The Hekla Eruption of 1970 *

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Course of Events

(S. THORARINSSON)

After a repose lasting at least two and a half centuries a new period of activity began in Hekla in 1104 A. D. The activity of the volcano since then is summed up in Table 1, which is based on detailed tephrochronological studies combined with a critical evaluation of written records (THORARINSSON, 1967*a*). These studies reduced the number of eruptions hitherto ascribed to Hekla. Their number is not 20, as it would be according to Thoroddsen's classical *Geschichte der isländischen Vulkane* (THORODDSEN, 1925), it is 15.

After the Hekla eruption of 1636 the lenght of repose between the eruptions steadily increased and the large eruption in 1947-48 was preceded by a repose of 101 years. It was therefore a rather unexpected eruption that broke out in the evening of May 5th 1970. The seismographs in Reykjavík registered earthquake shocks which began at 20:58 IMT (=GMT) and culminated about 22:00. Their maximum magnitude was about 4 on the Richter scale.

The only precursory symptoms noticed before the earthquake were nervousness and restlessness in the dogs at the Búrfell hydro-powerstation, situated 15 km NW of Hekla, which was noticed some hours before the first earthquake shocks were felt.

The eruption started visibly at 21:23 IMT $\pm$ 2 or 3 minutes, when fissures opened up nearly simultaneously on the SSW and W flanks of the Hekla ridge.

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The real Hekla fissure (Heklugjá) which is about 5.5 km long and splits the NE-SW running Hekla ridge lengthwise (Fig. 2) opens up in its entire length during major eruptions. This time it opened up only in the extreme SW.

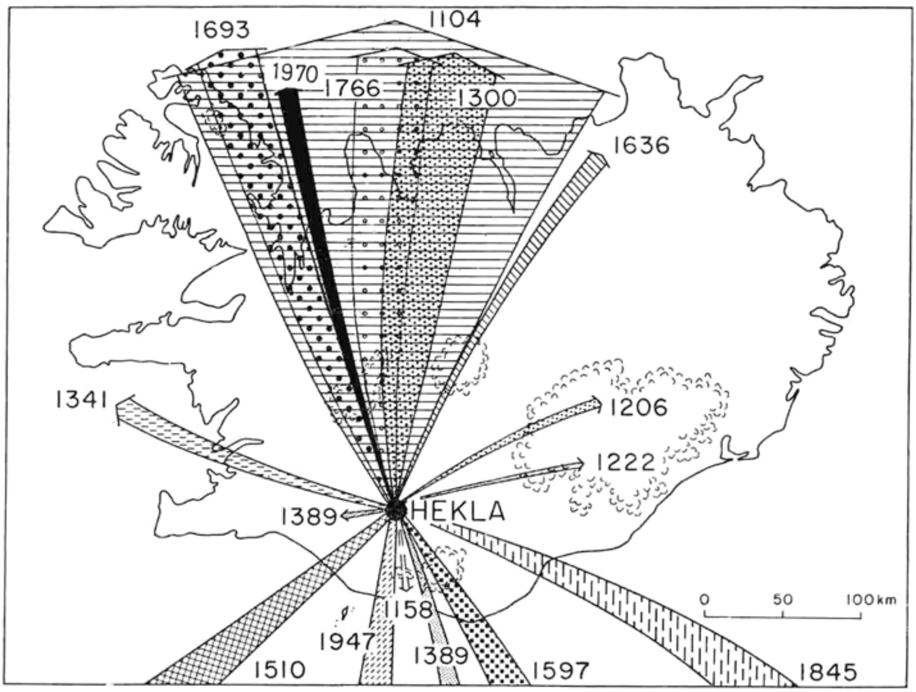

FIG. 1 - Map showing in which direction the tephra was dispersed during the initial phase of each of Hekla's 15 eruptions in historical times. The width of each arrow indicates roughly the relative size of the tephra layers' estimated volume.

The first two craters opened up on the SSW-flank, on a line running S55°W-N55°E, at an elevation of about 800 m. The distance between them was about 0.5 km. A third crater, and by far the most productive during the tephra producing phase of the eruption, opened up a little later at an elevation of 780 m. It is on a fissure running nearly N-S, which gradually opened up to a length of 0.8 km. At 22:30 a fountain of lava, continuously uprushing and glowing to a height of at least 1 km, rose from the largest crater. The fountains from the other two were considerably lower.

Some time during the first hours of the eruption there opened up a third fissure, running SW-NE through the large craters. Flashes of lightenings became frequent at about 22:00. The craters on the SSW-flank got the common name Sudurgígar (*cf.* the map Fig. 3).

