before the damage. At the northeast side the surface was bordered by a 5 cm vertical wall of *R. lanuginosum* carpet, at the southwest the carpet was gently sloping. The barren surface had been colonized by *P. glauca* in 1973.
Fig. 39. a. *Empetrum nigrum* and *Festuca rubra* in a moss carpet of *Racomitrium lanuginosum* in the Nordurhraun lava field from the 1389 eruption in July 1976 (50 cm × 50 cm). b. The same stand in August 1980. The retrogression of *E. nigrum* and *F. rubra* is obvious. A small rupture has been created by the wind.

but they were restricted to small depressions with densely packed humus. In 1979, small specimens of *P. glauca* were present only in a small patch.

Consequently, changes in pure and dense moss carpets of *R. lanuginosum* are very slow. The establishment of other plant species is favoured mainly by the occurrence of more or less big ruptures in the moss carpet (cf. Haapasaari 1988), especially where the moss carpet is influenced by tephra deposits (Chapter 10).
10 Influence of tephra fall on vegetation

10.1 Introduction

Mt. Hekla has emitted much tephra during the various eruptions, causing considerable damage to the vegetation already developed on the older lava fields. In this chapter the main emphasis will be on the physical influence of the tephra from the 1970 eruption on the main surface of five lava fields.

The bulk of the tephra was emitted during the initial phase of the 1970 eruption and was deposited in a narrow sector with a northnorthwest direction. It covered 22,000 km² of land. About 95 km² were within the 5 cm isopach, 33 km² within the 10 cm isopach and 9 km² within the 20 cm isopach (Thorarinsson 1970).

10.2 Thickness and distribution of the tephra

In the investigated area, nine sites (listed below) were influenced by the tephra deposits in 1970. The thickness there varied from 0.5 - 55 cm depending on the distance from the main tephra bulk, the irregularity of the surface and the amount of existing vegetation on the lava field.

As a rule, the tephra thickness decreases exponentially with the distance from the vents (Francis 1976). However, close to the vents the deposits vary considerably in depth. For example, a 1 - 2 km broad zone north of the summit of Mt. Hekla, between Lf 1970-I and Lf 1970-II, remained completely free from tephra (e.g. Lf 1766-II). As to particle size in the tephra, the median diameter decreases exponentially with the distance from the volcano (Francis 1976). Close to the vents, particle size may vary considerably, usually from 0.2 - 25 mm in diameter. The tephra thickness (cm) at the nine investigated sites was (1970):

<table>
<thead>
<tr>
<th>Site</th>
<th>Initial Tephra Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ef 1158</td>
<td>0.5 - 5 (-10)</td>
</tr>
<tr>
<td>No 1389-III</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Lf 1693</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Næ 1845-I</td>
<td>5 - 12</td>
</tr>
<tr>
<td>Næ 1845-II</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Næ 1845-III</td>
<td>20 - 40</td>
</tr>
<tr>
<td>Lf 1947-I</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Lf 1947-II</td>
<td>12 - 20</td>
</tr>
<tr>
<td>Lf 1947-III</td>
<td>&lt;3</td>
</tr>
</tbody>
</table>

These figures of initial tephra thickness are important to know in view of the future development of the tephra layer and its colonization by different sorts of plants.

On a horizontal surface the tephra is equally distributed. With irregular topography, as in apalhraun, the distribution becomes very unequal; a deposit less than 10 cm gets easily carried away by wind and water from hillocks into depressions and holes. Also, tephra sinks into the moss carpet, depending on how loose the carpet is. To follow the changes, the tephra cover (%) was estimated during the period 1970 - 1987 at 6 sites:

<table>
<thead>
<tr>
<th>Year</th>
<th>Ef 1158</th>
<th>No 1389-III</th>
<th>Lf 1693</th>
<th>Næ 1845-I</th>
<th>Næ 1845-II</th>
<th>Næ 1845-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>10</td>
<td>50</td>
<td>60</td>
<td>40</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1972</td>
<td>5</td>
<td>50</td>
<td>50</td>
<td>&lt;1</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1973</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1975</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1976</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1979</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1980</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1982</td>
<td>15</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>1987</td>
<td>15</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

In Lf 1947 the tephra soon percolated through the clinker layer, due to the roughness and barrenness of the lava field and disappeared. Some amounts were also accumulated quite quickly in holes and, therefore, the estimation of tephra cover was here inaccurate and has been excluded.

It is clear from the figures mentioned above, that where the thickness is less than 5 cm only small traces are left 5 years later. The difference between the duration period of tephra in No 1389-III and Næ 1845-I is caused by differences in the irregularity of the topography. In No 1389-III (and even in Ef 1158) the irregular topography had been leveled by thick deposits during recent decades. In Næ 1845 the topography is much more irregular due to the young age of the lava field. The tephra deposit from crags and boulders was soon accumulated in depressions, where it formed more or less big and thick tephra patches, clearly demarcated by surrounding moss-covered lava stones. Already two months after the eruption, crags and the...
uppermost parts of *R. lanuginosum* on top of boulders were almost free from tephra. The tephra deposit in Næ 1845-I never covered a large unbroken strip of land. The widest continuous strips of tephra were situated on slopes but not in the horizontal plane, which is broken by upraised rocks or big lava stones. The lava field with the large number of tephra patches looked like gray-mottled horses.

