THE GRIMSNES LAVAS
SW-ICELAND

BY
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WITH 5 PLATES
AND 7 FIGURES IN THE TEXT

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ABSTRACT

A postglacial volcanic area in Grímnes, SW-Iceland, is described and a geological map is presented in the scale 1 : 50,000. The older formations are dealt with briefly. In Grímnes the volcanism had an unusual areal distribution for Iceland. The lavas, covering an area of 54 sq. km, can be traced back to ten craters and crater rows. The eruptions were nearly contemporaneous. By study of the position of tephralayers from the Grímnes eruptions in soil profiles their age can be estimated as 5000–6000 years. The lavas are made up of uniform olivine-basalt, there is no sign of differentiation. A chemical analysis of one of the lavaflows is presented; it shows the same composition as the Skjoldhreidar lavas north of Grímnes. Xenoliths of granular olivine-gabbro and vitrified acid rock are common in some of the craters and are discussed briefly. The mineralogy of the gabbro is very similar to that of the lavas; and an endogenic magmatic origin is not excluded. A noteworthy feature of the gabbro is an olivine with highly developed cleavage. The high silica content and the mineralogy of the acid xenoliths suggest a liparite or granophyre intrusion at depth.
SVEINN JAKOBSSON

INTRODUCTION

Location and topography.

Grímssnes is situated in SW-Iceland (Fig. 1), in the neovolcanic zone which runs SW-NE through Iceland. This zone, which contains nearly all the active volcanoes, divides in South Iceland into two branches, the western one of which continues out through the Reykjanes peninsula. Grímssnes is situated on the eastern margin of this branch. Geomorphologically the area belongs to the South Icelandic lowland.

The mapped area is a postglacial volcanic area in the western part of the Grímssnes district, bounded south and west by the two big rivers Hvíta and Sog. The terrain rises gently from the Sog, which runs at a height of 14-18 m, and the Hvíta (14-25 m) above sea level, and reaches its highest point at Seyðishöllar (214 m). The palagonite mountain Búrfell (536 m) and the interglacial shield volcano Lyngdalsheidi (404 m) rise north of the lavafield (cf. Fig 7). The main part of the lavafield is covered by brush of birch and willow.

The volcanic area in Grímssnes has not been studied in detail before, although Kjartansson (1943) has given a description of the whole region in his book Arnesinga saga.

The Geological map is based on the topographical maps (1 : 50.000) of the Geodetic Institute, Copenhagen.

Acknowledgements.

I am indebted to my teacher, professor A. Noe-Nygaard, Director of the Mineralogical and Geological Institute of Copenhagen, for his instructive advice and discussions during the work, for excellent working facilities in the Institute, and for suggesting a chemical analysis of one of the lavas, which was kindly carried out by Mr Mouritzen, cand. poly.

I would like to thank the geologists at the University Research Institute, Reykjavik, for valuable discussions and for providing me with X-ray analyses and thin sections.

Thanks are also due to Dr. Sigurdur Thorarinsson for initiating me in the field of tephrochronology, to Mrs. Ragna Larsen for drawing the map, to Mrs. Petrina Jakobsson for drawing profiles in the text, to Mr. D. Bridgewater, B. Sc. for correcting the English of the manuscript, and to Mr. Ib Sørensen, chemical engineer for carrying out a silica analysis.

THE OLDER FORMATIONS

Palagonite breccias and basalts.

The oldest rocks in the area are palagonite breccias and basalts of Quaternary age. They are exposed at Hvíta south of the lavafield in low ridges orientated NNE-SSW, and more prominently in the mountain Búrfell to the north (see Geological map, Pl. V). The material is predominantly palagonite breccia locally intercalated with pillow lavas and cut by small dykes. Along Höskuldskirkur there are several outcrops of dark, fine-grained basalt, which is probably intrusive.

These rocks belong to the Palagonite Formation of Iceland. Most authors agree on the subglacial origin of this formation, the main part of it being Quarternary (Noe-Nygaard 1940, Kjartansson 1943, Askellsen et al. 1960).

The mountain Búrfell (Pl. Ia) is an example of a subglacial volcano. It is a 4 km long ridge trending N-S mainly made up of palagonite breccia. On the top of the mountain is a deep but narrow depression, evidently the rest of the crater. The mountain is cut by a tectonic fracture trending N 20°E, through the crater (Fig. 7). South of Búrfell small palagonite ridges extend SSW. It is probable that Búrfell was formed during a fissure eruption and was elongated to SSW, and that the present form of the mountain is mainly the result of glacial erosion.

Bombs of palagonite tuff are found both in the Tjarnarhöll and Selhóll I craters, suggesting that the palagonitic rocks extend under the lavas.

G. Kjartansson has made a subdivision of the Palagonite Formation. On the Geological Map of Iceland (1960, 1962), Búrfell is classified as belonging to the Palagonite Formation in sensu stricto (Quaternary), while all the other outcrops of palagonite breccia in the area are classified as belonging to the Old Gray Basalts (Quaternary and/or Tertiary). In his book, Arnesinga saga (1943), however, this author has classified Búrfell with the Old Gray Basalts.

The geology of the area surrounding the lavafield was not studied in detail, and I have not been able to see any clear difference between the palagonite breccia in for example the outcrops at Hvíta and Búrfell. They are therefore marked with the same signature on the map, and the age is supposed to be Quarternary.

Young Gray Basalts.