The main fissure that opened up on the W-flank begins just below the lava crater of 1947 (H on the map Fig. 3) at a good 840 m

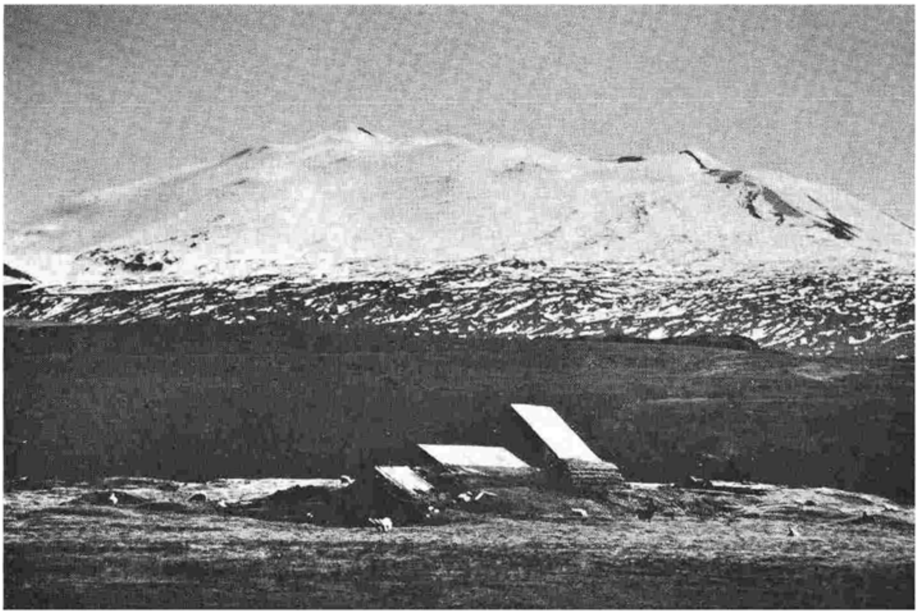

FIG. 2 - Hekla viewed from the East in the early spring 1969. The photo shows how the snow is melted along the southeastern part of the fissure which splits the volcano lengthwise during major eruptions (*Photo: G. Hannesson*).

elevation and from there bears W17°N. It soon attained a length of 500-600 m and within a few hours a small crater opened up 0.3 km still farther west. Just before midnight a new fissure opened up on the W-flank, 1 km N of the old lava crater and at an elevation of about 750 m. By 3:00 a.m. it had reached a length of about 350 m and threw virtually an unbroken lava fountain to a height of 200-300 m.

At about 22:35, or a little more than an hour after the eruption started in the SW part of Hekla, a fire broke out NNE of the Hekla ridge, at a distance of 7 km from the first eruption site. A black column rose with a speed estimated at 1 km/minute. From its base up to about 2.5 km the column was about 300 m in diameter and at that height it spread out like a tree. Lightenings flashed nearly incessantly through the column and at about 22:40 a column of fire could be seen through it. Twenty minutes later the fiery columns were two,

FIG. 3 - Hekla lava flows. 1: 1970-lava. Dash line shows the extent of the Hlídargígar lava beneath the Öldugígar lava. 2: 1947/48-lava. 3: Other Hekla lava flows younger than the settlement of Iceland. 4: Hekla lava certainly or probably prehistoric. 5: Lava from fissures in the Hekla region. 6: Thjórsá lava and Vatnafjöll lava. 7: Craters (the 1970-craters quite black). H: Hraungígwr (Lava Crater), Axlargígur (Shoulder Crater), Toppgígur (Summit Crater).

glowing to about 450 m height. These craters were on a fissure about 630 m above sea level, running S50°W-N50°E, obliquely down the low part of the slope above the prehistoric Skjólkvíar craters. The two craters had not been active long when a fissure opened up, running from the lower end of the first fissure a few hundred meters towards N10°W. A crater on the southern end of that fissure (Fig. 4) soon became the most powerful of the craters in this eruption area which got the name Hlídargígar.

The Tephra Phase

The initial phase of the eruption lasted two or three hours and was characterized by a very vigorous and continuous fountain activity, or rather a continuous, although somewhat spasmodic uprush of lava and tephra. At 22:10 the tephra-vapour column had reached its max. height, nearly 16.000 m. At 24:00 its height was 12.000 m and at 01:00 it was 7.500 m.

The tephra production during the two hours of the main tephra fall averaged about 10.000 m^3/sec and the total production of tephra was about 70 million m^3, or 45 million tons. The tephra was carried towards the NNW with a speed of 74 km/hour, and reached the north coast, at 180 km distance from Hekla, at midnight.

Table 2 shows the area and thickness distribution of the tephra layer and Fig. 5 is an isopach map.

Because of the strong wind prevailing and the relatively short duration of the tephra fall the tephra sector is narrow. Beneath the 700 mb (3.000 m) level the wind slowed considerably down at the north coast with the result that the tephra fall was heavier there than somewhat farther south. On a 70 km^2 area on the Vatnsnes peninsula the average thickness of the layer was 5 mm, and the tephra fall amounted to 40 tons/ha. The vol. weight of the fine-grained tephra in the north was 0.8, that of the coarser grained tephra near Hekla 0.6.

The rivers Rangá ytri and Thjórsá carried a great amount of tephra to the sea. Within 6 weeks it had drifted to the north coast of Iceland.

The tephra had a dark brown colour, in between were strewn pieces of light gray frothy pumice.

The tephra proved unusually rich in fluorine, or up to about 2.000 ppm. When released from the magma the fluorine gas adheres to the surface of the tephra grains, probably mainly as HF. There is thus proportionally more fluorine contained in the tephra the finer

TABLE 1 - Eruptions in Hekla and the Hekla region in historical times.