Where the thickness was less than 2 cm the tephra percolated directly into the moss carpet. Already a few months later the uppermost parts of the stems (5 - 10 cm) were nearly free from tephra. Where the thickness was 2 - 5 cm, the most fine-grained tephra also percolated into the moss carpet and formed a distinct tephra layer 0.53 cm below the uppermost sprouts of *R. lanuginosum*. Bigger particles remained attached to the sprouts of *R. lanuginosum* and thereby caused slight damage to the mosses. Usually, at a thickness exceeding 8 cm, most of the moss carpet was covered.

At Næ 1845-II the main surface and all types of holes were entirely covered by tephra. From a distance the field looked like a black desert. Only raised crags and some hillocks emerged from the surface, either nearly barren or covered by a thin carpet of *R. lanuginosum* with a scattered occurrence of other species. In the few places which jutted out, the carpet of *R. lanuginosum* was more or less intermingled by black, fine-grained tephra. It is therefore clear that when the thickness of tephra cover exceeds about 20 cm the area becomes nearly devastated, at least for a period of years.

Before the eruption of 1970, Næ 1845-III and Lf 1693 had previously been highly affected by deposits of tephra, mainly from the eruption of 1947. These sites are located in the upper part of Mt. Hekla and large tephra quantities are also transported there from the tephra-covered summit by wind and water during thaw. The main surface in Næ 1845-III is a sandy or tephric slope where the running water makes deep furrows in the ground. The lava has been almost buried by tephra; raised crags and some hillocks are sparse. Here and there small ridges covered by scanty vegetation are situated downhill between thick tephra-drifts.

10.3 Mechanical influence of tephra

The mechanical damage caused by tephra is due to the direct deposition of the tephra (primary damage). On level surfaces, especially with a supply of large amounts of tephra (15 - 20 cm or more), erosion starts (secondary damage) through the supply of wind-blown tephra (Fig. 40). Generally, the secondary damage does not really take place until one year after the tephra fall and is much more destructive than primary damage (cf. Hörner 1949, Sígbjarnarson 1969, Thorarinsson 1961).

The species of the lava fields are differently tolerant to the tephra supply. *R. lanuginosum* has a high tolerance against primary damage but low tolerance against secondary damage. A few species are capable of growing in highly eroded areas. Graminaceous species and *Salix* spp. are the most adapted ones. The most sensitive plants are the liverworts because they have a small size and susceptible leaves. Some liverworts, e.g., *Anthelia julacea*, *Gymnomitrium concinnatum* and *G. corallioides*, have their leaves densely arranged and survive if they are not totally covered by tephra. *Lophozia ventricosa* can survive a moderate tephra fall, as it often grows mixed into the moss carpet, living on the uppermost parts of the *R. lanuginosum* stems. Other liverworts living on the ground become very easily damaged.

The very porous tephra grains get easily attached to the plants. Already small amounts of deposits on the leaves decrease the total area for assimilation. A few examples were found where tephra grains up to 2 mm had damaged some leaves (perhaps scorch) of the stem apices of *R. lanuginosum*. Where folious lichens were partly covered, damage was only noticed on a few specimens. However, most species tolerate quite a lot of tephra fall without being killed. For example, a 8 - 10 cm thick tephra fall is needed to fill the carpet of *R. lanuginosum* completely.
In spite of the tephra fall in Ef 1158-I, No 1389-III and Næ 1845-I, only small secondary damage has been noticed, except for that on Empetrum nigrum (Næ 1845-I). Due to the surface roughness there, the damage is only restricted to places within or around the tephra patches.

In Næ 1845-II & III the tephra will remain unstable for a long time. Secondary damage was not noticeable during the first months after the tephra fall. In 1971, and especially 1972, the situation became the opposite. The visible remnants of R. lanuginosum carpet, not buried by tephra, were highly damaged by erosion or all the uppermost 5 - 10 cm of the living shoots were blown away and only the brown and decaying humus was left. Only few cryptogams were recorded in the tattered remnants, or in small sheltered rock ledges.

The influence of the tephra deposits from 1970 differs in some respect from that in the sandy/tephric areas, e.g., in No 1389-IV and in Kr 1878-I, which are continuously affected by aeolian material from surrounding openings. The difference is probably due to variation in substrate. Although that material also originates mostly from tephra, it has been weathered, resulting in a substantially different substrate regarding particle size, porosity and nutrient values.

10.4 Vegetation recovery on tephra

Vegetation recovery on tephra-damaged lava fields depends on whether the deposits are primary or secondary and also on the presence of survivors, which strongly influence the recovery (Fig. 41; Griggs 1933). The character of the colonization is also related to the types of tephra surface. The tephra surfaces, consisting of grains with mixed size, become hardened by some chemical reactions. When the fine-grained material is drying after percolation of trickling water, some kind of solidification occurs and a stable shell, up to 2 cm thick, is formed. The details of this process are not known. Tephra surfaces consisting only of coarse particles remain very loose for many years and are easily moved, even by weak winds.

The distinct tephra patches have undergone widely different changes. Some of them, 1 - 5 cm thick, disappeared in the course of 1 - 2 years. The tephra was carried away or incorporated in the substrate. R. lanuginosum also has a great capability to grow through the tephra, due to the ability of the species to develop lateral branches (Fig. 42). Generally, most of the tephra patches, with a tephra thickness of 5 - 25 cm, become colonized by R. lanuginosum from the sides. The rate of the process varies highly, depending on the forms of the margins. No invasion occurred in the tephra patches from sides with vertical moss-covered stones during a period of 12 years. From a horizontal to gently sloping moss carpet, R. lanuginosum managed to invade up to

Fig. 41. Salix lanata two years after the tephra fall in 1970. The deposit was 30 cm deep at this place. The Næfurholtsbraun lava field from 1845 - July 1972.

