NORDIC VOLCANOLOGICAL INSTITUTE 8401

UNIVERSITY OF ICELAND

Mývatn fires 1724-1729

Chemical composition of the lava

Karl Grönvold

Reykjavík 1984

ABSTRACT

The Myvatn fires eruption episode took place in North Iceland 1724 1729. It was a basaltic fissure eruption which produced 0.45 km^3 of basaltic lava with a fairly evolved chemical composition. The episode consisted of relatively short events in the early part and eruptions of longer duration towards the end. This is similar to what is happening in the present episode of rifting of the North Iceland plate boundary.

The crater scoria and lava show a limited but significant variation in major element composition. The mineral and glass phases were analyzed separately and significant variation also found in their chemical composition. It is suggested that the magma was stored at shallow levels for a short while just before the eruption for a final modification by mixing and fractionation. Separate and distinct magma batches of relatively evolved composition were already available during the short final modification but the distinct character of each magma batch was maintained. It is estimated that the difference in temperature between the most and least evolved magma liquids was about 30° C at the time of the eruption.

The fissure that erupted in the Myvatn fires is a part of the Krafla volcanic system which has erupted 15 times in the last ten thousand years. The data available shows a very restricted range of chemical composition for these fissure lavas and the lava of the Myvatn fires falls within that range.

INTRODUCTION

Myvatn fires (Mývatnseldar, in Icelandic) is a name given to an eruption episode, or series of eruptions, in North Iceland 1724 - 1729. In this episode about 0.45 cubic kilometers of basaltic lava covering 30 square kilometers were erupted from an 11 kilometer long discontinuous fissure. Most of the lava was erupted during the last two years of the episode, August 1727 - September 1729. Vivid accounts on the first three years, from May 1724, describe intense earthquake swarms, fault movements and elevation changes that took place in short sharp events. This is interpreted to be due to the rifting of the North Iceland plate boundary.

The Myvatn fires lava has been mapped in detail and the contemporary accounts evaluated and discussed (1). Samples from this lava and the crater scoria have now been chemically analyzed, both the glass and the mineral phases and a few whole rock samples. An attempt was made to use the maps and accounts so the samples represent a time sequence within the eruption. Analyzing both individual phases in the scoria and whole rock samples hopefully gives some further insight into the state of the magma at the time of eruption.

The main result of this work shows a significant but limited chemical variation among the samples both in glass and whole rock composition. This can not be explained by simple in situ crystallization but must reflect the state of the magma at the time of the eruption. The basalt has a fairly evolved chemical composition and no sign of any primitive basalt is found among the products except a few An rich plagioclases.

The Myvatn fires eruptive fissure is a part of the Krafla volcanic system and detailed geological mapping shows about 15 such eruptions in post glacial times, about the last 10 thousand years. The Myvatn fires were the first in historical time, so preceded by about quite 850 years.

In December 1975 the Krafla central volcano and its associated fault swarm came active again. Following a few months of abnormal earthquake activity a small basaltic fissure eruption occurred accompanied by intense earthquake activity, fault movements and land elevation changes. It also soon came apparent that accompanying this activity was a large scale underground movement of magma within the Krafla fissure swarm (2). Similar tectonic and magmatic events were then repeated until 1980 and the rifting of the North Iceland plate boundary is manifest by 5-7 meter dilation across the fault swarm. During 1980 and 1981 five basaltic fissure eruptions were the dominating feature of the activity.

This present episode is strikingly similar to that of the Myvatn fires. With much improved observation techniques it has been possible to observe magma reservoirs at about three kilometers depth as they inflate gradually and then deflate sharply during the rifting events and eruptions (3,4,5). Samples from these lavas are being analyzed in a similar way as described here but already show a much greater chemical variation than the lavas of the Myvatn fires. That, however, will be another installment of the story.

"MYVATN FIRES" - SEQUENCE OF EVENTS.

Contemporary accounts are available of the Myvatn fires by the local minister, pastor Jon Saemundsson, but other less detailed sources also exist. These accounts have been evaluated by Kristjan Saemundsson (1) in relation to the geological map of the area and the present rifting activity.

On May 17th 1724, at about 9 in the morning, an explosive eruption occurred on the western flanks of the mountain Krafla (figure 1). Strong earthquakes preceded the eruption during the previous night and it was accompanied by a large earthquake and a glowing ash column was seen. The main crater, Viti, formed in the explosion is subcircular and 350 meters in diameter. In addition 14 smaller explosion craters were formed (6). The explosion products, deposited southwards from the crater, are mainly altered lithic fragments of the country rock mixed with small amounts of fresh ash and scoria ranging in composition from basaltic to acid. Analytical work on the Viti products is in progress but the basalt composition included here. Viti is about 1.5 km east of Leirhnjukur where the following rifting and eruptions took place (figure 1).

The Viti explosion was the beginning of a large scale rifting episode where the plate boundary was rifted in short sharp events in apparently a similar way as in the present episode. The first major rifting and earthquake event accompanied the Viti eruption and the fault swarm to the south of Krafla rifted. In 1725 three short but sharp events of earthquake and rifting took place, again to the south of Krafla. During these events large number of earthquakes were felt, houses were damaged, large scale movements on faults and very significant increases in geothermal activity were observed. The initial Viti explosion was, however, the only eruption which was certainly associated with these early events. No activity is mentioned for 1726 and the first half of 1727 in the accounts but it is possible that during that period undetected rifting took place in the northern part of the fault swarm.

The second phase of the "Myvatn fires" started on August

21st 1727 when the lava eruption began and involved four pulses or events. The first two pulses apparently lasted only a few days but the final eruptions extended over longer periods.