Hekla							Hekla region
Beginning of eruption	*Duration Months*	*Length of preceding repose Years*	*Volume of lava 10^6 m^3*	*Volume of tephra 10^6 m^3*	*Direction of axis of max. thickness near Hekla*	*Damage caused by eruption*	*Beginning and location of eruption*
1970, 5 May	2	22	200	70	W 65° N	Some	1913, 25 April, near Mundafell and on Lambafit
1947, 29 March	13	101	800	210	S 15° W	Little	
1845, 2 Sept.	7	77	630	280	E 10° S	»	
1766, 5 April	24	73	∾ 1300	400	W 75° N	Considerable	
1693, 13 Febr.	7 to 10	56	Not known	300	W 55° N	Great	1878, 27 Febr., near Krakatindur
1636, 8 May	12	39	» »	((80))	N 30° E	Little	
1597, 3 Jan.	>6	86	» »	(240)	E 20° S	»	
1510, 25 July	Not known	120	» »	320	S 55° W	Great?	1725, 2 April, E and SE of Hekla
1389, early winter	» »	47	>200	((80))	(E 40° S)	Considerable	
1341, 19 May	» »	40	Not known	((80))	S 85° W	»	
1300, 11 or 12 July	12	78	>500	500	N	Great	1554, May, in Raudubjallar
1222, ?	Not known	15	Not known	((10))	N 60° E	Little	
1206, 4 Dec.	» »	46	» »	((30))	N 40° E	»	Ca. 1440, SE of Hekla
1158, 19 Jan.	» »	53	>150	Not known	SSE?	»	
∾1104, autumn?	» »	>230	No lava?	2500	W 80° N	Very great	

grained it is. Fine-grained tephra also adheres better to the blades of grass and other vegetation that the coarse grained, thus being more easily carried into herbivorous animals such as livestock. Experiments have shown that if the fluorine content exceeds 250 ppm of the dry content of the grass, it can cause fluorine poisoning which kills grazing sheep in a few days. Measurements of the ash-contaminated vegetation in the upland districts of Árnessýsla showed figures up

TABLE 2 - Area and thickness of the 1970 Hekla tephra.

Within	the	20	cm	isopach	9	km^2
»	»	10	»	»	33	»
»	»	5	»	»	95	»
»	»	2	»	»	500	»
»	»	1	»	»	2.080	»
»	»	0.5	»	»	3.300	»
»	»	0.1	»	»	6.950	»
Total area on land and sea					∾ 40.000	»
Total area on land					∾ 22.000	»

to 4.000 ppm of the dry content of the grass when samples were taken on the 7th of May. Samples taken in Húnavatnssýsla in North-Iceland on 18th-19th May revealed a fluorine content of 350-750 ppm.

The fluorine caused lethal fluorine poisoning in the grazing livestock, especially sheep, which were killed by thousands in West-Húnavatnssýsla (Fig. 6) and in the districts of Árnessýsla affected by the tephra fall. A layer of about 1 mm thickness or even less of fine-grained tephra proved sufficient to cause lethal poisoning. It should be taken into consideration that because of poor hay crop in Húnavatnssýsla in the summer of 1969 many sheep there were underfed in the late winter 1969-70 and their resistance was therefore weaker than normal.

The fluorine was gradually washed out of the tephra. By 20th of May the fluorine content of the tephra had generally fallen to a tenth part of what it was originally and by mid-June the grazing land had on the whole become fairly safe for the livestock.

During the first hours of the 1970-eruption the total production of lava averaged about 800 m^3/sec, calculated as solidified lava. This means that the average flow from the vents was probably about 1.500 m^3/sec. The total area of the lavaflows after the first 10 hours was about 7.5 km^2, where of 4.5 km^2 were from Sudurgígar (Fig. 7), 1.5 from the craters on the W-flank of the volcano and 1.5 from the Hlídargígar craters.

On 8th May the flow from the fissures on the W-flank had ceased altogether. Their lava had then covered 2.1 km^2. The lava flow from

FIG. 4 - The Hlídargígar craters seen from the East at about 5:30 a.m. 6th May, 1970. The height of the main lava fountain is about 250 m (*Photo: S. Thorarinsson*)

the Sudurgígar craters ceased on 10th May, having by then spread over an area of 6.5 km^2. In the main crater on the N-S running Hlídargígar fissure the effusive activity went on until May, 20th and by that time the new lava in Skjólkvíar had an area of 5.8 km^2. At 17:45 of the same day a new fissure opened up 1 km N of the main Hlídargígar crater. This fissure runs in the direction N40°E-S40°W thus making a striking similarity between the *en échelon* pattern of the 1970-eruption fissures in the Skjólkvíar and the Sudurgígar areas. It cuts through a whaleback-shaped 60 m high móberg ridge. At 21:00 the length of the fissure was estimated at 0.8 km, and at 23:25 it had a length of 0.9 km. Seventeen separate lava fountains, 20-50 m high, were then playing on the fissure.