Fig. 42. Racomitrium lanuginosum in 1980 in the Næfurholtsbraun lava field from 1845. The species was buried by tephra in 1970 but each stem has developed several lateral branches and continued to grow.

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10 cm in the period (see section 9.3), with an increasing growth of lateral branches.

Vascular species, which usually grow on rock ledges, colonize the tephra patches, mainly at the border. They are dispersed from nearby places. Examples are Car-daminopsis petraea, Cerastium alpinum, Oxyria digyna, Festuca rubra, Luzula spicata and Botrychium lunaria. These species are not long-lasting; they disappear mainly 4 - 5 years after they have become surrounded by R. lanuginosum.

Three ligneous species have a special position, Salix herbacea, Empetrum nigrum and Betula pubescens. B. pubescens will be discussed separately below (see section 10.5). S. herbacea has a high tolerance against unstable tephra but its growth is extremely slow; it is well documented (cf. Wood & del Moral 1987) that plants adapted to infertile soils generally exhibit reduced maximum growth. E. nigrum is very susceptible to secondary damage. The stems become entirely barren due to severe injury caused by the blowing tephra. On the other hand, where it grows at the border of stable tephra patches it develops new branches in the direction towards the patches and the shoot systems spread out close to the surface (Fig. 43). About 20% of all tephra patches were overgrown by Empetrum nigrum. The rate of growth is much higher in these patches than in a pure moss carpet, because the shoots are not covered by mosses.

The hardened shell of tephra surfaces is colonized by several cryptogams. The course of establishment is very similar on all such surfaces and resembles that on barren lava fields. When the solidification has finished, the first recorded species were Ceratodon purpureus and R. canescens. The specimens of C. purpureus were scattered on the surface but R. canescens grew at the edge close to the border of R. lanuginosum. Gradually more species followed. The following results of species frequencies were obtained in 1979 from 25 analyses within 100 cm² in Næ 1845-I, where the scattered tephra patches were colonized by 1 - 8 species each. Racomitrium lanuginosum, R. canescens, Antheia julacea and Gymnomitrion corallioides were moderately frequent, species which have a wide ecological amplitude in the lava fields as to topography of the surface. Infrequent or rare were species such as Cephalozia arctica, Gymnomitrion concinnatum, Lophozia sudetica, Saelania glaucescens, Barbilophozia hatcheri, Tritomaria quinquedentata and Stereocaulon alpinum.

In Næ 1845-II, plants were very slow in getting established. Very small changes have taken place during the last decade. In 1973, the first recorded colonizing species on the tephra flats were Oxyria digyna, Cerastium alpinum and Luzula spicata in sheltered places, mostly on small slopes. The colonization was very unstable and this instability has been maintained. Consequently, the succession became interrupted. The reason is certainly that while the thick tephra is loose and unstable, only a few plants are capable of developing roots. A place free of tephra on one day may be completely covered on the next day due to the weather conditions. The following species were recorded in tephra deposits exceeding 20 cm in Næ 1845-II during the period 1973 - 1987:
In some places, where the tephra fall had diminished to 8 - 10 cm, *Salix lanata* and *S. herbacea* grew through the tephra layer already in 1972. Some tussocks of *Silene acaulis* appeared to be severely damaged, where they justted out of the tephra.

In 1845-III the water washed off the tephra from the hillocks. The tephra in the furrows became continuously thicker and was still unvegetated in 1987. Where the tephra was thinned out, the most frequent species were *Poa alpina* and *P. glauca*, apart from *R. lanuginosum*. Other species, such as *Salix herbacea, S. lanata, Saxifraga rivularis, S. cespitosa, Cerastium alpinum, C. cerastoides, Oxyria digyna, Luzula spicata, Deschampsia alpina* and *Epilobium latifolium* occurred very scattered. The latter species is not uncommon in loose screes and seems to thrive there as well as on sandy banks along rivers and dried-out river beds.

It has been implied (see, e.g., Eggler 1959) that pure volcanic tephra is more deficient in nutrients, mainly fixed nitrogen, than lava. It has also been suggested that possibly the tephra exerts an inhibiting influence upon plants (cf. Eggler 1959). However, among vascular species established in areas with thick tephra no deficiency symptoms were observed within the present investigation. Nevertheless, a long period is required before 1845-II becomes equilibrated. The mechanical inhibition will be the wind-transported tephra.

### 10.5 Invasion of *Betula pubescens* into the moss carpet

The birch growing in the Hekla area throughout has characters ascribed to leaves and flowers of *Betula pubescens*. *B. nana* is entirely absent from the area although it is relatively common elsewhere throughout a large part of South Iceland.

The birch is usually fully leaved by the middle of June and the leaves usually become coloured before the end of September. The estimated period for the assimilation is 110 ± 5 days and the rate of growth is very slow. The birch trees are very sparse and the tree canopies do not form a continuous layer. Most of the trees are polycormic. Monocormic trees occur only occasionally.

The present woods close to Mt. Hekla may be remnants of a formerly much larger wooded area. The greatest threat to the distribution and growth of birch has most probably been the grazing by sheep. It is known from other parts of Iceland that sheep-grazing has prevented natural birch regeneration. Both the leaves and the buds of the birch form a significant part of the food, not least early in the winter when grazing by sheep was practiced (Bjarnason, H. 1942, 1947).