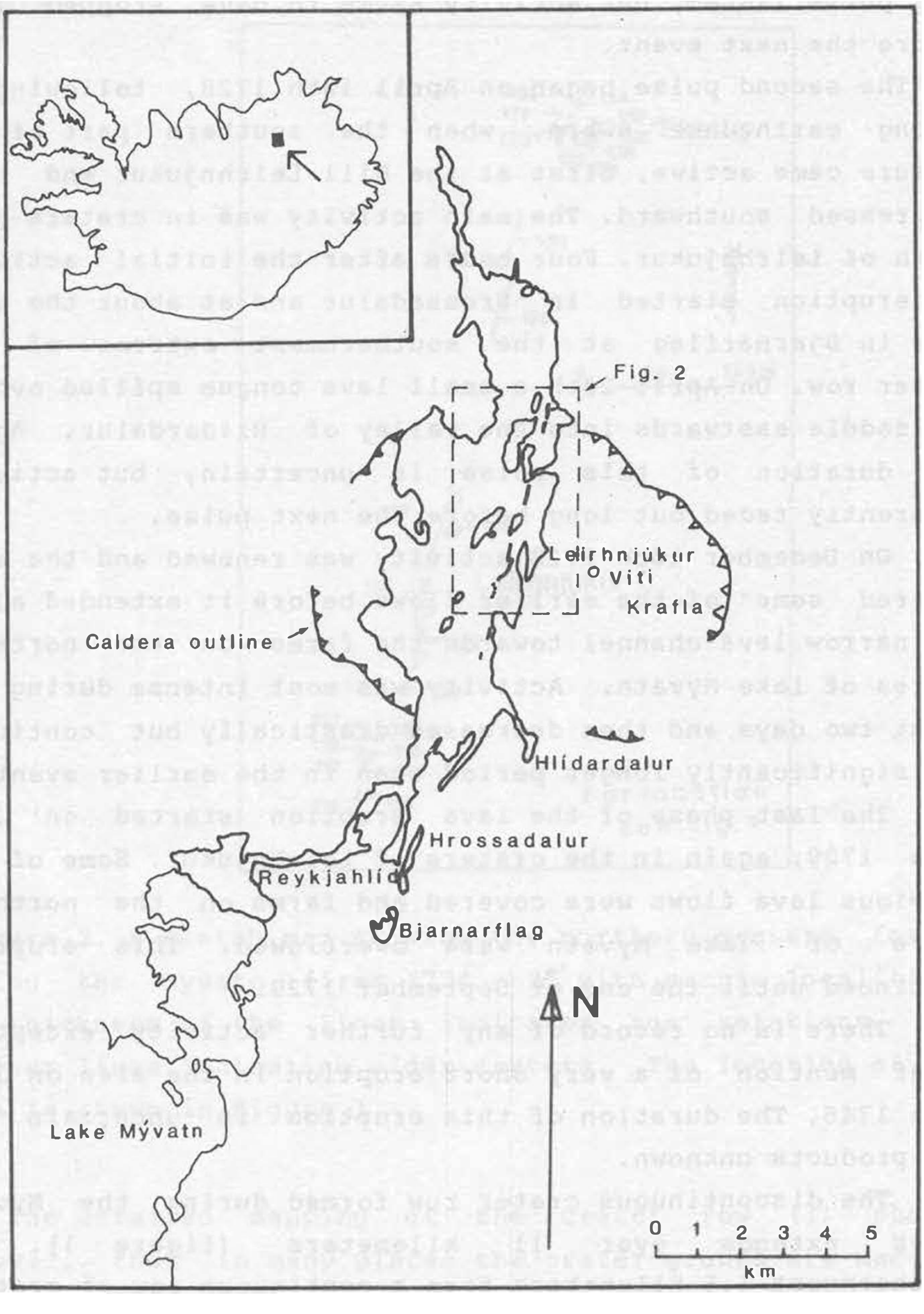

Figure 1. The lavas erupted in the Myvatn fires. Also shown is the outline of the Krafla caldera and Lake Myvatn. The craters and sample localities are shown in figure 2.

In the first event lava was erupted mainly from the northernmost part of the crater row. The lava tongue extending furthest to the north was most likely erupted at this time. There is very little indication as to how long this pulse lasted, but activity seems to have stopped long before the next event.

The second pulse began on April 18th 1728, following a strong earthquake swarm, when the southern part of the fissure came active, first at the hill Leirhnjukur and then progressed southward. The main activity was in craters just south of Leirhnjukur. Four hours after the initial activity an eruption started in Hrossadalur and at about the same time in Bjarnarflag at the southernmost extreme of the crater row. On April 20th a small lava tongue spilled over a low saddle eastwards into the valley of Hlidardalur. Again the duration of this pulse is uncertain, but activity apparently faded out long before the next pulse.

On December 18th 1728 activity was renewed and the lava covered some of the earlier flows before it extended along the narrow lava channel towards the farms on the northern shores of lake Myvatn. Activity was most intense during the first two days and then decreased drastically but continued for significantly longer period than in the earlier events.

The last phase of the lava eruption started on June 30th 1729, again in the craters of Leirhnjukur. Some of the previous lava flows were covered and farms on the northern shore of lake Myvatn were overflowed. This eruption continued until the end of September 1729.

There is no record of any further activity except a brief mention of a very short eruption in the area on July 10th 1746. The duration of this eruption is uncertain and the products unknown.

The discontinuous crater row formed during the Myvatn fires extends over 11 kilometers (figure 1). The northernmost 6.5 kilometers form a continuous row of craters (figure 2) from the northern rim of the Krafla caldera to south of Leirhnjukur. Further south are two crater groups, one in Hrossadalur and the other in Bjarnarflag, that erupted simultaneously relatively small lavas.

From flow structures in the main lava, as observed in areal photographs, it is obvious that the volumes erupted from the different crater groups are very variable. The actual craters formed during each pulse or phase of the eruption can not be identified, except the southernmost craters.

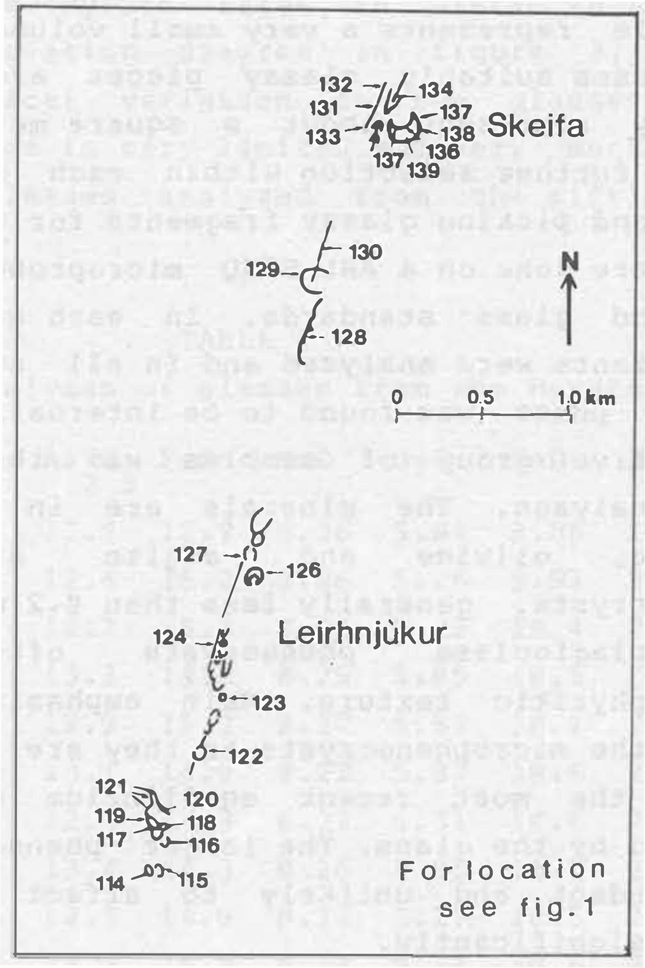

Figure 2. A sketch map showing the northern craters formed during the Myvatn fires 1724 - 29 with sample localities. The thickness of the lines indicates age relations, the thicker lines indicating older craters. The location of the area is shown in Figure 1.

The detailed mapping of the crater row (1) shows, however, that in many places the crater groups are made up of three different units of eruptive fissures or crater rows. The age relations of the different units can in some places be worked out. The most voluminous, often circular or sub-circular relatively regular craters, are in some cases clearly succeeded by a younger less voluminous crater row. The youngest in all cases are eruptive fissures with a more or less continuous cover of spatter but apparently very little lava production. Unfortunately the time scale of the relationship is unknown. The northern craters are shown on a sketch map in figure 2 with sample localities.

In most of the craters glassy scoria is abundant and each sample represents a very small volume of each crater. In a few cases suitably glassy pieces are scarce and a sample may represent about a square meter of the crater surface. A further selection within each sample was then made by hand picking glassy fragments for the thin section. Analyses were done on a ARL-SEMQ microprobe using natural mineral and glass standards. In each sample a number of glass fragments were analyzed and in all sections but two the glass phase was found to be internally homogeneous. A representative group of samples was then selected for mineral analyses. The minerals are in two size groups; plagioclase, olivine and augite are found as microphenocrysts, generally less than 0.2 mm in length, and larger plagioclase phenocrysts often with a glomeroporphyritic texture. Main emphasis was put into analyzing the microphenocrysts as they are more likely to represent the most recent equilibrium with a liquid now represented by the glass. The larger phenocrysts are much less abundant and unlikely to affect the whole rock chemistry significantly.