In the gorge at the farm Höxarendi, palagonite breccia and palagonitized conglomerate is covered by a light-gray basalt with a thickness of about 5 m. The basalt is striated on the surface, indicating that it is interglacial or interstadial. Many thin beds of the same gray basalt are seen farther west along the banks of the rivulet on the west side of Selhóll II lava. It is rather course-grained, light-gray olivine basalt with some variation in the olivine content. This basalt can be traced back to Lyngdalsheidi, a flat shield volcano (404 m), lying with its crater some 9 km farther north (Fig. 7).

Basalts of this type are common within the neovolcanic zone in Iceland, and seem generally to originate from shield volcanoes. These interglacial gray basalts have commonly been called dolerites in geological papers about Iceland. (The term was introduced by E. Robert: Mineralogie et Geologie I, P. Gaimard, Voyage en Islande etc. Paris 1840). As the term dolerite is used exclusively about basaltic dykes and sills in geological literature elsewhere, it is misleading to retain this term because of its genetic implications. The term Young Gray Basalts is used here, following Kjartansson (in Askellsen et al. 1960).
The rock is very similar in all exposures of the gray basalt in Grimsnes, and probably it all derives from Lyngdalsheiði. The Young Gray Basalts have originally covered the main part of western Grimsnes, but are now found as erosion remnants in the hills of the area. No other volcano producing this type of basalt is known in the neighbourhood. The hills south of the farm Ásgardar are entirely made up of gray basalt, at Búrfellslækur it is up to 19 m in thickness. Smalaskáli, a hillock at the edge of the Tjarnarhraðar lava near lake Alftavatn, probably belongs to the Young Gray Basalts. The rock contains glyomerophyres of olivine up to 1 cm across in addition to the olivines in the groundmass.

In the maar Kerid of the Tjarnarhraðar crater row, 7–8 m of the gray basalt are exposed. These sediments are deposits of the late glacial transgression, marks of which are found in all parts of Iceland. Very distinct gravel terraces have been formed along Ingólfsfjall and in Grafningur (west of the mapped area). These terraces are about 60 m above sea level according to the Geodetic Institute map. The marine sediments along the Sog, which are made up of alternating beds of sand and silt, are about 18–25 m above sea level. The same kind of sediments are found along the shores of Höskuldsfjörður between the farms Mýrar-kaot and Foss. At this locality these layers are about 40–50 m above sea level.

At Sog and Búrfellslækur the marine layers contain subfossil bivalves and gastropods. These have also been reported at Höskuldsfjörður (J. Hallgrímsson 1840, ed. 1933), but I have not succeeded in finding anything there. At Búrfellslækur, the layers are clearly disturbed by the ice, and the molluscs are found as fragments. The layers are up to 1/2 m in thickness here.

The following species were found at Sog and Búrfellslækur.

- Yoldia hyperborea
- Cyprina islandica
- Macoma calcarea
- Saxicava arctica
- Mya truncata
- Pecten islandicus
- Boreotrophon clathratus
- Balanus sp.
- Vertebra of a bony fish

Nos. 2–5 of the list were found as complete specimens. Most of the molluscs have thick shells, and as a whole the fauna suggests cold conditions. All the species are at present found in the seas around Iceland, except Yoldia hyperborea and Pecten islandicus, which are not found along the south coast (Oskarsson 1962, 1964). Yoldia hyperborea has not been found in these lateglacial deposits before with certainty, although Báðarson (1921, 1923) mentions three occurrences in Borgarfjörður and Breidafjörður as possibilities.

Recently C¹⁴ datings have been published on sea-shells from two localities, Spóstaðir and Hellishólaltölkur in S-Iceland. (Kjartansson et al. 1964). The dates were approximately 10000 and 9700 years respectively. At Spóstaðir and Hellishólaltölkur, which are 55–60 m and 70–75 m above sea level, all the species from Sog-Búrfellslækur have been found with the exception of Yoldia hyperborea. In addition many other species were found, and some of them as warmth-loving as Mytilus, Zirphaea and Lithotrya. In spite of this, it is thought probable that the
The individual volcanic centers.

Tjarnarhölar.

The Tjarnarhölar (hölar: hillocks) crater row is made up of four craters lying on a 800 m long fissure (Fig. 3), trending N 30° E, approximately. The three southernmost craters are made up of scoriae and schwass-schläcken and are crescent-shaped. They can be classified as spatter cones (or cinder cones). The craters are not pronounced, the highest one (126 m above sea level) rises 50 m above the surrounding country. The northermost crater, called Kerid (Fig. 4), is a typical explosive crater, maar, formed by one or few explosions. The crater is elliptical, about 270 by 170 m. A small lake lies in the crater with an average depth of 10 m. (G. Gigj a pers. comm.).

Kerid has an approximate total depth of 55 m. Bedrock is visible in the southeastern craterwall, it is light-gray basalt of the Young Gray Basalt Formation. The upper part of the craterwall consists of alternating beds of lava and scoria with a thickness of 25 m. Between the Tjarnarhölar lava and the interglacial basalt is a thin layer of soil mixed with scoria.

The lava from Tjarnarhölar has mainly flowed west and south down to the rivers. It is partly covered by four other lavas but the original size can be assumed to be about 11—12 sq. km.