The production of tephra was negligible, but the lava production considerable, and at 23:30 the area of the new lava flow was estimated at 1 km². During the following days various numbers of craters, called

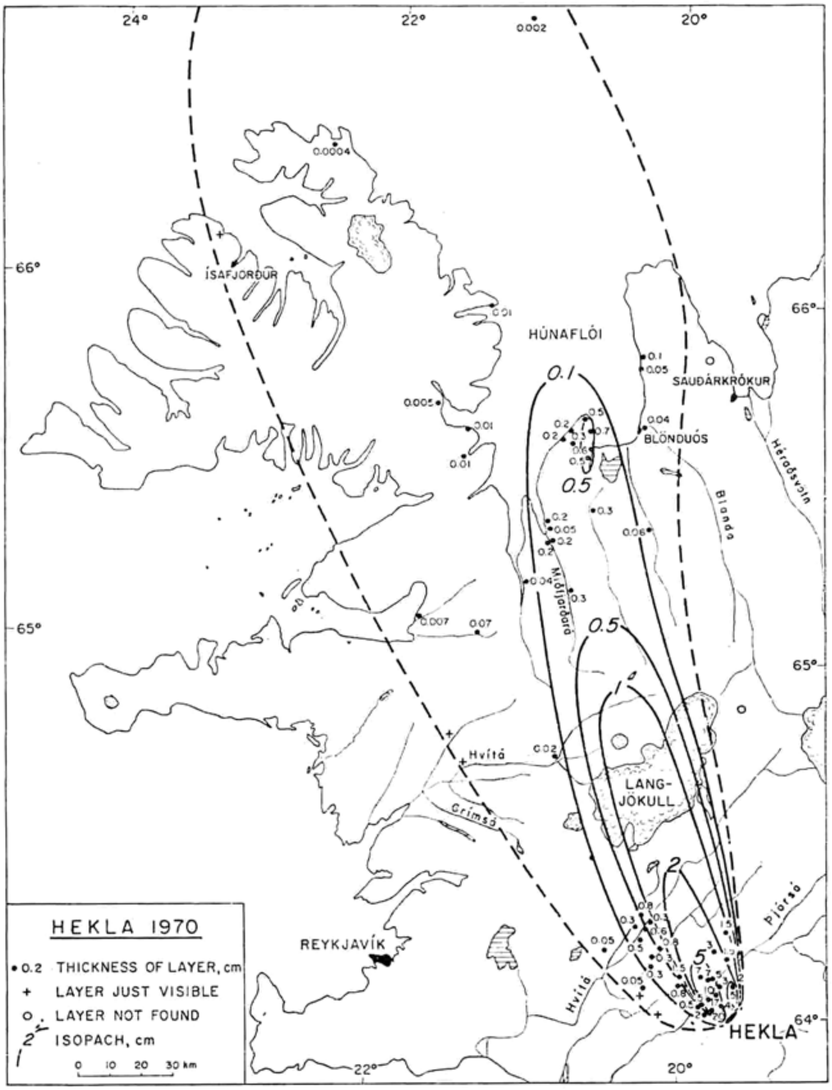

FIG. 5 - The distribution and thickness of the tephra layer H 1970.

Öldugígar, were active on the new fissure (Fig. 8), building up small spatter cones and producing lava which was partly superimposed on the Hlídargígar lava. After the first week 6-8 craters were still active. On 2nd June they were 4, and after that usually 2-3, one of which was by far the most active and built up a spatter cone ca 100 m high (Fig. 9). By the beginning of July the eruption had become insignificant and on July 5th it ceased altogether. The Hekla eruption of 1970 had then lasted exactly 2 months.

FIG. 6 - A farmer and his son beside a grave of their sheep killed by fluorine poisoning. The place is in Húnavatnssýsla, near the coast of Húnaflói, 190 km NNW of Hekla (*Photo: M. Finnsson*).

The lava from Öldugígar covered 6.6 km^2 and increased the area covered by new lava N of Hekla from 5.8 to 9.9 km^2 and the total area of 1970-lava to 18.5 km^2. Its estimated volume is about 85 million m^3 and the total volume of lava produced by the 1970 Hekla eruption is nearly 0.2 km^3, or about one quarter of the amount produced in the 1947-48 Hekla eruption.

The new Hekla lava is mostly a typical apalhraun (aa) lava (Fig. 10). Here and there along the tongue of the Öldugígar lava flow are tongues of escaped lava broken up in block lava.

The physicist T. Sigurgeirsson measured a temperature of about 1.050°C in a lavastream from the Hlídargígar crater.

By tephrochronological studies of the historical Hekla tephras and lavas and by critical analyses of written sources it has proved possible to trace the eruption history of the volcano since Iceland was settled as well as its earlier history to a certain extent. Hekla has since the end of the last glacial, or during the last 11.000 years

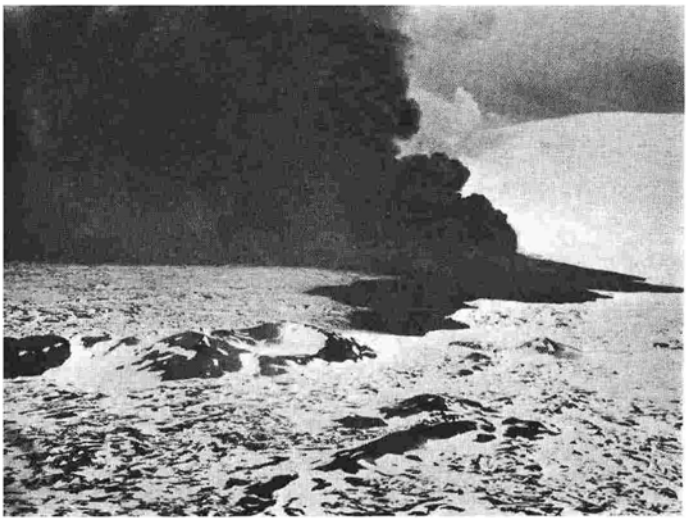

FIG. 7 - The lava flow and the tephra column from Sudurgígar viewed from an aeroplane at about 5:30 a.m. on 6th May, 8 hours after the eruption started there (*Photo: J. Reykdal*).