THE CHEMICAL COMPOSITION OF THE GLASS

The chemical composition of the glasses in the scoria samples from the Myvatn fires is listed in table 1 and plotted on MgO variation diagram in figure 3. There is significant chemical variation in the glasses but the compositional range is very limited and very much so when compared with glasses analyzed from the rifting present episode (7).

TABLE 1

Chemical analyses of glasses from the Myvatn fires

	SiO	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K O	P_2O_5
KRA111	50.5	2.29	12.5	15.7	0.26	5.04	9.80	2.48	0.31	0.24
KRA112	48.9	2.35	12.6	15.2	0.26	5.26	9.91	2.46	0.38	0.22
KRA113	49.8	2.30	12.7	15.3	0.24	5.25	10.4	2.52	0.34	0.23
KRA114	49.1	1.93	13.3	14.6	0.25	5.85	10.5	2.63	0.32	0.27
KRA117	49.3	2.09	12.9	15.2	0.27	5.59	10.1	2.58	0.35	0.27
KRA118	49.0	1.97	13.1	14.0	0.22	5.87	10.6	2.44	0.33	0.29
KRA119	49.4	2.12	12.4	14.9	0.27	5.31	10.6	2.34	0.38	0.24
KRA120	49.3	1.98	13.4	14.3	0.26	5.95	10.3	2.51	0.30	0.29
KRA121	49.3	2.14	12.3	14.9	0.22	5.27	10.5	2.13	0.37	0.24
KRA122	49.4	1.99	13.2	14.0	0.24	5.74	10.6	2.31	0.36	0.21
KRA125	49.7	2.04	13.3	14.6	0.27	5.87	10.4	2.83	0.30	0.19
KRA126	49.8	2.05	12.5	14.4	0.21	5.55	10.3	2.34	0.35	0.21
KRA127	49.5	1.94	13.2	14.2	0.25	5.89	10.6	2.42	0.33	0.20
KRA128	49.5	1.96	13.5	14.3	0.27	5.85	10.3	2.58	0.34	0.24
KRA129	49.7	2.07	12.9	14.7	0.21	5.60	10.3	2.22	0.31	0.20
KRA132	49.6	2.07	12.8	14.7	0.23	5.32	10.1	2.44	0.26	0.27
KRA136	49.8	2.12	12.7	14.7	0.25	5.44	10.3	2.33	0.35	0.22
KRA137	50.0	2.16	13.1	14.3	0.27	5.38	10.3	2.30	0.32	0.21
KRA139	49.9	2.05	13.0	14.9	0.23	5.61	10.3	2.41	0.35	0.23
KRA143	50.9	2.20	12.6	15.5	0.23	4.97	9.74	2.38	0.37	0.23

Each analysis is an average of at least 10 spot analyses. Sample localities are shown in figure 2 except for KRA111 which comes from Bjarnarflag, KRA113 from Hrossadalur and KRA143 from the Viti scoria. Total Fe as FeOt

The analyses in table 1 are of the glass phase only and without assessing the effects of the mineral content can not be compared with whole rock analyses. All the samples could have identical whole rock composition and the fairly limited variation observed in the glass composition could all be due to crystallization of different amounts of minerals within each sample.

The whole rock composition and the amount of crystallization was therefore explored further. Whole rock analyses were made by melting four scoria samples just above the liquidus in a graphite capsule in an experimental furnace. This glass was analyzed on the microprobe to produce whole rock analyses corresponding to glass plus minerals in the scoria samples. These analyses are listed in table 2 with some older whole rock analyses produced by the same method (7). The whole rock analyses show variable chemical composition so that variable crystal content within the samples is not adequate explanation for the variable glass composition.

TABLE 2

Chemical analyses of "whole rock" from the Myvatn fires

	SiO_2	TiO_2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
KRA111	50.0	2.07	13.2	15.1	0.25	5.51	10.2	2.30	0.30	0.21
KRA118	50.5	1.97	13.5	14.6	0.22	6.01	10.5	2.17	0.30	0.24
KRA126	50.6	2.00	13.3	15.0	0.26	5.75	10.4	2.20	0.29	0.22
KRA139	50.6	2.05	13.3	14.7	0.25	5.71	10.3	2.20	0.29	0.22
KRA101	50.0	2.12	13.5	14.3	0.26	6.02	10.4	2.29	0.36	0.23
KRA102	49.5	2.08	13.2	14.3	0.25	5.71	10.2	2.33	0.28	0.23
KRA105	50.2	2.05	13.5	13.7	0.24	6.07	10.4	2.31	0.37	0.22
KRA106	49.9	2.03	13.5	13.5	0.23	5.65	10.1	2.28	0.37	0.24
KRA107	49.5	1.97	13.4	14.3	0.25	5.70	10.5	2.25	0.32	0.20
KRA109	49.7	2.04	13.1	14.5	0.24	5.63	10.2	2.34	0.34	0.22
KRA074	50.8	1.82	13.6	13.8	0.31	6.20	11.1	2.02	0.30	0.15

The first four analyses are samples from the present study, glass analyses of the same samples in Table 1. The other samples are also from the lava but analyzed previously (7). The analyses are by microprobe using fused samples.

The amount of crystals in these four samples was estimated by point counting and by least square calculations mixing glass and minerals to produce the whole rock composition. The results of these calculations, table 3, give similar results, about 10% crystallization for the most evolved glass, KRA111. The main difference between point counting and calculations is that plagioclase is slightly overestimated but augite underestimated in the point counting.

TABLE 3

Modal composition estimated by point counting and calculations using mineral, glass and whole rock analyses.

Point counting recalculated to weight per cent crystals.

	Glass	Plag	Olivine	Augite
KRA111	90.0	7.4	1.7	0.9
KRA113	91.0	6.4	2.3	0.3
KRA118	99.5	0.5		
KRA126	95.1	2.9	1.7	0.3
KRA139	94.3	4.8	0.9	

Calculated by combining glass and minerals to make up whole rock.

	Glass	Plag	Olivine	Augite
KRA111	89.4	6.2	1.5	2.8
KRA118	Not significant			
KRA126	Not significant			
KRA139	97.6	1.9	0.5	

Point counting for sample KRA139 indicates 5.7% crystals but calculations give 2.4 %. For samples KRA126 and KRA118 point counting gave 4.9% and 0.5% crystals respectively but mixing calculations indicate that within analytical accuracy the mineral content is not significant.

Another mixing test was to calculate a mixture of KRA111, the most evolved glass, and its minerals to produce the most primitive composition KRA118 which is almost aphyric. To achieve this KRA118 would have to crystallize 18% in the proportions plagioclase 9.4%, olivine 2.5% and augite 5.9%. So if there was one parental liquid similar to

KRA118 it should have lost 8-9% of its weight by fractionation before being erupted as KRA 111.

The results of these mixing calculations and point counting indicate that magma of slightly but significantly variable composition was available at the time of eruption. During the present episode monitoring shows that only one or two hours pass from the onset of deflation and the beginning of the eruption. This is unlikely to be long enough for significant crystallization and fractionation during ascent. The microphenocrysts now found are therefore likely to have been present in the magma just before the final ascent. Some of these magma batches may have crystallized up to 10% while stored either in main magma reservoirs or possibly for, KRA111 and KRA113, while temporarily emplaced within the fault swarm between rifting events.