Clear lavatrails, the channel in which the lava flowed when the lava nearest to the crater was solidified, are developed in most of the Grimsnes lavas. They can
Fig. 4. Profile through the maar Kerid from NW to SE (cf. Fig. 3). L: Tjarnarhольr lava. B: Young Gray Basalts.

often be followed several kilometers in each flow. One of the clearest lava-tracks
comes from the maar Kerid.

In the beginning of the eruption, lava has obviously flowed from Kerid, making up much of the northern and western part of Tjarnarhольr lava. Probably the whole fissure erupted at the same time, and a scoria cone formed where Kerid is now situated. At the end of the eruption in Tjarnarhольr there was an explosive phase which formed Kerid. There is no sign of any ashlayer in Grimsnes from this explosion.

On the rim of the crater altered pieces of gray basalt and palagonite-tuff can be found. Vitified acid xenoliths are also found in the scoria quarry in the southernmost crater. These will be described together with xenoliths from other craters in a later chapter (p. 18).

Tjarnarhольr lava is made up of fine-grained, gray-blue basalt, sometimes porphyritic with small phenocrysts of feldspar and olivine.

Seydishольr.

The twin hillocks of Seydishольr are the largest craters in the volcanic area, rising to a height of 214 m above sea level. (Pl. Ib). They are actually two volcanic centres, the southernmost also being called Kerhольr. The northern crater, Seydis­
hольr proper, has a relative height of about 90 m, and consists almost completely of well stratified scoriae. The mound is slightly elongated from NE-SW, and this is most probably a fissure with the same direction as Tjarnarhольr, N 30°E. It seems to be in continuation with the Tjarnarhольr fissure. Most of the scoriae were formed at the end of the eruption and covered the fissure itself.

The volume of the scoriae in Seydishольr proper is about 30 mill. cu. m, measured with a planimeter, assuming the scoria cone to be 100 m thick. Scoriae are excellent for road ballast. Most of the craters in Grimsnes have therefore been quarried to this purpose. In Seydishольr the scoriae are of exceptionally good quality. They are very porous and homogenous, and have been used to make insulating bricks.

In the quarry in the south-end of Seydishольr a good section of the scoria layers can be seen. The scoria layers are of various colours, bluish and red scoriae are most common. Another colouring can be observed cutting across the scoria layers in the eastern side of the quarry (as it was in 1964). The scoriae are oxidized and have a deep-red colour. This colouring seems to be caused by volcanic gases after the deposition of the scoriae. In the quarry in Seydishольr, numerous xenoliths of gabbro and vitrified acid rock are found.

Kerhольr is a well formed crater with a height of 50 m above the surroundings. The craterwalls are made of alternating layers of lava and schweiss-schlacken. The crater can be described as something between spatter cone and lava cone. Most of Seydishольr lava was actually derived from Kerhольr, but as Seydishольr proper and Kerhольr erupted nearly simultaneously and their lavas can hardly be distinguished, the flows are marked with the same signature on the map. Seydishольr lava covers an area of 23 sq. km. At the road near the farm Myrarkot the lava is seen resting on a thin layer of carbonized heather or moss.

The eruption in Seydishольr seems to have started with some explosive activity. Along the bank of Hvedarendalrekur (the uppermost part of Bürfellslækur) north of Seydishольr, a thick layer of pumiceous scoriae can be followed. It is bluish-black basaltic pumice with grain-size under 3 cm in diameter. The layer thins rapidly away from Seydishольr (cf. Fig. 6, soilprof. 3 and 2). This pumice layer is also found west of Kerlingarhольr lava (soilprof. 4) and on the heath up to 3 km NE of Seydishольr. The volume of this pumice layer is not less than 1 mill. cu. m. Seydishольr lava can be distinguished from the other lavaflows as it is more finegrained and only contains phenocrysts of olivine.

Kálfsfóllur.

Kaflshólar, the crater row west of Seydishольr, is made up of two relatively big craters (Pl. IIa). Farther SW there are also some irregular mounds of scoria, so presumably the fissure originally had a length of about 800 m, with a N 45°E direction. The lava has flowed to the west down to Sog and rests here on the late­
glacial marine sediments. The contact is not visible. Kálfsfóllur lava covers an area of about 8.0 sq. km.

West of the farm Midengi there is a row of hillocks made up of schweiss- schlacken and scoriae, and a similar row of hillocks is seen in the lava along Bürfellslækur. These scoria mounds are probably pseudocraters. It is not unlikely that
the scoria hillocks along Búrfellsleikur formed when Kalfshólar lava flowed over the old course of Búrfellsleikur.

Kalfshólar lava rests on Tjarnarhólar lava and presumably Seydishólar lava. The rock is very similar to that of Tjarnarhólar lava and it is macroscopically impossible to distinguish between these two lavas.

No xenoliths have been found in Kalfshólar.

**Selhóll, Kerlingarhóll, Borgarhólar, and Kolgrafafróll.**

The two northernmost volcanic centers, Selhóll II and Kerlingarhóll, are crater rows of a moderate length, both about 400 m. The N 60° E direction of the Selhóll II crater row is more easterly than the others, while the Kerlingarhóll crater row has the same direction as the Kalfshólar craters with which it is in direct continuation. The craters are of spatter cone row type as Tjarnarhólar and Kalfshólar.

Borgarhólar, lying isolated from the main lavafield, and Kolgrafafróll are small single spatter cones, which have produced only little lava. Borgarhólar lava covers an area of only 0.4 sq. km and is the smallest lavaflow in the area.