or so, produced more tephra than any other Icelandic volcano, or altogether 6 to 7 km^3 calculated as solid rock (about 25 km^3 calculated as freshly fallen tephra), whereof about 50 % are dacitic-rhyolitic and about 50 % andesitic. The total volume of Hekla lava during the same period has been estimated at 18 km^3 (THORARINSSON, 1954; 1967). These studies reveal that the silica content of the magma in the upper or uppermost part of the magma chamber increases between Hekla's eruptions as a roughly linear function of time, but drops down during the eruptions (Fig. 11).

The increase of silica content and the gradual cooling of the magma in the chamber cause a building up of gas pressure. Consequently the violence and explosivity of a Hekla eruption is directly related to the length of the dormant period preceding each eruption.

If Hekla remains quiet for two centuries or so the following eruption is tremendously explosive and produces only acid tephra, whereas eruptions after shorter dormant periods produce both lava and tephra.

Hekla's behaviour seems to be typical for Iceland's differentiated central volcanoes that presumably are fed by separate magma cham-

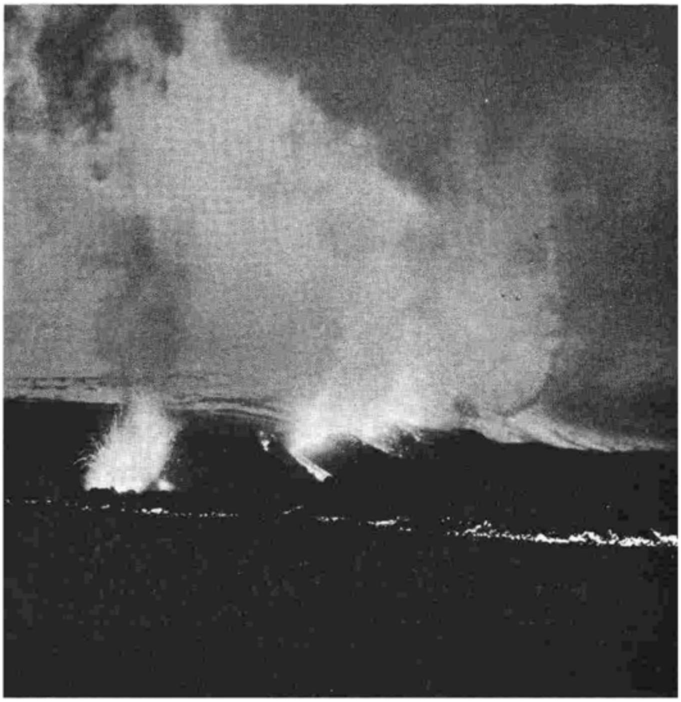

FIG. 8 - The Öldugígar craters and lava at night between 21st and 22nd May, 1970. The snow-covered Hekla ridge in the background (*Photo: Æ. Jóhannesson*).

bers at relatively shallow depth in the crust, whereas fissures such as those running parallel to the Hekla ridge on both sides, have produced only basalt magma which changes little between eruptions. These fissures are probably deep-fed and the difference between them and Hekla is shown schematically on Fig. 12.

Comparison with Older Hekla Eruptions

During major Hekla eruptions of long duration, such as the 1947-48 eruption, three types of lava can be discriminated (TÓMASSON, 1967). In Type I, found at the start of the eruption, the ground mass is crypto crystalline and has a fluidal texture, and the amount of phenocrysts is about 2 %. The phenocrysts are plagioclase, pyroxene, titanomagnetite, with a few olivine crystals, and a sprinkling of apatite

FIG. 9 - The northeastern part of the Hlídargígar crater row. The crater in the background is the highest one in the row (*Photo: Æ. Jóhannesson, June 14, 1970*).

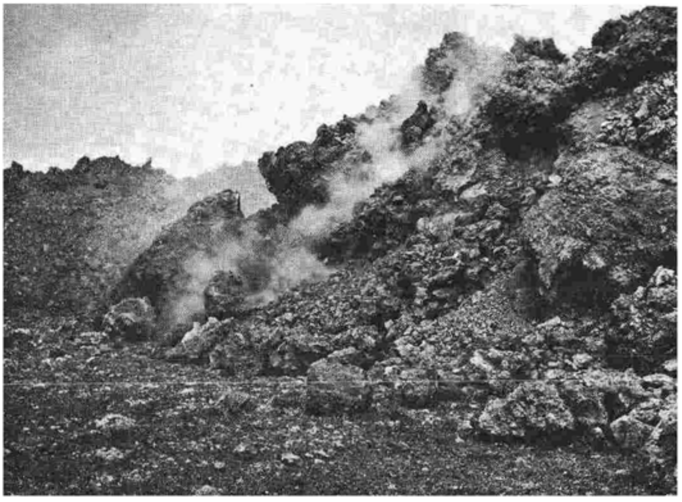

FIG. 10 - Front of the lava from Öldugígar 6 km from the craters, on June 1st 1970 (*Photo: S. Thorarinsson*).

crystals. The silica content is 57-60 % and the lava may be termed as dacite. In Type II, which was formed most of the time during the 1947-48 eruption, the groundmass is considerably coarser grained and has a fluidal texture. The minerals are the same as in Type I, but the lava contains proportionally more olivine and larger crystals. The silica content is 55-56 %. This lava is andesite.