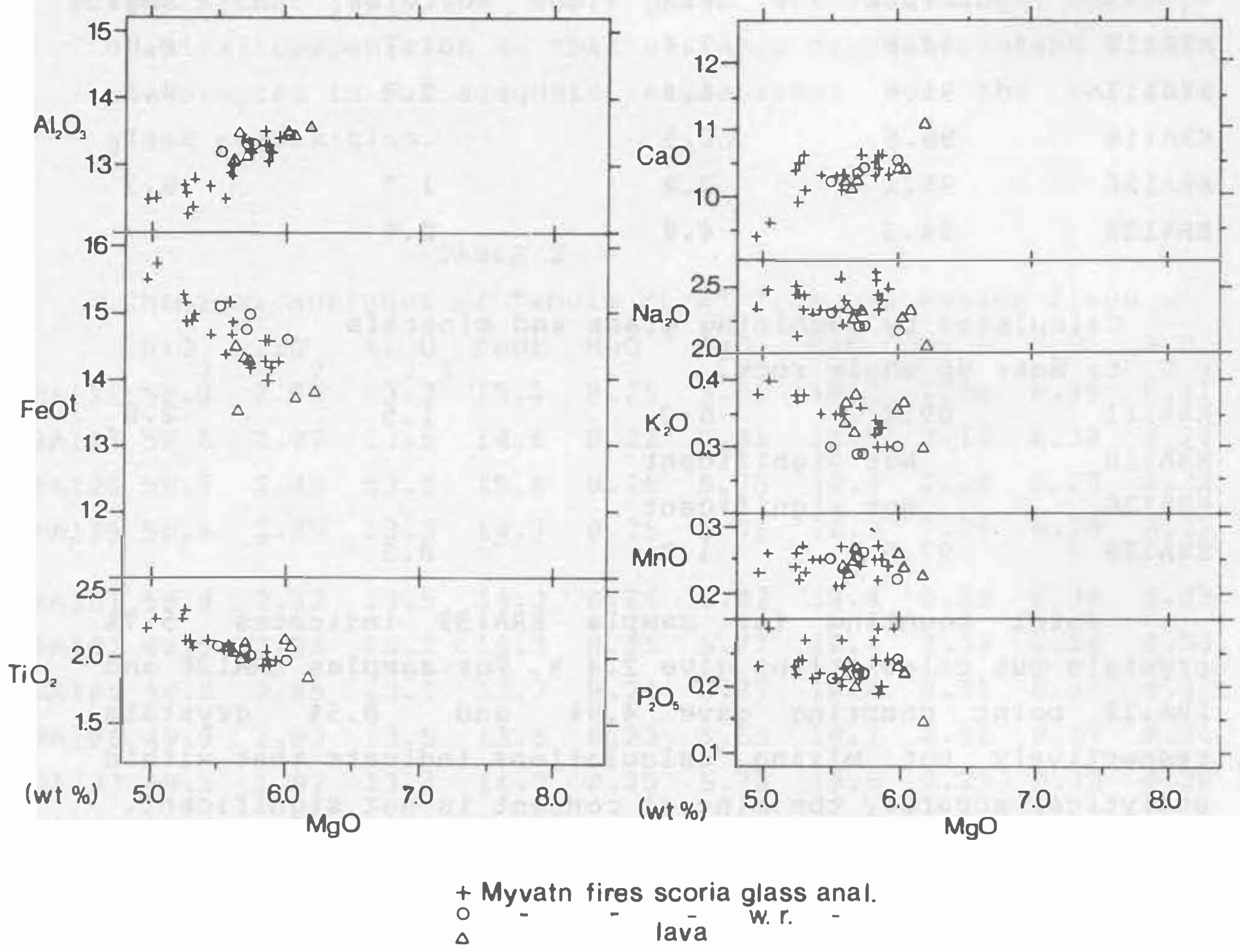

Figure 3. Variation diagram for glasses and whole rock analyses for samples from the Myvatn fires.

The variation in the chemical composition of the glass can not be systematically related to any time sequence. Two or three different time units can be distinguished in the craters, as shown in figure 2. Samples from the different units have been analyzed but no significant compositional evolution related to time is seen. Scoria from the initial Viti explosion, 1.5 km east of the main crater row KRA143, contains the most evolved basalt glass composition (MgO 4.9%). That explosion also erupted acid and intermediate glassy scoria.

Geographical distribution was also looked for but only the craters of Hrossadalur and Bjarnarflag forming the southern end of the fissure system are markedly different from the rest. These contain the most crystalline scoria and the most evolved glasses in the crater row, KRA111 and KRA113. The whole rock analysis of KRA111 is however not significantly more evolved than samples from other parts of the lava.

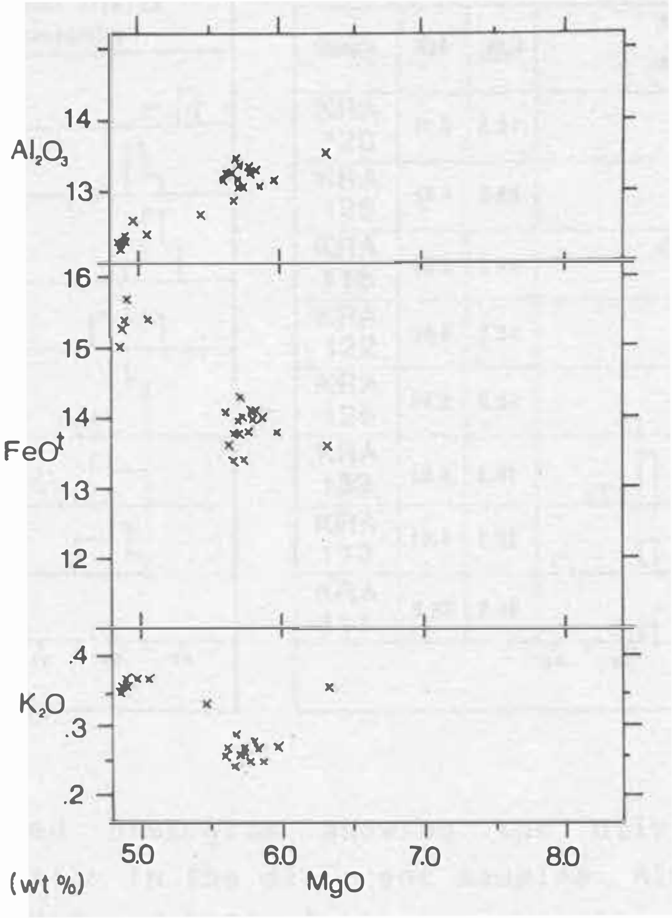

Figure 4. Variation diagram for glass compositions in sample KRA123.

Variation in glass composition was observed within two individual samples and one of them, KRA123, covers virtually the whole chemical range observed in the other samples, figure 4. This is a small sample and should represent a very short time within the eruption. This implies that variable liquid compositions were available at the same time and at the same place during the eruption.

The same type of chemical variation within single samples is also found in some samples from the present episode (7,8). Each composition in figure 4 is from a single spot analyses which results in poorer precision than for the other glass samples (figure 3) where each composition is represented by an average for at least 10 spot analyses.

COMPOSITION OF THE MINERALS.

The mineral assembly of the scoria samples is relatively simple with microphenocrysts of plagioclase, olivine and augite, always less than 0.2 mm along the longest axis. Plagioclase and olivine are found in all the samples but augite is only found in the more evolved glasses, with MgO lower than about 5.6%. A similar observation has been made for the present lavas (7) and preliminary melting experiments also indicate that augite crystallizes near the liquidus only in the more evolved samples. A few glomerophyric plagioclases are present but have higher An content than the microphenocrysts and do not therefore reflect the last equilibrium conditions of this magma.