**Selhóll I, Raudhólar, and Alftarhóll.**

These three single craters are situated in the southwest corner of the lavafield. Selhóll I and Raudhólar are spatter cones comparable in size to Borgarhólar and Kolgrafafróll. The relative height of Selhóll I is about 15—16 m, the crater is crescent shaped with the opening to the SW, the diameter at the base (NW-SE) is 140 m. There are irregular prolongations to the SW. The Alftarhóll crater is considerably bigger. No distinct crater is visible at first, the lava rising gradually up to relatively small scoria walls. There is an irregular depression up to 250 m in diameter within the crater. On the north side, where scoriae have been removed for road ballast, a 19 m deep section of scoriae are laid bare. The lava has partly covered the crater.

Little lava flowed from Selhóll I and Raudhólar, whereas the lava from Alftarhóll covers an area of about 6.2 sq. km. In all three craters vitriified acid xenoliths are common, particularly in Alftarhóll and Selhóll, while in Selhóll I there are many inclusions of palagonite breccia and basalt with amygdales.

The origin of Selhóll I, Raudhólar, and Alftarhóll.

It has not been thought previously that all the scoria mounds in Grímsnes were real craters. Kjartansson (1943, 1960, 1962) refers to seven volcanic centres (if Seydishólar and Kerhóll are considered one center), but does not discuss the origin of the rest of the craters. Similarly, Tr. Einarsson (1949) considers it improbable that all the small mounds are real craters, but thinks they are more easily understood as pseudocraters.
scoriae from Seyðishólár with that from some of the smaller mounds in the southwestern part of the lavafield (not specified), and found that the scoriae from Seyðishólár were light and spongy in contrast to the more dense scoriae in the other craters. Scoriae from Raudhólár near Reykjavík, — which are generally considered to be pseudocraters, — were found to be of the dense type.

I have not been able to see any overall differences between the scoriae from the various craters in Grímsnes, if those from Seyðishólár are excluded. The scoriae from Borgarhólár, Tjarnarhólár, Raudhólár, Selhöll I and Álfarhólár for example seem to be of similar type, however, it should be emphasized that the scoriae are very variable in each crater as regards density and porosity, and it is therefore not easy to take a representative sample from each locality. Seyðishólár is an exception, the scoriae are light and spongy and surprisingly homogenous throughout.

The origin of the scoriae mounds in the lava south of Kolgrafarhólár is much more questionable. They have been marked as pseudocraters on the map as there is little to suggest that they are real craters. On the contrary they form a cluster of small mounds which do not appear to have emitted any lava. No xenoliths have been found in them.

Petrography.

The lavas.

Only a preliminary petrographic study has been made on the rocks from Grímsnes, which show little difference in the petrography of the separate lava-flows. The rock is a fine-grained, grey-blue olivine-basalt, occasionally containing small phenocrysts of plagioclase and olivine. Both grain-size and abundance of the phenocrysts can vary to some extent, even in a single flow. This makes it very difficult to distinguish between the lavas macroscopically.

The texture is ophtitic-quasiophtitic to porphyritic (Pl. IVa). The rock is generally holocrystalline, glass was only found in small amounts, except in the scoriae, which are mainly made up of glass with scattered crystals of plagioclase, pyroxene and olivine. The scoriae are found in many colours, with red, bluish, and brownish scoriae as the most common. Other colours are also met with together in the same crater. Not much is known about the origin of this colouring, the red is most probably due to oxidation of ferrooxide.

A few determinations of the three essential minerals, plagioclase, pyroxene, and olivine have been made.

The plagioclase is usually found as lath-shaped polysynthetic twins ranging in size from 0.05 to 0.2 mm in the groundmass and as phenocrysts generally ranging between 0.3—0.5 mm. Measurements of extinction angles between albite-cariboid twins in the zone (010) in plagioclase from the Tjarnarhólár lava, showed a composition near 60—65% An. A determination of the refractive index of plagioclase-phenocryst from the Borgarhólár lava gave n\(_p\): 1.5702 ± 0.0005, corresponding to 74.7% ± 1.0% An using the glass method (Micheelsen 1957). Zoning in the plagioclase was observed in a few cases.

The pyroxene was often found in ophtitic intergrowth with the plagioclase, the size ranging from 0.2 to 0.5 mm. Four determinations of the optical angle in pyroxenes in the Tjarnarhólár lava measured with the universal stage gave the values: 2\(\psi\): 47°, 51°, 55°, 56°. A phenocryst from the Kálshólár lava, near the crater, measuring 6 x 5 mm was the only pyroxene-phenocryst found in the lavas, 2\(\psi\) of the phenocryst was determined to be 54°, and the extinction angle \(\alpha_{ym}\) was found to be 42°. The pyroxene in both lavas is diopsidic augite.

The olivine is occasionally found as phenocrysts, mainly in the Seyðishólár lava. In the groundmass the olivine reaches a size of 0.1 x 0.2 mm and is in most cases automorphic, whereas the phenocrysts are often found as skeletal crystals, up to 1 mm across. One olivine-phenocryst from the Seyðishólár lava (proper) was determined by X-ray powder diffraction to have a composition of Fa 25% ± 4%, using the data by Yoder and Sahama (1957). In a few cases the olivine was partly altered to an iddingsitic mineral. Small grains of black ore are abundant in the groundmass.