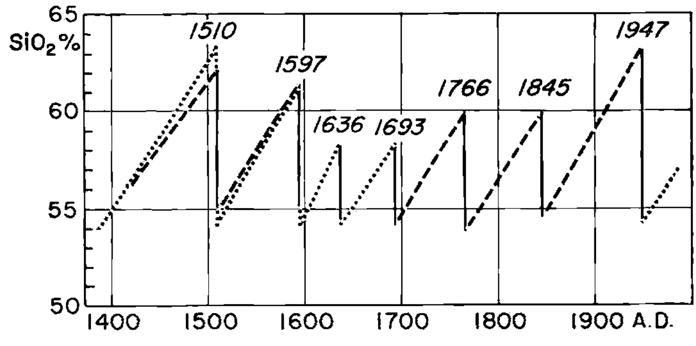

FIG. 11 - Diagram showing the relation between the SiO_2-content of the initial tephra of seven Hekla eruptions and the length of the preceding intervals of repose. The continuous and broken lines are based on chemical analyses. The hypothetical dotted lines show the SiO_2-content as a strictly linear function of time.

Type III-lava is found in lava that flows towards the end of large Hekla eruptions. The chemical composition is shown in Table III. The groundmass is crystallized and the fluidal texture is not so conspicuous as in the other types. It is rich enough in olivine to be classified as olivine andesite.

Petrography and Chemistry

(G. E. SIGVALDASON)

Products of the 1970 Hekla eruption are divided into: (1) xenoliths, (2) acid tephras, (3) basic tephras, and (4) lavas. The volume relations between the individual groups are such that the lavas take up two thirds of the total, the basic tephras one third, and the acid tephras and xenoliths only a fraction of a percent.

Xenoliths occurred in abundance especially at the Hlídargígar craters. Five types were found: (1) Fluvioglacial sediments (varved clay), (2) palagonite tuff, (3) vesicular lava with amygdale fillings, (4) fragments of andesite lavas, and (5) ignimbrites.

The varved clay and the ignimbrite came from craters lying 7 km apart indicating extensive continuous layers of these rock types at

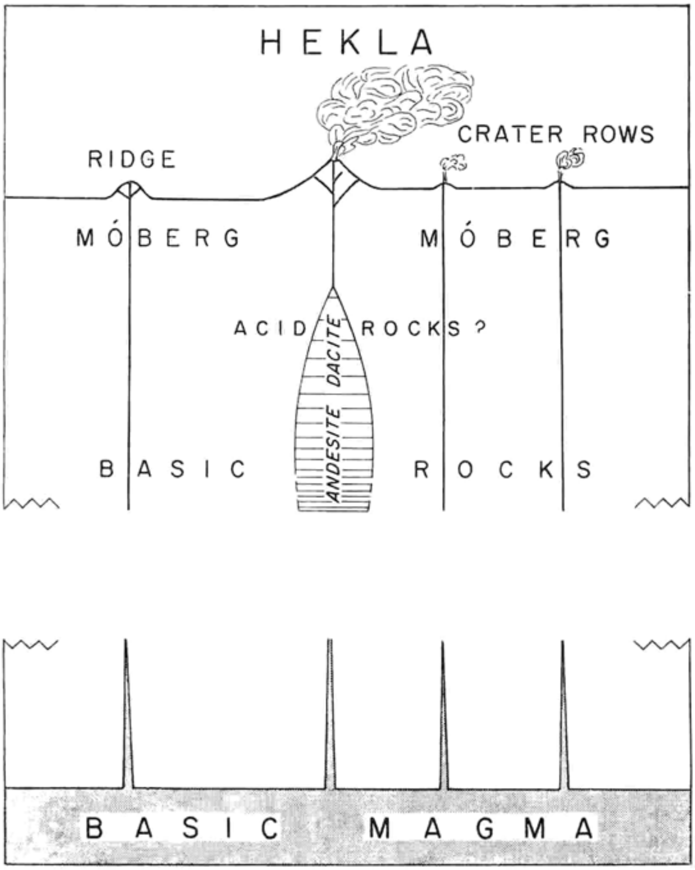

FIG. 12 - Skeleton drawing illustrating how Hekla differs from the ridges and crater rows in her vicinity (from THORARINSSON, 1970).

depth. The ignimbrites have the characteristic lenticular texture, but are poorly consolidated. They are hydrothermally altered to a varying degree, with a water content ranging up to about 9 % H_2O.

Acid tephras were found as individual pumice particles mingled with the basic tephras and as rare spongy glassfroths which were found in larger pieces up to 10-15 cm in diameter.