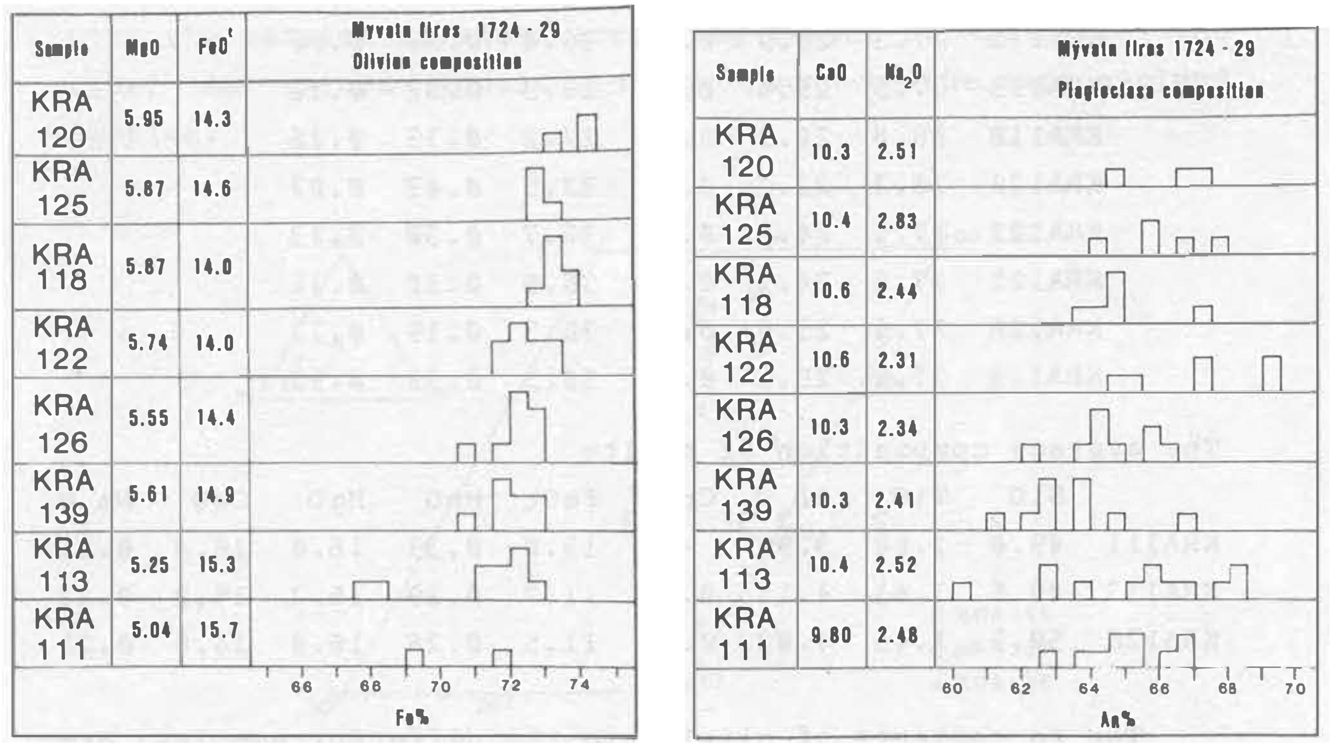

Figure 5. Combined histogram showing the olivine and plagioclase composition in the different samples. Also shown are the MgO, FeOt, CaO and Na2O of the accompanying glass.

The average composition of the minerals for each sample is listed in table 4 and the individual analyses are listed in appendix.

TABLE 4

Average composition of the minerals

The average composition of plagioclase

	SiO_2	Al_2O_3	FeOt	CaO	Na_2O	K_2O
KRA111	53.0	29.1	1.15	13.2	3.87	0.08
KRA113	52.0	29.9	1.12	13.4	3.81	0.07
KRA118	52.5	28.1	1.88	13.0	3.81	0.08
KRA120	52.2	29.5	1.12	13.3	3.67	0.08
KRA122	52.9	29.4	1.07	13.4	3.57	0.09
KRA125	51.8	29.4	1.17	13.2	3.69	0.09
KRA126	52.5	29.5	1.14	13.1	3.92	0.09
KRA139	52.7	29.2	1.16	13.0	4.08	0.08

The average composition of olivine

	SiO_2	FeOt	MnO	MgO	CaO	NiO
KRA111	37.3	26.9	0.50	36.4	0.31	0.00
KRA113	37.5	25.4	0.37	36.3	0.32	0.12
KRA118	38.0	24.3	0.37	37.2	0.39	0.16
KRA120	38.3	23.7	0.39	37.5	0.43	0.07
KRA122	37.1	24.8	0.36	36.7	0.30	0.13
KRA125	37.6	24.5	0.44	36.6	0.38	0.11
KRA126	37.4	25.0	0.35	36.3	0.19	0.11
KRA139	37.6	25.6	0.38	36.3	0.33	0.11

The average composition of augite

	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeOt	MnO	MgO	CaO	Na_2O
KRA111	49.0	1.08	3.99		15.0	0.39	16.8	16.4	0.31
KRA113	49.6	1.61	4.15	0.13	11.7	0.29	15.7	16.2	0.23
KRA126	50.5	1.45	4.02	0.24	11.5	0.28	16.9	14.8	0.21

The Fo contents of olivine in the different samples are plotted on a combined histogram in figure 5. This shows good correlation between the olivine composition and the MgO/FeOt ratio of the enclosing glass. This indicates that the olivines were in equilibrium with the liquid shortly before the eruption. The close similarities with the present rifting episode suggest that the last chance for equilibrium was in magma reservoirs at upper crustal levels of the order of three km depth or less. Under these conditions time was adequate for the liquid to crystallize olivine and the variable Fo content reflects magmas that already had variable chemical composition and degree of crystallization.

An contents of the plagioclase microphenocrysts are also plotted in figure 5. No correlation with the CaO and Na O content of the enclosing glass is found and there is a greater scatter of the An content within individual samples than for the olivines. A difficulty found for plagioclase but not olivine is that the Na content of the glass and plagioclase is relatively low and some Na loss may have occurred during the microprobe analysis.

The analyses in figure 5 are for microphenocrysts but the samples also contain macrophenocrysts significantly An richer than most of the microphenocrysts, up to An 78. Fragments of the macrophenocrysts are likely to be present with the microphenocrysts, possibly at different degrees of equilibrium, and extend the range to An richer compositions. With the samples arranged according to the Fe/MgO ratio the lower An values appear to be found in the more evolved samples.

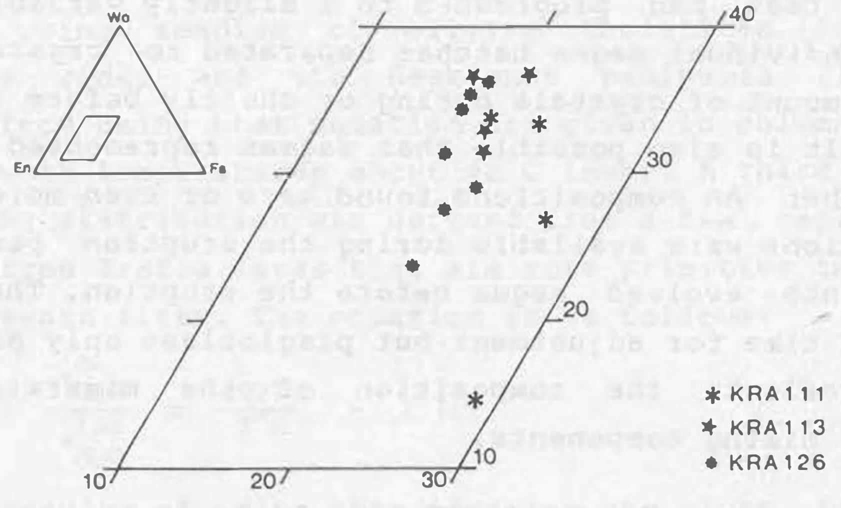

Figure 6. The composition of the augite crystalls plotted in the pyroxene triangle. Each sample is represented by slightly different stars.