Five modal analyses of the Grímsnes lavas were carried out. Two of the Tjarnarhólár lava and one each of the Raudhólár, Kálshólár and Borgarhólár lavas. In each slide 1000—1600 points were counted. The modes are presented in fig. 9, which shows the proportions of plagioclase, pyroxene, and olivine of the lavas in relation to the gabbro xenoliths. As the lavas are very finegrained and identification of the minerals therefore difficult, the modes must be regarded as provisional. The shaded area is believed to represent the lavas in general.

A preliminary microscopical examination of the Grímsnes lavas does not reveal any sign of differentiation. There seems, however, to be some difference between the individual lava-flows as regards texture and amount of phenocrysts, which developed as the eruptions went on. The size and number of the phenocrysts increase gradually in the younger lavas. This agrees with the age relations between the lavas as far as seen from the topography, and the soil profile taken at Hólaskoitalekur. A much more detailed study of the lavas is required before anything can be said with certainty about their development.

T. Tryggvason (1943) found an increase in the amount of phenocrysts in the last flows from Skjaldbreid, although there were no clear signs of differentiation. A chemical analysis of Tjarnarhólár lava, carried out by M. Mouritsen is presented in Table 1.

The sample was taken 250 m west of the southernmost Tjarnarhólár crater. The molecular norms are calculated, using T. W. Barth's method (Barth 1962, p. 65—70), and the Niggli-values in the usual manner. The modal analysis of the sample does not show good agreement with the norm.

This analysis of the Tjarnarhólár lava may be regarded as representative of the Grímsnes lavas as there is hardly any noteworthy change in the chemical composition within the lavas. It shows practically the same composition as the lavas of the shield volcano Skjaldbreidur and the Tindfjallahéði fissure, 15—35 km north of Grímsnes. The Tjarnarhólár analysis falls within the group of the six analyses of the Skjaldbreidur area presented by T. Tryggvason (1943). According to a recent C14-dating of the lavas of Skjaldbreidur and the Tindfjallahéði fissure are about 9000—10000 years old (Kjarlansson et al. 1964). The lavas of the Skjaldbreidur area and the Grímsnes lavas must be assumed to be comagmatic in spite of the time interval.
The eruptions in the former area were entirely effusive, while the Grimsnes volcanicism displayed more explosive activity (Kerid, Seydisfjöll).

Xenoliths of gabbro were only found in Seydisfjöll, the biggest xenolith in Iceland (J. J. Skjalfandafljót). The xenoliths are usually angular and always have sharp boundaries against the host rock. Reference to gabbro xenoliths in Seydisfjöll was made in Fig. 5. In each slide 1000–3000 counts were made. The modes of five gabbro xenoliths are shown in Table 1. All the xenoliths examined fall in the general range of olivine gabbro.

### Table 1

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<td>31 0.2</td>
<td>Il 2.5</td>
</tr>
<tr>
<td>H₂O⁺</td>
<td>0.11</td>
<td>Ap 0.5</td>
<td></td>
</tr>
<tr>
<td>H₂O⁻</td>
<td>0.04</td>
<td>23em 48.7</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>100.0</td>
<td>17860 100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Anal: Me Mouritzen.

Although the material emitted is of the same chemical composition there is difference in the character of the eruptions in the Skjálfandibraun area and Grímsnes. The eruptions in the former area were entirely effusive, while the Grímsnes volcanism displayed more explosive activity (Kerid, Seydisfjöll).

**The xenoliths.**

**Gabbro.** Xenoliths of gabbro were only found in Seydisfjöll, the biggest crater in Grímsnes. They are easily found in the scoria quarry and seem to occur mainly in the lowest scoria layers as loose blocks about the size of a fist or smaller. They are numerous small inclusions of this gabbro in a little lavaflow coming from the north side of Seydisfjöll, although it was not found in other parts of Seydisfjöll lava. The xenoliths are usually angular and always have sharp boundaries against the host rock. Reference to gabbro xenoliths in Seydisfjöll was made by T. Tryggvason in a footnote in Thorarinsson (1953).

The rock is a medium-grained gabbro of granular appearance, it is rather porous and crumbles easily. It is made up of plagioclase, clinopyroxene, and olivine with black ore as an accessory mineral. The composition of the rock is variable. The proportions of the three principal minerals in ten gabbro xenoliths are shown in Fig. 5. In each slide 1000–3000 counts were made. The modes of five gabbro xenoliths from different localities in Iceland (J. J. Skjalfandafljót 1963) are also plotted on the diagram. All the xenoliths examined fall in the general range of olivine gabbro. Individual blocks may approach anorthosite, pyroxenite, and troctolite in composition.

**The pyroxene.**

The pyroxene occurs mainly as xenomorphic grains 1–2 mm in diameter and is only poikilitic in habit in a few examples. Five determinations on the universal stage gave: 2V 48°, 52°, 53°, 53°, 55°, respectively. The (010) extinction, c/α was 43° (the average of six measurements from a powder preparation). The pyroxene is diopside augite.

The olivine is quite fresh in most specimens and is similar in size to the pyroxene. These two minerals were often difficult to distinguish from each other. Two grains of olivine were determined by X-ray powder diffraction, they gave "V 4% in both cases.