*B. pubescens* now occurs in four historical lava fields up to 400 m a.s.l.: Ef 1158, Su 1300, No 1389 and with a few specimens in Næ 1845. The most splendid birchwood in the lava fields is growing in Ef 1158. As mentioned earlier, the name comes from the farm Ef: Efin-Hvoll, Hvollhreppur county, which formerly had the right to use the woodland in the lava field. In the Járabók (Farm Register) of Magnusson and Víðalfn (1913) from 1709 it is stated that the woodland in Næfurholts territory, which belongs to the farm (i.e. to Efri-Hvoll), was almost of no importance any longer, due both to former utilization of the woodland and by accumulation of tephra from Mt. Hekla. From this description, which is given by the farmer 16 years after the eruption in 1693, one can get an impression of the negative effect of the heavy tephra fall. As the farmers suspected that the register would be used for taxation, they tended to minimize the benefits and exaggerate the disadvantages (Bjarnason, A.H. 1980).

The *Betula* shrubs cover isolated spots and are entirely absent over a very large part of the lava. About 20% of the main surface of Ef 1158 is now covered by *B. pubescens* in one form or another, especially on hillsides towards the south and west. The highest tree was 2.40 m but such trees are very rare in the area. The
shrubs are usually 0.75 - 1.5 m high (average 1.20 m) with very sparse sprouts and often many dead shoots. About 60 years ago most birch shrubs were not more than 30 - 50 cm high, according to the farmers at the Næfurholt farm. They consider that reduced grazing by sheep and totally abolished winter grazing caused a considerable height increase of Betula shrubs.

The recovery by formation of shoots is presumably the most effective way although it occurs only occasionally. Most of the trees have a large thickening at the base, which indicates a high age and highly frequent damage. The few recorded seedlings of B. pubescens in the moss carpet of the three oldest lava fields all occur in small ruptures. In 1972, eight seedlings were noticed in Næ 1845-I. It was particularly interesting to note that they were growing at the edges of the tephra patches, but not in deep depressions, fissures or thick moss carpet as is found for, e.g., Salix spp. There was no evidence of secondary damage of the stems at the bases. Most often the stems were, or became eventually, shielded by some R. lanuginosum within a few years. In 1987 all the tephra patches had disappeared around the birch except in one place. Of the 16 specimens in 1975, all had developed numerous branches growing from the roots, and the height was 5 - 12 cm. The numbers of specimens are presented below:

<table>
<thead>
<tr>
<th>year</th>
<th>1972</th>
<th>75</th>
<th>76</th>
<th>79</th>
<th>80</th>
<th>83</th>
<th>88</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. pubescens</td>
<td>8</td>
<td>16</td>
<td>14</td>
<td>-</td>
<td>12</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>max. height</td>
<td>-</td>
<td>12</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>

The ability of B. pubescens to colonize and survive in the lava field depends on the supply of the seeds, on favourable conditions of germination in small ruptures or tephra patches, and the survival of the seedlings. Continuation of growth depends on the effects of weather conditions, grazing, etc. As the seed of Betula is a small nut with two wings, it is easily dispersed over long distances by the wind. The nearest place with B. pubescens is on the hillside of the mountain Melfell, only a few hundred meters away.

Germination depends, among other things, on (a) temperature, (b) light, (c) water supply and (d) thickness of the sward. These factors have not been examined. An examination of germination in different habitats in Iceland has, however, shown that the seeds fail to germinate in a sward more than 1 cm thick and the seedlings were shortest in the carpet of R. lanuginosum in comparison with four other communities (Magnússon 1989).

This observation confirms that the establishment of B. pubescens in the dense moss carpet is promoted by the presence of some kind of rupture (Fig. 44). A moderate tephra fall must be considered as one of the most favourable substrates for the invasion of B. pubescens, as it splits the thick moss carpet. Sheep-grazing may perhaps also favour reaforestation in some way, as trampling creates habitats for seed germination (cf. Haapasaari 1988).

In Su 1300 the birch wood has an interesting distribution. It grows only at 100 m a.s.l. at the northern point. In the middle of the lava field the birchwood forms an unusually straight border diagonally to the lava stream. The birchwood covers ca. 8 - 10 % of the main surface. This remarkable distribution is probably not related to grazing, although the sheep-fold of the farm Selsund is
found in the vicinity (see 2.2.2). The distribution of *B. pubescens* coincides with the area which is influenced by accumulation of the ‘Selsund pumice’ originating from the flat areas northwest of the mountain Botnafjall. Probably, the distribution can also be related to the accumulation of tephra.

In some summers it was noticed that 5 - 15% of the older branches of many birch shrubs in Ef 1158 were dead, being most obvious in the summer of 1987. Similar damage was reported also from other localities in South Iceland. Possible explanations include:

1. The sheep often cause damage to *Betula* by gnawing the bark around the stem. Careful observations confirmed definite bite-marks on several trees; however not sufficient to explain the total damage.

2. Eight species of lepidopteran larvae are known to cause damage to *B. pubescens* in Iceland. The most abundant species are *Acleris notana*, *Operophtera brumata*, *Epinotia solandriana*, *Rheumaptera hastata* and *Apotomis sororculana* (Koponen 1980). There was, however, no clear indication of defoliation by the larvae.

