Tyrrell, G. W.: The principles of petrology. — Methuen, London 1926.
Umbgrove, J. H. F.: Verschillende typen van tertiaire geosynclinalen in den Indischen Archipel. — Leid. Geol. Meded., **6**, 1, 33—43, 1933.
Urey, H. C.: The planets (their origin and development). — Oxford Univ. Press, 1952, 245 pp.
—: Chemical evidence relative to the origin of the solar system. — Roy. Astron. Soc. Monthly Notices **131**, 3, 199—223, 1966.
Van Andel, Tjeerd H.: A structural model for part of the mid-atlantic rift-valley. — UMC symposium on the World Rift System, I. U. G. G., XIVth Gen. Assembly Switserland 1967. (Abstract.)
Weyl, R.: Tektonik, Magmatismus und Krustenbau in Mittelamerika und Westindien. — Geotekt. Forsch., **23**, 67—109, 1966 a.
—: Die paläogeographische Entwicklung des mittelamerikanischen Raumes. — — Z. der Deutsch. Geol. Ges., **116**, 3, 578—583, 1966 b.
—: Krustenbau und sialischer Magmatismus. — Geol. Rdsch., **56**, 369—372, 1967.
Winkler, T. C.: Op en in de Aarde. — Nijgh en van den Heuvel & van Santen, Rotterdam en Leiden, 561 pp., 34 plates, 2 maps and many engravings, 1868.
Woodring, W. P.: Caribbean land and sea through the ages. — Bull. Geol. Soc. Am., **65**, 719—732, 1954.
Zeil, W.: Die Verbreitung des jungen Vulkanismus in der Hochkordillere Nordchiles. — Geol. Rdsch., **53**, 731—757, Stuttgart 1963.
Zeil, W. & Pichler, H.: Die känozoische Rhyolith-Formation im mittleren Abschnitt der Anden. — Geol. Rdsch., **57**, 1, 48—81, Nov. 1967.
Zenkevich, L. A.: On the antiquity of the ocean and the significance of the history of the marine fauna in the solution of this question. — Okeanologiya, **6**, 2, 195—207, 1966.

On the rate of lava- and tephra production and the upward migration of magma in four Icelandic eruptions

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With 8 figures and 2 tables

Dedicated to Professor Dr. A. Rittmann on the occasion of his 75. birthday

Zusammenfassung

Die Rate der Lavaförderung bei drei isländischen Spalteneruptionen (Lakagígar 1783, Hekla 1947, Askja 1961) wird errechnet, und es wird versucht, einen Annäherungswert zu gewinnen über die Rate der Lavaförderung, bezogen auf Länge und Weite der Zuführungsspalten und die Rate der Aufwärtsbewegung des Magma durch die Spalten. Die Ergebnisse sind in Tafel 2 zusammengefaßt. Die darin angegebenen Zahlen für die maximale Aufwärtsbewegung sollten als Minimum aufgefaßt werden. Als Vergleich mit den hauptsächlich Lava führen-

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den Spalteneruptionen wird die Tephraproduktion der sauren und hochexplosiven Askja Eruption von 1875 behandelt. Bisher wurde angenommen, daß die enorme Menge Tephra — ungefähr 2 km³, die diese Eruption in 8¹/₂ Stunden hervorbrachte — ausschließlich aus dem Víti Krater kam; aber in Anbetracht seines geringen Durchmessers scheint es wahrscheinlich, daß die sehr feinkörnige Tephra, die während der ersten Stunden der Eruption entstand, teilweise von nahegelegenen Spalten ausgeworfen wurde, die jetzt vom Öskjuvatn-See bedeckt sind.

Abstract

The rate of the lava production of three Icelandic fissure eruptions (Lakagígar 1783, Hekla 1947, Askja 1961) is calculated and an attempt is made at a reasonable approximation of the rate of lava production per length and width of the feeding fissures and the rate of upward migration of the magma through the fissures. The results are summed up in Table 2. The figures for the maximum upward migration there presented should be regarded as minimum figures. As a comparison with the mainly lava producing fissure eruptions the tephra production of the acid and highly explosive Askja eruption of 1875 is discussed. It has hitherto been assumed that the enormous amount of tephra, about 2 km³, which was produced by this eruption in 8¹/₂ hours, came entirely from the Víti crater, but with regard to its small diameter it seems likely that the very fine grained tephra produced during the first hours of the eruption was partly expelled from nearby fissures now covered by Lake Öskjuvatn.