A very unusual looking olivine was found in some of the gabbro xenoliths from Seydisfjöll (P. 1). It appears as brown, 1–4 mm grains. In thin section it showed a distinct cleavage pattern as well as the usual irregular cracks characteristic of olivine. It thus has a striking resemblance to pyroxene. X-ray diffraction analysis, however, showed quite clearly that the mineral was olivine with a composition of Fa 25 ± 4%, identical with the fresh olivine. Determinations of the optical angle on twelve grains gave 2V 80°–92° with an average of 85°; corresponding to 23° Fa.

By plotting the poles of the various cleavage planes in 12 grains against the optical directions on a stereogram, five cleavage directions were detected. The most common cleavages were on the (100), (010) and (001) planes, (101) and (121) (?). were more unusual. These are all common crystal faces in olivine. There were usually 3–4 cleavage directions in each grain.

All the olivines showing this intense cleavage were altered to some degree. The grains were coloured strongly red-brown. Under high magnification this could be seen to be due to red-brown microscopical "threads", undulating through the grain. These "threads" have a diameter of 4–5 μ, and where they are especially abundant the mineral becomes red-brown in colour. This alteration product is pleochroic from dark- to light red-brown and green-blue to light-brown. It is possibly "iddingsite".

Well developed cleavage is rare in olivines. Cleavage after (010) is most common, and (100) is occasionally found. Hawkes (1946) has described an olivine in dunite from Dunsmuir, California, with perfect cleavage on the (100) and (100) crystal planes. Cleavage parallel to (001) and (110) was also observed.

There is no sign of the olivine being affected by mechanical stress. It seems clear that the cleavage occurred in connection with the alteration of the mineral as the cleavage is only developed in the altered olivine. The red-brown secondary mineral is introduced along at least 5 crystallographic directions in the olivine.

The altered olivine is only found in xenoliths collected from red or reddish scoriae, that is lumps of molten lava, which have been subjected to intense oxidation.
Fig. 5. Diagram showing the proportions (vol. %) of the three principal minerals in the Grimsnes lavas (shaded area), the gabbro xenoliths from Seydishólár (black dots) and five gabbro xenoliths quoted from Jonsson (1963) (particoloured).

shows a higher An-content in the gabbro, but this may equally well be expected, supposing an endogenic as an exogenic origin. The range in the composition of the gabbro is considerable. The average composition, however, of the ten xenoliths in fig. 9 is plagioclase 55%, pyroxene 36%, and olivine 9%, and that is within the shaded area of the Grimsnes lavas. The most noteworthy difference between the two rocks is in the amount of ore, which is not included in the diagram. Only a minimal amount of ore (<0.1%) was found in the xenoliths, whereas five analyses of the lavas showed a range from 6.0—10.7% in volume. None of the minerals of the gabbro showed sign of deformation.

No definite conclusion can be arrived at from the preliminary examination of the xenoliths presented here. An endogenic magmatic origin of the gabbro is not ruled out, however. Further comparative studies on the xenoliths and the host rock are being made and will be presented later.

Vitrified acid xenoliths. Glassy inclusions up to 10 cm across were found in the scoriae layers of five of the craters: Seydishólár, Tjarnarhólár, Raudhólár, Selhóll I, and Álfatarhóll.
The xenoliths are a pumiceous, fragile, white rock, varying from very porous or frothlike in Seydishólar and Tjarnarhólar to a more dense porcellanic material in Álfarhóll and Selhóll I. Some of the pieces have sharp edges, and where the contact between the siliceous inclusions and the enclosing scoria is seen, it is very sharp and shows no sign of reaction. The vitrified xenoliths are quite common in the Grímsnes craters and they exceed the gabбро xenoliths in quantity.

The xenoliths are mainly made up of clear liparitic glass with ng'l: 1.490—1.499, containing scattered crystals of quartz and altered feldspar. The quartz is up to 1.2 mm in diameter and is often found as aggregates of shattered grains. It generally has a sharp contact with the glass. The feldspars are altered, but it has been possible to distinguish both plagioclase and potash feldspar. Small grains of black ore are found, and the glass has in places a hematitic pigment. The glass normally shows a glass-bubble or glass-shard texture except in areas where the rock is completely remelted. In one xenolith from Seydishólar granophytic texture could be distinguished. In some of the xenoliths from Álfarhóll and Selhóll I the rock appears to have split up along certain planes when expanding.

The xenoliths are obviously fragments of an acid rock melted and vitrified to a high degree. In order to get some idea of the composition of the original rock, the silica content of a xenolith from Álfarhóll was determined. This showed an amount of 74.76% SiO₂. This is identical with the average silica content of five chemical analysis of liparites from Vatnajökull, presented by Noe-Nygaard (1952). In an analysis of granophyre from Hafnarfjall, West-Iceland (unpubl., anal. J. Jakobsson, Univ. Research Inst. Reykjavik) the silica content was determined to be 74.47%.

In Selhóll I two small pieces of unaltered white rock were found. The largest (Pl. IIa) was 3 x 2 x 2 cm in size. This rock consists solely of quartz and feldspar approximately in the ratio 1:4. The feldspar is plagioclase with refractive index ny: 1.535 ± 0.005, indicating an An-content around 40%. No glass could be found. The grain size is 0.1—0.2 mm, while the texture is aplitiromorphic.

It is unlikely that this quartz-andesine aggregate represents the source of the vitrified xenoliths. Apart from the mineralogical differences, no widespread volcanic rock of this composition is known (Johannsen 1939—45).