The number of augite crystals suitable for analysis in each sample is very restricted and the trend is more likely to be due to cooling rather than fractionation (figure 6). As augite is apparently only present in the more evolved samples it indicates that the appearance of augite is not due to erratic xenocrysts but in some way controlled by the liquid composition.

The apparent correlation of the composition of olivine microphenocrysts with the glass composition suggests that at least the olivine-glass pairs represent equilibrium crystallization within each magma batch. The variation in the composition of the plagioclase microphenocrysts is much larger and not all compositions can be in equilibrium at the same time. Plagioclase was apparently crystallizing with the olivine. The macrophenocrysts are An richer so the smaller and An poorer plagioclases are most likely to have been crystallizing with the olivines. Crystallization proceeded at or near equilibrium conditions shortly before eruption long enough to leave its mark on the magma.

The spread of glass compositions within a narrow range indicates that they are closely related to one another. The ultimate cause of this variation could be a fractionation process that had progressed to a slightly variable degree before individual magma batches separated to crystallize a small amount of crystals during or shortly before the final ascent. It is also possible that magmas represented by the end member An compositions found here or even more extreme compositions were available during the eruption period and mixed into evolved magma before the eruption. The olivine then had time for adjustment but plagioclase only partly and still reflects the composition of the minerals of the original mixing components.

Temperature estimates

Geothermometers based on melting experiments can be used to estimate the magma temperature at the last site of equilibrium crystallization. For olivines the Roedder and Emslie (9) geothermometer can be used for both the distribution of Mg and Fe2+ between olivine and basaltic liquid. Only total Fe (i.e. Fe2+ + Fe3+) can be determined on the microprobe so that only the Mg distribution could be used for the temperature estimates in column one in table 5.

TABLE 5

Results of temperature calculations

	(1)	(2)	(3)	(4)	(5)	(6)
KRA111	1144	1100	1108	1147	1131	1124
KRA113	1151	1108	1119	1161	1139	1131
KRA118	1176	1137	1148	1166	1137	
KRA120	1176	1137	1148	1173	1146	
KRA122	1171	1131	1141	1171	1142	
KRA125	1174	1134	1145	1178	1154	
KRA126	1165	1126	1134	1149	1126	1140
KRA139	1167	1126	1137	1150	1125	

(1) Olivine temperature using equation from Roedder and Emslie (9)
(2) Olivine temperature using equation from Fisk et al (10)
(3) Olivine temperature using an unpublished equation, see text.
(4) Plagioclase temperature using equation from Mathez (11)
(5) Plagioclase temperature using unpublished equation, see text.
(6) Clinopyroxene temperature using method of Nielsen and Drake (13)

The experimental data used for this geothermometer is mainly from Hawaiian basalts. A different set of equations were derived using samples of olivine tholeiites from the Reykjanes ridge and the Reykjanes peninsula (10). The results from using that equation are given in column two in table 5 with temperatures about 40°C lower. A third equation for the Mg distribution was derived from a few experimental results from Krafla lavas that are more primitive than those of the Myvatn fires. The equation is as follows:

$$\log \frac{x^{ol}_{MgO}}{x^{liq}_{MgO}} = \frac{2927}{T^{\circ}K} - 1.349 \qquad x \text{ - mole fraction}$$

The results of using this equation are given in column three in table 5 and fall between the other two. This discrepancy in the derived temperatures suggests that the distribution coefficient depends to some extent on other components than those directly involved in the crystallization of olivine.

A geothermometer using the plagioclase - liquid pair was formulated by Kudo and Weill (11) and later modified for basaltic compositions by Mathez (12). Temperature estimates using this second method are listed in column four in table 5. The same unpublished experiments as were used for olivine produced a modified Kudo and Weill plagioclase equation (Makipaa, pers. comm.). The Mathez type refinement method gave no significant improvement to this equation.

$$\ln \lambda/\sigma + 8.06\mathrm{x}10^{3}\phi'/T = 9.95\mathrm{x}10^{-3}T - 15.03$$

$$\lambda = x_{Na}x_{Si}/x_{Ca}x_{Al}, \quad \sigma = X_{Ab}/X_{An}, \quad \phi' = x_{Ca} + x_{Al} - x_{Na} - x_{Si}$$

x - atomic fraction in the liquid

X - mole fraction in plagioclase

Results from using this equation are listed in column five in table 5.

A third geothermometer depends on the pyroxene-melt relationship (13). The experiments used to derive the equation are all done under reducing conditions (13) so that all the Fe is present as Fe2+. The Fe2+/Fe3+ ratio in the glass was assumed to be 0.17. The temperature estimates calculated this way are listed in column six in table 5. If all the Fe is assumed to be Fe2+ the temperature estimates are lower by about 7°C.

There are discrepancies between the results of the different geothermometers but keeping in mind possible errors involved and uncertainties the results look promising. It is not obvious which data set is most accurate but there is a consistent temperature difference of about 30°C between the most and least evolved samples.

DISCUSSION

In general the rocks and glasses of the Myvatn fires show a rather limited but significant range of chemical composition. No significant deviation for the whole rock is observed from that trend shown by the glasses. The whole rock compositions show a less evolved character than the glasses as expected. The significant variation in the glass phase of the crater scoria can, however, not be explained by in situ crystallization nor all the difference between glass and whole rock. Some sort of fractionation process or mixing must therefore have taken place prior to eruption. The olivine and possibly some of the plagioclase appears to have been in equilibrium with the liquid. Due to the likely rapid ascent of the magma and almost instant cooling at the surface this should represent or reflect conditions of the magma shortly before the eruption. The augite data are limited and show some scatter but since it is only found in more evolved samples it suggests some systematic controlling effects.

The total amount of crystals in the scoria samples is less than 10% and the crystal size small, similar to that observed in the present lavas. Comparision with the present rifting episode suggests similar conditions where the minerals were wholly or partly equilibrated.

The samples with highest crystal content come from the southern end of the fissure system. They may have resided there in a few meter thick dyke intruded in previous events and crystallized some time before the eruption.

Other attempts to correlate the composition of the samples with the time sequence of the samples or a geographical distribution have been unsuccessful. Virtually the whole range of compositions is actually found in one fistful of scoria from about the middle of the main crater group. This indicates that magmas with variable compositions were available simultaneously and mixed during the eruption. But since there is very little control on in which pulse the different lavas were erupted it is possible that the final pulse of the eruption accounts for most of the samples.

Lavas from 14 fissure eruptions in post glacial times are found in the Krafla central volcano. Detailed mapping shows that this activity can be divided into two phases the Ludent phase older than 7000 years and the Hverfjall phase younger than 2900 years(14). A limited number of whole rock analyses from these lavas are available and show very limited variation in chemical composition and their range is similar to that observed from the Myvatn fires(7). And no time related trend is observed. Only two samples are separated from the main group and both are markedly more plagioclase porphyritic than the rest. If it is assumed that the samples are representative for the fissure lavas and that the chemical variation in individual lavas is not markedly greater than that observed in the Myvatn fires then the lavas of the Krafla fissure swarm show a very restricted compositional range during these ten thousand years. This observation has to be carefully qualified as it refers to fissure eruptions connected to the Krafla volcano only. When sampling is extended to include shield lavas from the vicinity of the fissure swarm and even from within the fissure swarm much more primitive magmas are found and a much larger variation is observed.