Résumé

La mesure de production de lave de trois éruptions fissurales de l'Islande (Lakagígar 1783, Hekla 1947, Askja 1961) est calculée et il est essayé de rapprocher la mesure de cette production à l'égard de longueur et largeur des fissures d'alimentation, et la mesure de la migration vers le haut du magma par les fissures. Les résultats sont présentés au tableau 2. Les chiffres de la migration maximum vers le haut doivent être entendus comme minimum. En comparaison avec l'éruption fissurale produisant principalement de la lave, la téphra production de l'acide et fort explosive éruption de l'Askja de 1875 est discutée. On a supposé jusqu'à présent que l'énorme masse de téphra, environ 2 km³, qui fut produite lors de cette éruption en 8¹/₂ heures, provenait seulement du cratère Víti; mais considérant son petit diamètre il est probable que la téphra de grain fin fut en partie lancée par des fissures voisines et qui à présent sont couvertes par le Lac Öskjuvatn.

Краткое содержание

Вычислена норма поднятия лавы трех вулканов (Lakagígar 1783; Hekla 1947; Askja 1961). Делается попытка приблизительно установить соотношение между количеством выброса продуктов извержения в зависимости от длины и ширины трещин и количеством мигрирующей массы магмы вверх по ним. Для сравнения обсуждается кислый взрывной выброс вулкана Askja в 1875 г, поднявший гл. образом продукты тефритов.

Many volcanic eruptions in Iceland and elsewhere have been rather thoroughly described as regards the course of events. Yet relatively few of these descriptions contain quantitative information enough to enable approximate calculation of the speed of the upward migration of the magma through the feeding fissures or conduits during the eruptions. For such a calculation we must know not only the production of lava, tephra and gases as a function of time. We must also know the length and width of the fissure if it is a linear eruption and the diameter of a circular conduit.

Iceland is the classical country of fissure eruptions, but only for three of these do we have sufficient information for an attempt at a reasonable approximation of the rate of lava production per given length and width of the feeding fissure.

The width of the feeding fissures

Let us first try to find out the probable width of the eruption fissures in Iceland. It may be regarded as pretty certain that most of the country's numerous plateau basalt layers were extruded from fissures and that a lot of the dykes so frequent in the plateau basalt areas are feeder dykes of lava flows. G. WALKER has measured the width of a great number of dykes in East Iceland. These measurements have shown that in the Reydarfjördur area, on a 53 km stretch from Gerpir to Grímsá there are about 1000 dykes at sea level with a total thickness of 3 km (WALKER 1959, BODVARSSON and WALKER 1964). 570 dykes measured more exactly had an average thickness of 11 feet, individual dykes ranging from a few inches to over 100 feet, but of these dykes only about 10% are wider than 6 m and nearly 40% are 2.5—4.5 m wide. In a 37 km strip of country in the Berufjördur area there are some 450 dykes with an aggregate thickness of 2.3 km (WALKER 1960), the average thickness thus 5.1 m and the average of about 1450 dykes is thus about 3.7 m. In two places WALKER found lava in visible continuity with its dyke-feeder. In one of the cases a 30 feet wide dyke in the other a 20 feet wide one were joined to their respective flows. But we may assume that these dykes narrowed downwards. The present writer has studied a feeder dyke of a postglacial fissure eruption in North Iceland which formed the 35 km long Sveinar crater row. This dyke is exposed in the eastern wall of the Jökulsá canyon which has been formed by erosion after the eruption occurred 7000 years or so ago. The dyke can be followed for nearly 100 m down from the pre-eruption surface (Fig. 1). At about 20 m depth below the surface the dyke is about 7 m wide, widening upwards towards the surface and narrowing a little downwards so that the width at the river level is little more than 4 m. The dyke is horizontally joined until it reaches the mouth of the vent where columnar basalt of rosette structure gradually emerges into vertically jointed lava. The lava is normal basalt lava.