T. Tryggvason (pers. inform.) reports that veinfillings of quartz, feldspar, and ore with a similar texture as the liparitic xenoliths from Selhóll I are found in connection with the liparite intrusion near Thyrill, Hvalfjörður.

Acid xenoliths are widespread in Iceland. Tryggvason (1965) has described acid xenoliths from Hekla. No absolute proof of the origin of these is found. Acid glassy xenoliths have been found recently on Snæfellnes (G. Sigvaldsson pers. inform.). Xenoliths of similar type are abundant both in Aska and Surtsey, the new volcanic island.

Milton (1944) gives a description of white bombs from the eruption of Pari-cutin. These show a striking similarity to the xenoliths described here, and the description by Milton could be adapted here to cover most of the material from Grímsnes. The material was identified as liparitic, possibly originally a liparitic breccia. White pumice, consisting of glass with scattered crystals of quartz and feldspar, was ejected in the eruption of Nilahue, Chile (Müller & Vey 1957). The pumice was believed to indicate a granitic source close to surface.

Considering the origin of the vitrified acid xenoliths from the Grímsnes craters, it is unlikely that they are differentiation products of the magma. The Grímsnes and the Skjálfandbreidar lavas show no sign of differentiation in spite of great amount of emitted material. No indication of an acid layer in the crust of Iceland has been found yet according to Bátth (1960) and Pálímason (1963). The acid xenoliths therefore probably represent intrusions of liparitic composition at depth. Granites are unknown in Iceland, whereas liparitic intrusions are common and granophyres are known from several localities in West and East Iceland.

The age of the lavas.

The two farms Míðengi and Klausturhólar (formerly Hálkkelshólar) lie on the lavas. According to the Book of Settlement (Landnámabók), these farms were built in the 10th century. This proves that the lavas were already covered with vegetation a thousand years ago and must therefore be considerably older.

It is possible to estimate the age of the lavas by studying soil profiles. Four soil profiles from Grímsnes are shown in Fig. 6. Profile 1 is taken at Selhóll I (Finnheiði), profile 2 and 3 along the banks of Hóla-kot west of Hekla, and profile 4 at Hóla-kot near the coast. No glass could be found. In all the profiles 2 and 3 there is a thin black ashlayer, most probably the Hekla layer H 5 (Thorarinsson pel's. inform.). If so, it is one of the westernmost points found so far. The H 5 is about 2800 years old (Thorarinsson 1954).

Acid xenoliths are widespread in Iceland. By comparing the position of the scoriae and pumice layers from Selhóll I, Seydishólar, and Kerlingarhóll to the layer H 5 it is evident that they are considerably older than 2800 years. Profiles 2 and 3 rest on gravel and profile 4 on "móðinu" (hardened eolian soil). It is assumed that each of the profiles 2 and 4 represent a total of approximately ten thousand years, and that the thin white ashlayer in profile
Remarks on the volcanism.

The volcanism in Grímnsnes had an areal distribution not commonly reported from Iceland. There were eruptions from 10 volcanic vents within a short period of time. The craters lie in a zone, 12 km in length and up to 4 km in breadth, stretching from SW to NE, which is the characteristic orientation of volcanic and tectonic fissures in S-Iceland.

Crater groups are not uncommon in Iceland and were formerly thought to indicate eruptions over a large area. Thorarinsson (1951), however, has shown that all crater groups in Iceland are of secondary origin with the possible exception of a group of explosive craters in the Veidivotn district described by Nielsen (1933). This consists of 17 explosive craters in an area of 1 sq. km.

It is necessary to emphasize the linear character of the volcanism in the Grímnsnes district in contrast to the irregular pseudo crater groups.

At least five fissure eruptions occurred in the Grímnsnes area, however Kálfshólarselí and Tjarnarhólar-Seyðishólur respectively should probably be regarded as parts of the same fissure line. The Álfarhóll crater is elongated to SW, so probably the eruption was linear in the beginning. The orientation of the crater rows varies slightly, but when viewed as a whole is identical with that of the zone.

Fig. 6. Four soil profiles from Grímnsnes (cf. Plate V).
ly speaking, although the pleistocene Búrfell and Lyngdalsheiði show a more southerly direction of fractures and faults. The faults in the NW-part of Lyngdalsheiði are at the margin of the Thingvöllir graben. The length of the fissures varies from 500 to 800 m. Eruptive fissures of this length are frequent in Iceland. The central eruptive craters do not differ from single craters in the crater rows, they have the same shape and a similar size. The craters are made up of scoria and schweiss-schläcken and occasionally of a lava layer (Kerði). The Grimsnes craters are classified as spatter cones and spatter cone rows, while Kerði alone is maar. (cf. the classification of Thorarinsson in: Kjartansson et al. 1960).

It is possible to calculate the volume of the Grimsnes lavas, as the thickness is known from several localities. Drilling was made for water at the Midengi farm; the lava showed to be 18 m thick. The thickness of the lava- and scorialayers at Kerði is about 25 m. Assuming an average thickness as 18–20 m, the total volume of the lavas is approximately 1 cu. km.

The volcanic events in the Grimsnes district started with the formation of Tjarnarhöllar and Seydishöllar, which are the two volcanic centres displaying the highest explosive activity. The pumice layer which can be traced back to Seydís­höllar and the light, spongy scoriae of Seydishöllar proper show the relatively high gas content of the magma at the beginning. The volcanic activity then continued with the eruption of other craters and crater rows which were largely effusive.