3. The death of some branches may be regarded as a physiological adaptation to withstand water deficiency. This would then be an effect related to the local topography, resulting from the very ramified root system. In my opinion, these three factors interact to cause the damage observed.
11 General discussion

11.1 Vegetation typology

It has not been easy to classify the vegetation of the lava fields, although the application of the program TABORD with the elaboration of clusters of the first and second order was satisfactory. Due to the relatively young age of the historical lava fields, the vegetation largely consists of primary successional phases and has not yet fully developed. A common element in the vegetation classifications is the dominance of *Racomitrium* species, mostly *R. lanuginosum* but also *R. canescens*. These two species form plant communities of their own. At higher altitudes, mainly in the northeast part of the area, *Stereocaulon vesuvianum* also forms a community of its own. Variants of several communities exist and are characterized by locally dominant species. A full floristic-sociological characterization of community types is difficult because (1) only few species in a given site occur with higher cover-abundance values and most species scores (> 95%) fall in cover class 1; (2) the species composition varies widely between similar sites and only few species reach a high frequency of occurrence in any one cluster.

There are also problems with comparisons between the vegetation of the lava fields in the Hekla area and (a) lava vegetation described from other countries and (b) similar plant communities described from other countries but not necessarily growing on lava substrate.

(a) Most descriptions of lava vegetation elsewhere mainly cover the first step in the primary succession, i.e., colonization and establishment. Moreover, most of the dominating species in other lava areas do not occur in Iceland as these areas belong to quite different phytogeographical regions (e.g., alpine Japan, tropical Indonesia and Hawaii).

(b) Because of the differences in phytogeography and climate, succession on other lava fields is more divergent than on Iceland and ends in various types. Communities dominated by *Racomitrium* species, so common in the Hekla area, although known from oceanic locations in many parts of the world, are not at all common in other volcanic areas. Similar communities are only known from parts of North Europe, e.g., the species-poor *Racomitrium* heath association (Cariceto - *Rhamnetum lanuginosi*) in Scotland (McVean 1964a) and the northern boreal *Racomitrium lanuginosum* type in northern Fennoscandia (Haapaasaari 1988). Hekla dwarf-shrub communities, which follow the *Racomitrium lanuginosum* comm., such as the *Empetrum nigrum - Racomitrium lanuginosum* comm. (including its variants) are similar to communities in Scotland, e.g., *Rhacomitretum - Empetretum* (McVean 1964b) and to oceanic heathlands of the heath scrub types (arctic, hemiarctic and northern boreal types) in Fennoscandia (Haapaasaari 1988). However, this resemblance is mainly physiognomical and less floristical (cf. Gunnlaugsdóttir 1985). The same applies to the *Racomitrium canescens*-rich vegetation types described for the Faroes (Bócher 1937) and Scotland (Birse 1980). Their physiognomical resemblance is high but they differ floristically.

Due to the prevalence of bryophytes in the *Racomitrium* heath in the Hekla area, often neglected in earlier descriptions from Iceland, a comparison with earlier Icelandic descriptions is difficult. The most relevant descriptions are these from Jónsdóttir Svane (1964) and Gunnlaugsdóttir (1985).

The following community types distinguished are well-characterized and could be compared with existing descriptions:

(a) The *Racomitrium lanuginosum* comm. with the *Rhamnetum type of Jónsdóttir Svane (1964) and the inops subass. of the *Racomitrio lanuginosi - Thalic­


(b) The *Salix herbacea* variant of the *R. lanuginosum* comm. with the *Salix herbacea - Rhacomitrium soc. of Jónsdóttir Svane (1964).

(c) The *Empetrum nigrum* variant of the *R. lanu­
ginosum comm. is related to a part of the ‘Rham­
mitrium-reiche Zwergstrauchheide’ (mainly nos. V:2 & 3 and V:11-14) of Jónsdóttir Svane (1964) and partly to the inops subass. of the *Racomitrio lanuginosi - Thalic­tretum alpini of Gunnlaugsdóttir (1985).

(d) The *Empetrum nigrum - R. lanuginosum* comm. (especially the *Vaccinium uliginosum* variant) is very similar to the ‘Rham­mitrium-reiche Zwergstrauch-

The community types recognized in the Hekla area differ slightly from those included in the above-mentioned descriptions in the floristical composition of the field layer, as some of the characteristic vascular plants are presented only with low frequency and cover value. Regarding the bottom layer, the differences are mainly due to the low abundance of lichens in the Hekla area.

The Racomitrium canescens comm. (including its variants) in the Hekla area deviates widely floristically and cannot be related to existing descriptions (Jónsdóttir Svane 1964 and Gunnlaugsdóttir 1985). Further studies elsewhere in Iceland are necessary to confirm whether this community type is only confined to young lava fields or more widespread.

At high altitudes, mainly in the northeast part of the area, the Stereocaulon vesuvianum comm. seems to be the only community restricted to relatively young lava fields. It has also been found in other lava fields of the apalhraun type, mainly at high altitudes in northeast Iceland (Gallée 1920, Venzke 1982). Further studies must be made to confirm its phytosociological status. The Drepanocladus uncinatus - Carex bigelowii comm. is restricted to one lava field. Its phytosociological status is uncertain; perhaps it is most related to some of the Carex bigelowii soc. (nos. 386-393) in the Rhacomitrium heath of Steindórsson (1974). The Anthelia julacea - Pohlia drummondii comm. shows close resemblance to the alliance Polytrichion norvegici (Gjørevoll 1956) but no corresponding investigations are available from Iceland.