The most recent fissure eruption episode is that presently in progress with the first rifting event and minor eruption beginning on December 20th 1975. During this episode 14 major rifting events have taken place in the Krafla fault swarm injecting large amount of magma into the rifting fault swarm. Between rifting events that take place at a few months interval magma collects in magma reservoirs at about 3 km depth below the Krafla volcano. Lavas have now been erupted from about 10 km long part of the fissure system and the crater row coincides almost exactly with that of the Myvatn fires, but extends further 7 km to the north (5). In 1980 and 1981 a large portion of the magma leaving the reservoirs has found its way to the surface in each event. A detailed study of the chemical composition of these lavas is in progress. The range of compositions erupted now is much greater than found for the previous fissure eruptions. There is no apparent variation in time of the chemical composition but there is a very clear geographical variation.

The lavas erupted on the northern part of the fissure have chemical composition much less evolved than that of the Myvatn fires and similar to that of the post-glacial lavas erupted from single craters or shields outside the fissure system itself.

The lavas erupted at the southern part of the fissure system where it coincides with the old fissure have a chemical composition very similar to that observed for the Myvatn fires and these lavas are erupted above the inflating and deflating magma reservoirs. The evolved magma type that has been available in the area for the last 10000 years at least and was erupted during the Myvatn fires is therefore still available or produced in the area. The Krafla volcano therefore has some controlling mechanism that buffers its basaltic lava composition within a restricted but slightly variable range while the lavas are erupted at time intervals of a few hundred to a few thousand years.

ACKNOWLEDGEMENT

The sampling of the crater scoria is based on the mapping by Kristjan Saemundsson who made a preprint on the Myvatn fires lava available. Niels Oskarsson, Peter Thy and Gudmundur E. Sigvaldason made many valuable comments on an earlier draft of this report. The new equations for olivine and plagioclase were derived from experiments by Heikki Makipaa done at the University in Reykjavik.

REFERENCES

(1) Saemundsson,K.
Myvatnseldar 1724 - 1729.
In preparation.

(2) Bjornsson,A., Saemundsson,K.,Einarsson,P.,Trygvason,E. and Gronvold,K. (1977)
Current rifting episode in North Iceland.
Nature 266,318-323.

(3) Bjornsson,A.,Johnsen,G.,Sigurdsson,S.,Thorbergsson,G. and Tryggvason,E. (1979).
Rifting of the plate boundary in North Iceland.
J.Geophys.Res. 84,3029-3038.

(4) Tryggvason,E. (1980).
Subsidence events in the Krafla area, North Iceland 1975-1980.
J.Geophys. 47,141-153.

(5) Gronvold,K. and Saemundsson,K.
Eruptions of Krafla volcano 1975-1981
In preparation

(6) Noll,H. (1967).
Maare und maar-ahnliche explosionskrater im Island.
Sonderveroff.D.Geol.Inst.D.Universitat Koln 11,3-117.

(7) Gronvold,K. and Makipaa,H. (1978).
Chemical coposition of Krafla lavas 1975 - 1977.
Nordic Volcanoligical Institute 78 16.

(8) Gronvold,K.
Chemical composition of Krafla lavas 1979 - 1981.
In preparation.

(9) Roeder,P.L. and Emslie,R.F. (1970).
Olivine - liquid equilibrium.
Contri. Minerl. Petrol. 29,275-289.

(10) Fisk,M.R.,Schilling,J.-G. and Sigurdsson,H. (1978).
Olivine geothermometry of Reykjanes ridge and Iceland tholeiites.
EOS (abstract), 59,410.

(11) Kudo,A.M. and Weill,D.F. (1970).
An igneous plagioclase thermometer.
Contrib. Mineral. Petrol. 25,52-65.

(12) Matherz,E.A. (1973).
Refinement of the Kudo and Weill plagioclase thermometer and its application to basaltic rocks.
Contrib. Mineral. Petrol. 41,61-72.

(13) Nielsen,R.L. and Drake,M.J. (1979).
Pyroxene - melt equilibria.
Geochim. Cosmochim.Acta 43,1259-1272.

(14) Thorarinsson,S. (1951).
Laxargljufur and Laxarhraun. A tephrochronological study.
Geogr. Ann. 1-2, 1-88.

APPENDIX 1

Plagioclase analyses.

	Si02	Al203	Fe0t	Ca0	Na20	K20	TOT	An%
KRA111	52.9	29.3	1.05	13.6	3.71	0.08	100.6	67.0
	52.1	28.8	1.13	12.9	3.82	0.06	98.8	65.1
	53.0	29.5	1.23	13.4	3.83	0.13	101.1	65.9
	52.9	29.1	1.17	13.1	4.02	0.08	100.4	64.3
	52.9	29.2	1.04	13.4	3.90	0.09	100.5	65.5
	52.4	29.1	1.07	12.9	3.83	0.09	99.4	65.1
	52.9	29.8	1.02	13.9	3.73	0.07	101.4	67.3
	54.3	28.2	1.67	12.7	4.11	0.09	101.1	63.1
	53.6	29.0	1.23	13.0	4.01	0.09	100.9	64.2
	52.5	29.4	0.91	13.5	3.70	0.09	100.1	66.9
KRA113	52.7	29.6	1.21	12.7	4.10	0.06	100.3	63.1
	52.1	29.5	1.54	12.6	4.09	0.09	99.8	63.0
	52.8	30.2	1.13	13.4	3.80	0.08	101.3	66.1
	51.6	29.3	1.10	13.3	3.79	0.06	99.1	66.0
	51.6	29.2	0.99	13.5	3.77	0.07	99.1	66.4
	51.8	30.0	1.25	13.7	3.75	0.07	100.5	66.9
	52.2	30.6	1.16	13.8	3.48	0.07	101.2	68.7
	50.9	30.7	0.89	14.1	3.52	0.08	100.2	68.9
	51.5	30.3	0.99	13.8	3.60	0.06	100.2	67.9
	52.5	29.3	1.05	13.1	4.11	0.07	100.1	63.8
	52.1	29.9	1.19	13.3	3.89	0.07	100.5	65.4
KRA118	52.2	28.9	2.24	12.7	3.85	0.08	99.9	64.6
	53.2	29.0	1.28	13.3	3.91	0.09	100.7	65.3
	52.7	28.7	1.37	13.0	4.01	0.09	99.9	64.2
	52.3	26.5	2.82	12.7	3.75	0.13	98.2	65.2
	52.1	27.2	1.68	13.4	3.54	0.08	98.1	67.7
KRA120	49.3	32.2	0.72	15.4	2.57	0.05	100.2	76.8
	47.7	31.8	0.87	15.7	2.35	0.04	98.5	78.7
	53.1	29.3	1.00	13.5	3.58	0.10	100.6	67.6
	52.1	29.5	1.24	13.3	3.58	0.05	99.7	67.3
	51.4	29.5	1.12	13.1	3.84	0.09	99.1	65.3
KRA122	50.0	29.4	1.06	13.2	3.50	0.11	97.2	67.6
	52.9	29.6	1.13	12.9	3.72	0.12	100.3	65.7
	53.7	28.7	1.11	13.7	3.67	0.09	101.0	67.4
	51.8	29.9	1.07	13.6	3.32	0.05	99.8	69.4
	52.0	30.5	1.01	13.9	3.39	0.09	100.9	69.4