From the above said we can conclude that the width of the feeder dykes of Icelandic basalt lava flows varies a great deal, but it seems reasonable to calculate with 4 m width of basalt lava producing fissures at 100 to 200 m depth below the surface. A. NOE-NYGAARD who has great experience of the basalts of the Faroes has informed me that most dykes there are 3—5 m wide. In the following I will calculate with 4 m width of the basalt feeder dykes at 200 m depth.

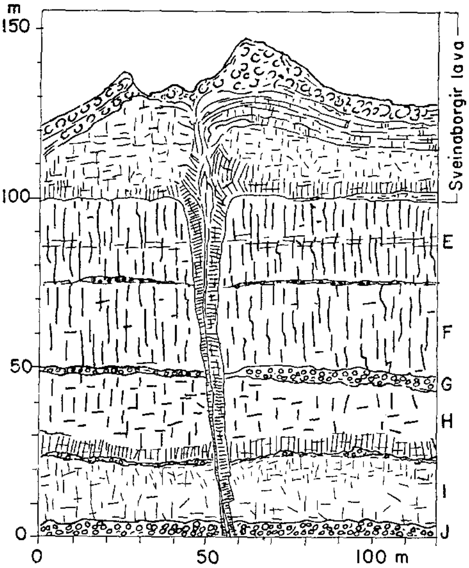

Fig. 1. Section through the Sveinar crater row in the E canyon wall of Jökulsá, North Iceland. Drawn from a photograph by S. THORARINSSON.

Lakagígar 1783

By far the largest lava eruption ever witnessed by man is the Lakagígar eruption of 1783. In the volcanological literature this eruption is usually referred to as the Laki eruption which is somewhat misleading as Laki, a "móberg" mountain situated near the middle of the nearly 25 km long crater row (cf. the map Fig. 2) was not cut through by the eruption fissure although it cuts into its flanks both from NE and SW (Fig. 4). A thorough and remarkably realistic description of this tremendous eruption was written by an eyewitness, the reverend JÓN STEINGRÍMSSON of Prestsbakki. This description has unfortunately not been translated in extenso, but a good extract of it is found in THORODDSEN's "Geschichte der isländischen Vulkane" together with a description of the Lakagígar crater row, which has also been described by PÁLSSON (1794), HELLAND (1886), ANDERSON (1903), RECK (1908) and SAPPER (1910), but never mapped in detail.

The eruption started on June 8, 1783. The initial phase produced a great amount of tephra, although far from as much as THORODDSEN estimated, and this tephra seems to be mainly the result of a tremendous lava fountaining and thus not the result of a real explosive activity.

Until July 29 the lava flowed down the canyon of the river Skaftá (cf. the map), but on that day a violent activity of the same type as on the first day began again and lava began to flow eastwards towards the Hverfisfljót river. From Jón STEINGRÍMSSON's description it can be con-

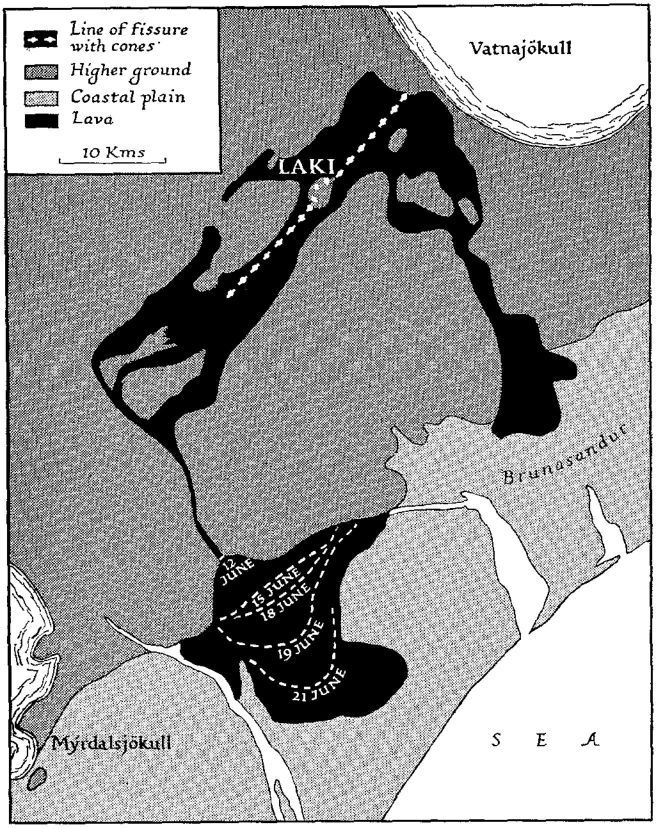

Fig. 2. Schematic map of the Lakagígar lava flows. (From GODFREY 1942.)