The dwarf-shrub heath Empetrum nigrum - Racomitrium lanuginosum comm. (including its variants), has developed from the Empetrum nigrum variant of the Racomitrium lanuginosum comm.; it may pass abruptly into that community, but gradual transitions are also frequently found. The Arctostaphyllos uva-ursi variant is similar to the Empetrum nigrum - Arctostaphylos uva-ursi soc. of the 'forest sward vegetation' of Steindórsson (1974). The closest relatives that can be found to the Vaccinium uliginosum variant are the Empetrum nigrum - Racomitrium lanuginosum comm. of Gunnlaugsdóttir (1985), several sociations (Tables IV and V) of Jónsdóttir Svane (1964) and the Empetrum - Vaccinium uliginosum soc. of the dwarf-shrub vegetation of Steindórsson (1974). As pointed out by McVean (1955, 1964b), Hylcomium splendens is an important constituent of the Icelandic moss heath. The Hylcomium splendens variant seems to be a transition between the Empetrum nigrum - Racomitrium lanuginosum comm. and the grass heath community types.

The Salix phylicifolia variant has no direct counterpart in Icelandic vegetation, although Steindórsson has described some sociations with S. phylicifolia.

The phytosociological status of the Agrostis vinealis - Drepanocladus uncinatus comm., occurring on only one site, has been regarded as intermediate between the nutrient-rich grasslands and the vegetation types of the R. lanuginosum heath (see 7.5.4). The sand and open field vegetation communities are of little importance in the characteristic lava field vegetation.

In conclusion, the plant communities of the historical lava fields in the Hekla area, even the most developed ones, are still phytosociologically 'unsaturated'.

11.2 Community - environment relations

The use of the canonical ordination program CANOCO has generally been effective. Altogether eight environmental factors were included in the environmental description of the sites, two of which were only recorded in Lf 1947. In the following integrated description of all lava fields together (see section 11.3), the age of the lava fields is added as a ninth factor.

As has become clear from the descriptions of the individual lava fields, most of the environmental factors show variation in only part of the fields. In seven of the 11 fields only three factors or less show variation; in two fields there are five varying factors and in two other fields there are six. Hence, the use of CANOCO was rather to indicate the extent to which the factors included relate to floristic variation, rather than to detect the significant factors in a much larger series of factors.

Some of the environmental factors are common linear variables, e.g., number of tephra falls (N), elevation (E), age (A), others are quasi-linear ordinal factors, such as surface roughness (R), tephra cover (T), quantity of accumulated material (Q) and irregularity (I). Position (P) is a nominal variable. Although the environmental factors included are not all linear, the relationship vegetation-environment was described with the biplot scores of the environmental variables, the option advised for linearly varying variables (ter Braak 1987, Jongman et al. 1987). The alternative approach, the use of the centroid options for the environmental factors which is recommended when nominal factors are in-
volved (Jongman et al. 1987), was tried for some lava fields but the resulting diagrams were less easy to interpret.

The biplot diagrams could be easily interpreted and contributed greatly to an effective description and also a further subdivision of the community types on the individual lava fields. If we compare the CCA results obtained for the 11 fields, it appears that the percentage variance explained on the first axis generally decreases with the number of environmental factors included in the analysis, as may be expected.

As mentioned above, most of the environmental factors included in the local analyses are a variable factor in only part of the lava fields. The surface roughness and tephra cover are the two factors varying in most of the fields. However, they are not always the most important factors in terms of the strength of the correlation with the axes of floristical variation (Table 17). No less than five of the seven environmental factors are the most important factor in at least one field. Another observation is that there is no relation between the age of the lava fields and the preponderance of a certain factor as the most important one. The conclusion is that the physiographic conditions determining the floristical composition of the vegetation in each lava field are at least partly independent of the age of the lava fields. This will, of course, obscure the successional patterns.

### 11.3 Multivariate analyses of the eleven historical lava fields together

The results of the CCA on the material for all the lava fields together, shown in Figs. 45 and 46, can be summarized as follows:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>axis</td>
<td>30.4</td>
<td>16.0</td>
<td>14.2</td>
<td>11.4</td>
</tr>
<tr>
<td>% variance explained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biplot scores of environmental variables:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface roughness (R)</td>
<td>276</td>
<td>50</td>
<td>104</td>
<td>140</td>
</tr>
<tr>
<td>tephra cover (T)</td>
<td>215</td>
<td>223</td>
<td>203</td>
<td>64</td>
</tr>
<tr>
<td>age (A)</td>
<td>-430</td>
<td>3</td>
<td>46</td>
<td>-1</td>
</tr>
<tr>
<td>elevation (E)</td>
<td>406</td>
<td>-6</td>
<td>-104</td>
<td>-61</td>
</tr>
<tr>
<td>no. of tephra falls (N)</td>
<td>-411</td>
<td>15</td>
<td>31</td>
<td>19</td>
</tr>
<tr>
<td>quantity of acc. mat. (Q)</td>
<td>260</td>
<td>-170</td>
<td>-47</td>
<td>107</td>
</tr>
<tr>
<td>irregularity (I)</td>
<td>130</td>
<td>147</td>
<td>202</td>
<td>162</td>
</tr>
</tbody>
</table>

Seven environmental factors have been included in the analysis of the CCA of all the material together. The environmental situation in the ordination diagram can be interpreted in view of (a) the distribution of each lava field and (b) the relation between the plant communities distinguished and the seven main environmental factors - the age of the lava fields, number of tephra falls, elevation, surface roughness, quantity of accumulated material, tephra cover and irregularity - for the 11 historical lava fields.

The main differentiation runs along axis 1. It is related to the age of the lava fields, number of tephra layers and partly to the quantity of accumulated material to the left versus the elevation, surface roughness and partly the irregularity, which run to the right. The factor tephra cover runs diagonally downwards to the right. The reason for the negative correlation between the age and elevation is mainly due to the older lava fields being covered by the younger ones at higher altitudes. Moreover, the older fields have more often been exposed to tephra falls and other aeolian accumulation.