The bulk of the basic tephras were produced during the first two hours of activity. They are best described as black highly vesicular pumice fragments ranging in size from large frothy blocks near the craters to a sand or dust fraction in the farthest parts of the tephra sector.

The lavas were relatively viscous and formed typical aa-flows, identical with older Hekla lavas of intermediate character.

TABLE 3

	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	53.66	55.21	54.52	53.58	72.22	62.11	54.25
Al_2O_3	14.50	15.16	14.80	14.54	13.23	16.17	16.34
Fe_2O_3	4.86	5.11	2.93	3.35	0.63	2.61	2.24
FeO	7.01	6.92	9.14	9.05	1.51	5.71	10.05
MgO	2.93	2.86	3.03	3.25	0.35	1.63	3.39
CaO	6.65	6.81	6.76	6.91	0.33	5.24	7.09
Na_2O	4.03	4.16	4.08	3.91	5.20	4.12	3.41
K_2O	1.24	1.26	1.24	1.19	3.89	0.98	0.95
MnO	0.25	0.26	0.26	0.26	0.09	0.18	0.26
TiO_2	1.84	1.83	1.91	2.02	0.30	1.02	1.54
P_2O_5	0.61	0.68	0.71	0.76	0.09	0.34	0.35
H_2O	0.48	0.44	0.59	0.21	0.54	0.33	0.50

1: H-70-2 Pumice, Sudurgígar 5/5 '70.
2: H-70-3 Bomb, Hlídargígar 5/5 '70.
3: H-70-14 May-14 lava, Hlídargígar.
4: H-70-70 June-28 lava, Öldugígar.
5: H-70-12 Glassfroth, 1970 eruption.
6: Central part of bomb beginning of eruption 1947 (EINARSSON, 1950).
7: Last lava to appear in 1948 (EINARSSON, 1950).

Chemical analyses of the volcanic products are listed in Table 3 along with analyses of the first and the last products of the 1947-eruption (EINARSSON, 1950).

THORARINSSON (1967*a*) has shown that the silica content of the initial products of each Hekla eruption is a function of the length of the preceding repose. The repose preceding the 1970-eruption was only 23 years and it provided a welcome opportunity to test the initial stage of chemical variation in the Hekla magma. Analyses 1 and 2 in Table 3 show the composition of the very first products of Sudurgígar craters and Hlídargígar craters respectively. If Thorarinsson's curve is extrapolated down to a value of 23 years the expected silica value of the initial products would be about 55 %, as compared to 55.21 % of the first bomb from Hlídargígar craters. However, the first tephras from Sudurgígar craters have a silica content of only 53.66 % SiO_2, exactly the same value as was found in the last lavas of the eruption. Furthermore, the acid tephras and white glass froths produced during the initial phase have a silica content ranging up to 72.22 %. Fig. 13 shows the variation in silica and titania with time during the 1970 eruption; values from unpublished analyses are also included. This diagram shows clearly that the initial basic tephras and lavas are relatively heterogenous as compared to the later lavas. This is a sharp contrast with the regular variation with time which was observed during the 1947 eruption.

The 1970 eruption was preceded by a repose which was shorter than any previous repose followed by an eruption where data on initial products are available. The apparent lack of clearcut relation between the length of the preceding repose and the silica content might be explained as an indication of a process where the rate of variation is insufficient to produce homogenous material in a relatively short time.

In Fig. 14 Thorarinsson's curve has been redrawn to express the possible path of variation in Hekla's magma chamber. It is safe to assume that the silica concentration will reach a saturation value close to 70 % SiO_2. The longest known repose period of approximately 250 years was followed by the eruption of 1104 A.D. The silica content of the initial products of this eruption still has a linear relation, on the logarithmic time scale, to material produced after shorter repose periods. The very large prehistoric Hekla tephra layer H4 has a silica content of 71.37 %. A linear extrapolation on the curve would indicate a repose period of 500 years, but very little can be said in favour of that figure. A more likely trend is that shown in Fig. 14 where the rate of increase in silica becomes slower as an upper value of approximately 70 % silica is approached. A notable feature of the variation curve is the increasingly looser fit of points as the repose period becomes shorter than 40 years. This is especially pronounced in the initial products of the 1970 eruption. The relatively large range in silica values of the basic tephras and the simultaneous production of acid tephra might be interpreted as a system consisting of two phases in the initial stages of mixing. The original silica content of the basic component would be close to 53 %, the same as the last lavas of either the 1947 or the 1970 eruption. The composition of the acid phase is represented by the acid tephras and glass froth.