plagioclase analyses continued

	SiO_2	Al_2O_3	FeO	CaO	Na_2O	K_2O	TOT	An%
KRA125	52.2	29.4	1.24	13.1	3.74	0.08	99.7	65.9
	51.2	29.5	1.06	12.9	3.85	0.11	98.6	64.9
	51.3	29.4	1.14	13.0	3.73	0.06	98.4	65.8
	52.4	28.8	1.34	13.5	3.65	0.10	99.7	67.2
	52.2	29.9	1.08	13.6	3.48	0.10	100.4	68.4
KRA126	51.6	29.5	0.87	13.4	3.75	0.09	99.3	66.4
	52.6	29.3	1.19	13.1	4.03	0.10	100.3	64.2
	52.2	29.4	1.08	13.0	3.94	0.09	99.7	64.6
	53.6	29.1	1.07	12.7	4.24	0.06	100.8	62.3
	53.3	30.0	1.12	13.5	3.98	0.06	101.9	65.2
	52.1	28.7	1.70	12.9	3.92	0.12	99.5	64.5
	50.8	29.9	1.33	13.3	3.77	0.08	99.1	66.1
	53.0	29.5	1.02	13.0	3.91	0.10	100.5	64.8
	53.1	30.0	0.92	13.4	3.78	0.10	101.2	66.2
KRA139	52.9	29.3	1.20	12.9	4.11	0.12	100.6	63.4
	52.4	29.3	1.23	13.0	4.15	0.09	100.1	63.4
	52.4	27.6	1.18	12.8	3.99	0.08	98.1	63.9
	52.7	29.3	1.04	12.9	4.22	0.11	100.3	62.8
	53.0	29.5	1.05	13.3	3.89	0.06	100.9	65.4
	52.0	30.0	1.17	13.8	3.79	0.05	100.8	66.8
	53.2	28.9	1.05	12.5	4.33	0.09	100.1	61.5
	52.6	29.1	1.17	12.9	4.02	0.08	99.9	63.9
	52.7	29.0	1.24	12.9	4.02	0.08	100.0	63.9
	53.0	29.5	1.27	12.9	4.19	0.06	100.9	63.0

APPENDIX 2

Olivine analyses

	SiO2	FeOt	MnO	MgO	CaO	NiO	TOT	Fo%
KRA111	37.7	25.9	0.49	37.0	0.28	0.00	101.4	71.8
	37.0	27.8	0.52	35.7	0.34	0.00	101.4	69.6
KRA113	38.5	24.9	0.42	36.2	0.29	0.08	100.4	72.1
	36.5	26.0	0.38	36.5	0.27	0.13	99.8	71.5
	36.4	26.4	0.33	36.4	0.30	0.13	99.9	71.1
	37.9	25.0	0.35	36.9	0.30	0.12	100.6	72.5
	37.8	28.7	0.34	33.6	0.39	0.12	101.0	67.6
	38.3	24.7	0.38	36.2	0.29	0.19	100.1	72.3
	37.5	25.4	0.38	36.3	0.36	0.12	100.0	71.9
	37.0	25.3	0.34	35.1	0.41	0.08	99.2	71.2
	37.3	28.4	0.37	33.9	0.36	0.09	100.4	68.0
	38.1	25.1	0.39	36.7	0.34	0.09	100.7	72.2
KRA118	38.2	23.9	0.41	37.5	0.41	0.17	100.6	73.6
	37.6	24.3	0.39	36.9	0.32	0.20	99.7	73.0
	38.0	24.3	0.36	37.1	0.49	0.09	100.2	73.2
	38.0	24.4	0.32	37.3	0.32	0.13	100.5	73.2
	38.0	24.2	0.40	37.5	0.40	0.16	100.7	73.5
	38.3	24.6	0.33	37.1	0.39	0.19	100.9	72.9
KRA120	38.7	23.9	0.47	38.2	0.46	0.00	101.8	74.0
	36.2	31.2	0.45	31.5	0.42	0.05	99.8	64.3
	36.7	30.4	0.45	31.8	0.41	0.13	99.9	65.1
	38.1	24.0	0.33	36.8	0.42	0.03	99.7	73.2
	38.1	23.3	0.36	37.5	0.40	0.19	99.9	74.1
KRA122	36.9	25.6	0.30	36.4	0.27	0.20	99.7	71.7
	37.6	24.6	0.36	37.7	0.35	0.05	100.6	73.2
	36.9	24.1	0.29	37.0	0.36	0.08	98.7	73.2
	36.4	25.0	0.24	36.2	0.28	0.22	98.4	72.0
	37.3	25.2	0.36	36.2	0.30	0.22	99.7	71.9
	36.9	25.1	0.43	37.0	0.27	0.23	99.9	72.4
	37.4	24.6	0.38	37.2	0.33	0.13	99.9	72.9
	36.8	24.7	0.43	36.4	0.30	0.06	98.8	72.4
	38.1	24.3	0.42	36.1	0.28	0.02	99.2	72.6

Olivine analyses continued.

	SiO2	FeOt	MnO	MgO	CaO	NiO	TOT	Fo%
KRA125	37.4	24.7	0.48	37.4	0.36	0.06	100.4	73.0
	37.7	24.6	0.29	36.7	0.37	0.01	99.7	72.7
	37.0	24.5	0.52	36.3	0.28	0.21	98.9	72.5
	38.2	24.2	0.48	36.2	0.52	0.15	99.7	72.7
KRA126	37.0	24.0	0.37	36.3	0.25	0.19	98.1	72.9
	37.4	24.4	0.39	36.4	0.20		98.8	72.7
	37.3	25.1	0.38	36.4	0.17		99.4	72.1
	37.7	24.7	0.30	36.9	0.17		99.8	72.7
	37.0	25.8	0.39	35.3	0.16		98.7	70.9
	37.2	25.0	0.36	36.3	0.16		99.0	72.1
	37.6	24.9	0.41	36.1	0.17		99.2	72.1
	37.7	25.3	0.28	36.5	0.20		100.0	72.0
	37.6	25.5	0.30	36.1	0.19		99.7	71.6
KRA139	38.1	25.2	0.36	36.4	0.35	0.19	100.6	72.0
	38.1	25.2	0.39	35.8	0.33	0.11	99.9	71.7
	37.9	26.1	0.34	35.4	0.28	0.11	100.1	70.8
	36.5	25.2	0.40	36.6	0.31	0.16	99.2	72.2
	37.1	25.7	0.43	36.3	0.38	0.05	100.0	71.5
	37.9	25.3	0.37	36.2	0.36	0.08	100.2	71.8
	37.3	24.8	0.43	36.7	0.28	0.04	99.6	72.5
	37.7	24.6	0.33	36.7	0.38	0.15	99.9	72.6

APPENDIX 3

Clinopyroxexe analyses

	SiO_2	TiO_2	Al_2O_3	Cr_2O_5	FeOt	MnO	MgO	CaO	Na_2O	TOT
KRA111	48.7	1.49	4.50		13.8	0.37	15.2	16.1	0.29	100.4
	50.5	0.65	2.84		18.4	0.47	20.3	7.4	0.10	100.7
	47.8	1.15	4.66		15.5	0.38	15.5	12.3	0.66	98.0
	49.2	1.01	3.95		12.2	0.35	16.3	16.7	0.21	99.9
KRA113	50.1	1.53	4.18	0.16	10.4	0.22	15.7	17.2	0.21	99.7
	49.3	1.61	4.15	0.24	12.2	0.30	16.3	14.8	0.19	99.2
	49.1	1.96	4.89	0.03	12.0	0.30	14.3	17.0	0.30	98.0
	49.5	1.35	3.40	0.07	12.2	0.35	16.3	15.7	0.20	99.1
KRA126	51.6	1.01	3.35	0.32	12.4	0.29	18.0	13.1	0.18	100.3
	50.4	1.57	4.79	0.16	12.3	0.32	16.3	13.3	0.29	99.6
	51.7	1.02	3.09	0.19	12.3	0.30	19.2	11.3	0.13	99.2
	50.3	1.66	3.62	0.49	11.1	0.31	17.2	15.1	0.17	100.1
	49.6	1.43	4.30	0.14	10.6	0.19	16.2	16.3	0.23	99.3
	49.6	1.92	4.60	0.23	10.9	0.27	15.4	17.2	0.22	100.4
	50.0	1.55	4.42	0.14	10.7	0.26	15.9	16.9	0.24	100.1