The former ordination diagram shows the relation between the sites of the 11 lava fields and the environmental factors (Fig. 45 a and b). On the basis of the environmental factors the lava fields can roughly be divided into three main groups: 1. Lava fields issued during the period 1158 to 1554 are situated to the left of the diagram and are related to high age, numerous tephra falls, and quantity of accumulated aeolian material; 2. Lava fields issued between 1693 and 1845 are situated in the middle or slightly to the right, and 3. The youngest ones, where Kr 1878 stretches to the left towards the top where Lf 1947 is located. Moreover, Su 1300 and Næ 1845 extend towards the lower part of the diagram as they are partly influenced by aeolian material, and Kr 1878 reaches a high altitude.

The latter ordination diagram shows the relation between the sites and the plant community distinguished (Fig. 46).
The *R. lanuginosum* comm. is restricted to the middle part of the diagram along axis 1. It is absent at high quantities of accumulated material and thick tephra cover. The *R. canescens* comm. is a little more scattered but is also mainly found in the middle part along axis 1. It shows a clear preference for higher elevation and surface roughness. The chionophilous vegetation types are related to high elevation, except for the *Drepanocladus uncinatus - Carex bigelowii* comm. in Pá 1554. Moreover, the *Stereocaulon vesuvianum* comm. is also linked to surface roughness and high irregularity of the lava field.

The dwarf shrub *Empetrum nigrum - R. lanuginosum* comm. with its variants is situated to the left, mainly related to the older lava fields and high number of tephra layers. The grass heath vegetation type, the *Agrostis vinealis - Drepanocladus uncinatus* comm., is located farthest to the left.

The sand field vegetation types, the *Oxyria digyna - Silene maritima* comm., the *Festuca rubra - Agrostis stolonifera* comm. and the *Calamagrostis stricta - Festuca rubra* comm., are mainly related to high tephra cover. The *Luzula spicata - Festuca vivipara* comm. is more related to the quantity of accumulated material.

The position of some species in relation to the environmental factors indicates a clear preference for certain communities. Vascular species such as *Galium boreale, Erigeron borealis, Luzula multiflora* and...
Deschampsia flexuosa, are confined to the left, i.e., to the older lava fields. Carex maritima, Oxyria digyna and Calamagrostis stricta are linked to sandy or tephric areas. A few vascular species, e.g., Deschampsia alpina, are restricted to high altitudes. Mainly bryophyte species and lichens are linked to the upper part to the right of the diagram, such as Placopsis gelida, Peltigera spuria, Scapania curta and Conostomum tetragonum.

11.4 The vegetation development on the main surface

In this section a summary will be presented of the process of colonization and succession on the historical lava fields. Colonization and establishment of plants on new surfaces are processes of great significance for ecologists. Areas which have quite recently become ice-free (Cooper 1923, 1931, Polunin 1946, Persson 1964, Matthews & Whittaker 1987), coastal sand dunes (van der Maarel 1978, 1979b), man-made environments (Rydin & Borgegård 1988, Borgegård 1990), deltas (Waldemarson Jønsen 1979), volcanic rocks (see Chapter 1), or any ‘bare’ area (Lötschert 1974) are examples of virginal substrates which are colonized by plants. They offer fundamental problems regarding transport of diaspores, initial colonization, establishment and development, reflecting the often extreme environmental characteristics. The lava fields are a very extreme environment indeed, where only a few vascular plants are adapted. The few species which can establish there show a slow development and a low degree of interaction with other species. A further limitation seems to be created by the early development of the moss carpet of Racomitrium lanuginosum, which makes it impossible for most other species to establish on the main surface. Lava fields are evidently suitable environments to study succession, the most central form of dynamics.

The concept of vegetation dynamics includes several components, namely fluctuation, patch dynamics, regeneration succession and primary succession (van der Maarel 1988), which are relevant for the dynamics on lava fields.

The supply of diaspores to a lava field starts immediately after its formation. The first diaspores to arrive
are mainly those carried by wind, as small fragments of cryptogams and vascular plants. Dispersal of diaspores into a new lava field by birds is negligible. Some seedlings of vascular plants may sometimes occur only where the young lava field is supplied with certain amounts of drifting sand. However, the sand is loose and the seedlings die quickly. Vigorous fragments of mosses, mainly of the dominating species Racomitrium lanuginosum, may get sufficient anchorage on the spongy lava surface and establish easily. Fragmentation of the other major cryptogam Stereocaulon vesuvianum could not be confirmed but some other lichen species (e.g., Pseudephebe minuscula, Peltigera spuria) are likely to spread in this way. Although fragments of S. vesuvianum cannot become established they are generally equipped with many soredia which may easily give rise to new specimens in nearby suitable habitats. Thus, colonization from specialized organs for sexual propagation is certainly the principal way of dispersal of the species, especially for bryophytes and lichens. Many species produce spores (also R. lanuginosum) that may be especially important in colonising vertical surfaces.

During the first ten years the initial colonization occurs rapidly. The most favourable habitats are those with loose material (in small patches on rock ledges or in microfurrows) in holes that are not too deep, in depressions and in the middle part of the layer of clinkers. Relatively few species colonize the scoriaceous rock surfaces, where the surface texture is unfavourable. R. lanuginosum is the most successful species. Epilithic lichens (e.g., Stereocaulon vesuvianum) suffer on the spongy surface due to the fast weathering of the most fragile points during the first years. The initial colonization does not seem to vary with elevation in the Hekla area.