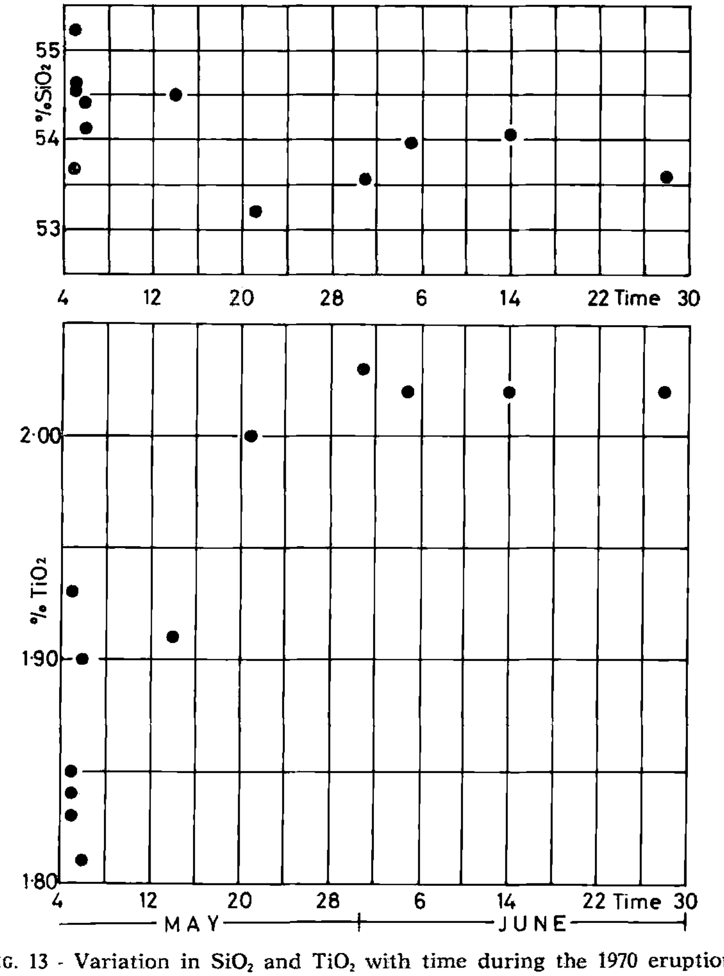

FIG. 13 - Variation in SiO_2 and TiO_2 with time during the 1970 eruption.

The lower end of the variation curve would therefore show a slow and irregular rate of increase at first while mixing is incomplete.

EINARSSON (1950) suggested that the chemical variation observed during the 1947 eruption might indicate fractional crystallization in the magma chamber during the preceding repose. One of the arguments against fractional crystallization was the very small grain size of constituent minerals in the lavas, and absence of larger phenocrysts. The mineralogy of the 1970 lavas is identical with the lavas of the 1947 eruption (TRYGGVASON, 1965). The maximum amount of phenocrysts is about 30 %. Plagioclases make up 25 % (An 50 %). The lavas contain 3 % olivine which often has reaction rims of pyroxene,

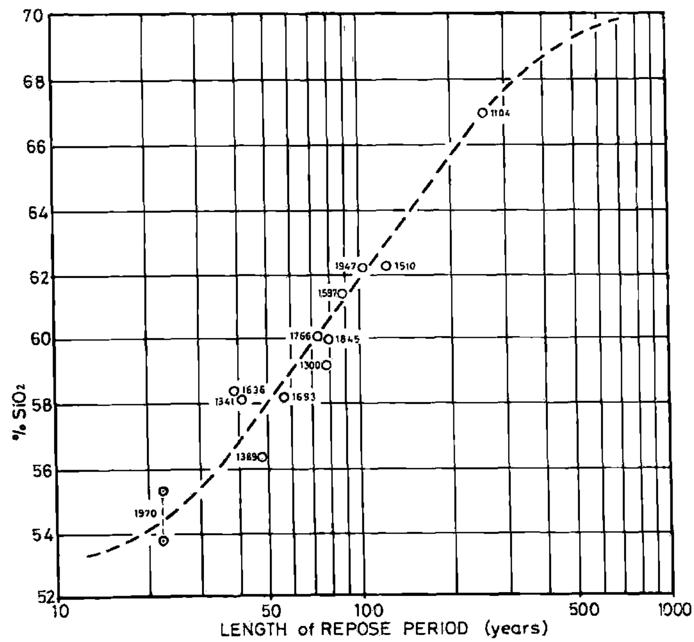

FIG. 14 - Variation in SiO_2-content of initial products of Hekla with length of the preceding repose.

and 2 % magnetite. The groundmass is dark brown to opaque glass with microlites of pyroxenes and ore. The plagioclases are occasionally 2-3 mm in diameter, but the bulk of the laths are 0.5 mm in the longest sections. Olivine grains ara smaller, 0.2-0.3 mm. Much of the crystallization occurs in the flowing lava since the initial tephras contain only about 5 % crystallized material.

If the 1947 products are interpreted as a liquid residue after complete removal of some proportion of phenocrysts one would expect to find some indication of a more advanced crystallization in the 1970 products since the differentiation process is interrupted at such an early stage. This is not the case, but instead we observe two liquids, and material which appears to be the result of incomplete mixing between the two. Acid rocks which were found as xenoliths among the eruption products might be looked upon as a source for the acid fluid.

The present incomplete data do therefore favour the idea that assimilation of acid rocks is the process which causes the rise in silica in the Hekla magma during repose periods. This preliminary conclusion only implies that the present cycle of activity in Hekla is chemically influenced by the location of a secondary magma chamber in contact with acid rocks, which in turn may have formed by fractional crystallization during an earlier phase of igneous activity in this area.

This conclusion leaves unexplained the reason for the relatively high silica content of the magma which has apparently not been contaminated by the acid component, but is nevertheless significantly more acid than other recent lavas in the immediate vicinity of Hekla.

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