It is interesting to compare the volcanism in the Grimsnes district to the volcanic eruptions near Myvatn, the "Myvatn-fires", in 1724–1729 (Thoroddsen 1925 p. 226–229). The eruptions in the Grimsnes district may have developed in a similar way.

The eruptions started with vigorous explosive activity in 1724 which resulted in the formation of the maar Viti (diam. 350 m). In 1725 fissures opened farther west at Leirhnúkur and Bjarnarflög producing lava. In 1727 and 1728 the Leirhnúkur and Bjarnarflög fissures had a renewed activity and in addition a fissure opened at Hrossadalur and Dalfjall also producing lava. The production of lava ceased in 1729, but according to one source there was some explosive activity in the Leirhnúkur-fissure as late as 1746.

The Leirhnúkur-fissure which has a length of 10 km, gradually grew during the eruptions. Hrossadalur and Bjarnarflög which are much shorter, lie on the same fissure line as the Leirhnúkur fissure. The Dalfjall fissure is parallel to the others. The total output of lava in the "Myvatn-fires" is approximately 1 cu. km, i.e. the same as in Grimsnes.

The Askja-eruption of 1961 (Thorarinsson and Sigvaldason 1962) is of the same magnitude as the eruptions in Tjarnarhöllar and Kalfshöllar. The Askja fissure is 700 m long and the lavaflow covers an area of 11 sq. km, the total volume being 0.1 cu. km. These are about the same figures as for Tjarnarhöllar lava and Kalfshöllar lava.

Rittmann (1960) has introduced the explosivity index E, the ratio between tephra and total material ejected. In lava volcanoes E is lower than 10. The amount of tephra in Grimsnes is estimated to be 0.07 cu. km (Seydishöllar alone is 0.03 cu. km), and the explosivity index is then:
According to this classification the Grimsnes volcanism is effusive. However, as Thorarinsson (1954) has noticed, it is necessary to use comparable specifications regarding the volume of the tephra, when eruptions are classified. "In order to obtain comparable sizes, the volume of tephra and lava should be reduced to a corresponding volume of compact lava of the same chemical composition, i.e. it is necessary to measure not only the thickness of the tephra layer but also its volume-weight, or its absolute weight per unit area".

Four hot wells are found in the mapped area. The temperature does not exceed 50° C. The hydrothermal activity does not appear to have any direct connection to the volcanism in the Grimsnes area. Numerous low-temperature alkaline hot wells (springs) are found all over the country but are mainly found outside the neovolcanic areas (Barth 1950).

**HYDROLOGY**

The Grimsnes lavas are typical block lavas. The surface is very uneven and consists mainly of loose blocks. This means that all precipitation drains directly through the lavas and emerges out as springs at the edges of the lavas. These may be observed particularly at two places, at Nautavakir south of Snæfellsstadur farm, and at Álfavatn, where the springs are called Vadlæsk. A considerable amount of water with a constant temperature the year round streams out with the result that Hvítá and Sog never freeze near these springs.

A drilling was made for water at the Midengi farm on the Kálffshólar lava. Water was found just below the lava at a depth of 18 m. The height of the farm is about 65-70 m above sea level according to the Geodetic Institute map. The height of the ground-water is thus near 50 m above sea level. This is about the same as the height of the small lake in Kerid. So presumably the lake in Kerid simply shows the height of the ground-water; it is a hydrographic window.

According to G. Gigj's measurements in 1943 (pers. comm.), the depth of the lake varied between 7-14 m during the summer, thus showing the variations of the height of the ground water-table.

The formation of the Grimsnes lavas has not changed the course of the two rivers Sog and Hvítá to any extent. The outcrops of late glacial sediments under the Kálffshólar lava and the lava-free north-coast of Álfavatn shows that the Sog has the same course as before the eruptions at least so far as Álfavatn. In the southernmost part of Álfavatn there is a deep, narrow fissure in the bottom of the lake, which seems to extend farther south in the bottom of the Sog. When seen from a boat, the fissure can be estimated as several meters deep below the normal bottom of the lake; which is at a depth of about 5 m here. This cannot be a tectonic fissure because of its irregular course. P. Hannesson has written a note about this fissure in one of his diaries. (*Frá dýggum*, 1958, p. 319, transl.): "A distinct fissure can be seen on the bottom of the lake, probably eroded by the older Sog before the

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Pl. la. A view from Tjarnarhölar across the lavafield towards the mountain Búrfell (536 m).

Pl. lb. Seydishölar seen from SW. To the right Kerhóll.
Pl. IIIa. Three types of xenoliths from Grimsnes. At left, gabbro xenolith from Seydisfjordur showing crystal sorting, then vitrified acid xenolith from Seydisfjordur and at right quartz-plagioclase aggregate in scoria from Selhóll I.

Pl. IIIb. Soil profile 1 (Finnheidi) in fig. 6. From above, black ash layer, K ~ 1500° (1), the brown ash layer (2), the white Hekla layer H 3 (3), and scoria from Selhóll I (4). The foot rule is 1 m.
PLATE IV.

Pl. IVa. Tjarnarhólar lava. Ophitic to quasiophitic texture. The scale is 0.2 mm. Crossed nicols.

Pl. IVb. Gabbro xenolith. Olivine with highly developed cleavage. The scale is 0.2 mm. Crossed nicols.
The postglacial volcanic area in Grímsnes.