The limited occurrence of loose material prevents continuous distribution of most of the small pioneers. The unique ability of R. lanuginosum to tolerate the prevailing xeric conditions and its wide ecological amplitude as a whole is an advantage. R. lanuginosum develops into a thick, mainly monospecific carpet over the middle of the layer of clinkers, forming the main surface.

The modification of the environment by the progressive development of the moss carpet of R. lanuginosum secures the space and other available resources in a lava field. The species suppress the growth of the pioneers by overgrowing and inhibits the invasion of subsequent colonists. The vegetative regeneration of R. lanuginosum is the main factor which excludes all other species in the primary succession on the virginal substrate. This may be considered a clear case of the inhibition model of succession as indicated by Connell and Slatyer (1977). So far, inhibition as a mechanism has been considered to belong to regeneration succession but here we seem to have an example of inhibition during primary succession, through occupation of the available space.

Intermittent environmental changes of various kinds in the moss carpet may delay, obstruct or pave the way for vegetation development. Disturbances occur over a wide range of magnitudes. Wind force, frost damage, trampling or grazing and accumulation of aeolian material, especially tephra falls, are some of the most important disturbing factors in the Hekla area.

Various kinds of disturbances may occur in the moss carpet of R. lanuginosum. Small ruptures are formed around protruding stones by running water in periods of thaw and sudden heavy rainfall. Trampling (sheep paths), frost and wind may also create more or less big ruptures as well as small amounts of aeolian deposits from the surroundings. The influence must be relatively long-lasting or very heavy; vegetation damage caused by temporary, weak influences is repaired quickly by R. lanuginosum. Mainly small acrocarpous mosses and liverworts grow in these ruptures, but also some vascular species may establish (e.g., Emeptrum nigrum, Salix herbacea). In rarely used sheep paths graminaceous species grow with R. lanuginosum in the bottom layer but the heavily trampled ones are ‘bare’ or with only a scattered vegetation of small herbs and grasses.

Accumulation of aeolian material is the most important disturbance. It is a rather complex phenomenon. The severity of the impact of accumulation is mainly related to the stage of development of the main surface and the vegetation types. Considerable amounts of deposits are needed to fill the thick layer of clinkers in a young and ‘barren’ lava field. In fields with a more or less developed main surface, the deposits level the irregularity of the topography. It is necessary to make a distinction between two different forms of deposit:

1. Tephra falls from an eruption. Mainly of short duration, with variation in thickness, linked to the distance from the vent and the main bulk of the fall. The time of the year when this occurs is decisive. The degree of damage ranges from none to catastrophic, and may sometimes have a positive influence. Particle size ranges from 0.2 - 25 mm.

2. Wind-blown deposits from the surroundings. There is a permanent supply, with different amounts, and this is linked to the distance from the openings and prevailing winds. The damage is catastrophic and
always has a destructive influence. Particle size ranges from 0.2 - 2 mm.

The tephra deposit may disturb and even destroy the moss carpet totally when it is completely covering the existing vegetation. A new main surface of quite different community types, mainly composed of graminaceous species will be developed (e.g., the *Oxyria digyna - Silene maritima* comm. in Næ 1845- II). The loose material causes great disturbance and the recovery is delayed for at least several decades. Surviving species, such as *Salix lanata* and *S. herbacea*, may speed up the process of recovery, as they have a great tolerance to wind-blown tephra. These tephra flats become exposed to heavy sheep grazing as soon as they are vegetated and that will also delay the recovery process.

Moderate accumulation of aeolian material may change the species composition in a way that several vascular species become more abundant, such as *Empetrum nigrum*, *Salix herbacea* and several herbs. The conditions are stepwise changed and *R. lanuginosum* will be replaced by other mosses, especially *Hylocomium splendens* and *Drepanocladus uncinatus*. A dwarf-shrub community has become established. Repeated accumulation creates conditions for other vascular plants to take over. In situations where grazing is minimal or absent, *Betula pubescens* will invade the dwarf-shrub community or the grass heath and transform them into birch shrubland or woodland. This is not the situation when sheep grazing, especially in winter time, takes place. Heavy grazing pressure may virtually change the dwarf-shrub community into a grass heath (cf. Su 1300). Then some species will be favoured, such as graminoids and herbs, which easily regenerate vegetatively (e.g., *Cerastium fontanum*) or annual species (e.g., *Stellaria media*).

Fig. 47 presents a comprehensive scheme of the various pathways of succession and may conclude this study of the vegetation dynamics on the historical lava fields in the Hekla area.
Fig. 47. Successional pathways in the vegetation of the historical lava fields of the Hekla area.

Loose substrate

Acrocarpous mosses: e.g. Bryum pallens, Ceratodon purpureus
Pleurocarpous mosses: Racomitrium canescens
Folious lichens: e.g. Peltigera spuria, P. venosa

Racomitrium lanuginosum
Stereocaulon vesuvianum
(Placopsis gelida)

> 500 m a.s.l.

400 - 500 m
R. lanuginosum
S. vesuvianum
variant

Stereocaulon vesuvianum comm.

Weak disturbance of various kinds

Empetrum nigrum variant
Salix herbacea variant

Heavy accumulation of aeolian deposit (grazing)

Moderate accumulation of aeolian material

R. lanuginosum comm.

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400 - 500 m

R. lanuginosum
S. vesuvianum
variant

Stereocaulon vesuvianum comm.

> 500 m a.s.l.

Heavy accumulation of aeolian deposit (grazing)

Moderate grazing

(dwarf-shrub community)

grazing

(protected)

grass heath or open field vegetation

shrubland

protected
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