cluded as nearly certain that until July 29 only the part of the fissure which is SW of Mt. Laki opened up. After that only a small amount of lava seems to have been emitted by the fissure SW of Laki.

According to THORODDSEN's measurements verified by KJARTANSSON's geological map (KJARTANSSON 1962) the area of the lava that has flowed from the Lakagígar fissure SW of Laki is about 370 km^2 and its volume about 10 km^3. Assuming that about 9.5 km^3 of lava was produced during the period June 9—July 29, that is in 50 days, we have an average production of solidified lava of about 2200 m^3/sec, which means that the rate of flow where the lava left the vents was hardly less than 5000 m^3/sec. This is more than twice the average discharge of the river Rhine where it flows into the Netherlands. Assuming as nearly certain that all this lava flowed from the Lakagígar fissure SW of Laki, which has a length of about 10 km, and calculating with an average fissure width of 4 m at a depth of 200 m, where we can assume the vol. weight of the magma to be of the same order as that of the solidified lava (cf. MOORE 1965) the

Fig. 3. Lakagígar. View from Mount Laki over the south west part of the crater row. Photo S. THORARINSSON.

Fig. 4. The Lakagígar fissure cuts into the SW flank of the Laki mountain without cutting through it. Note the fault scarps in the mountain on both sides of the fissure. Photo S. THORARINSSON.

average upward migration of the magma through the fissure at that depth during these 50 days has been about 6 cm/sec. We know from the contemporary descriptions that the rate of flow varied a great deal during these 50 days and we may assume as likely that the maximum flow was at least 10 times the average flow for so long a period, which brings us to the figure of about 60 cm/sec for maximum upward migration. Further it should be kept in mind that hardly did the 10 km long fissure pour out lava in its entire length during the entire 50 days period, which means that 60 cm/sec is nearly certainly a minimum figure for the maximum upward migration. An analysis of the Lakagígar lava is shown in Table 1. Its viscosity near the vents can be estimated to have been between 10^3 and 10^4 poises.

Table 1

	1. Lakagígar 1783	2. Hekla 1947	3. Askja 1961	4. Askja 1875
SiO_2	49.55	55.41	50.31	70.50
TiO_2	2.84	1.60	2.98	0.75
Al_2O_3	13.79	15.84	13.10	12.70
Fe_2O_3	2.49	2.43	1.93	2.20
FeO	11.34	9.10	13.68	2.70
MnO	0.25	0.23	0.23	—
M_9O	5.84	2.82	4.88	1.02
CaO	10.63	6.93	8.87	3.02
Na_2O	2.79	3.84	2.86	3.56
K_2O	0.42	0.80	0.53	2.12
P_2O_5	0.30	0.40	0.27	—
H_2O^+	0.17	0.33	0.30	0.78
H_2O^-	0.11	0.03	0.04	0.11
CO_2	0.11	—	—	—
Total	100.63	99.76	99.98	99.46

1. Lava emitted from the SW part of the Lakagígar crater row. Sample collected on the lowland (HEIER et al. 1966).
2. Lava from the beginning of July 1947 (EINARSSON 1950).
3. Lava from the first day of the 1961 eruption (from THORARINSSON and SIGVALDASON 1962).
4. Pumice collected in Askja (HOPPE 1938).

Hekla 1947

The latest eruption of Hekla and its fourteenth one since Iceland became settled, began on the morning of March 29, 1947, at 06:41 ± 3 minutes IMT (THORARINSSON 1950, p. 20). The initial phase, lasting a little more than one hour, was entirely explosive (Plinian). During the first half an hour the production of tephra, vol. weight 0.60, averaged 75 000 m^3/sec, and calculated as solid lava it was 17 000 m^3/sec. During the second half an hour the corresponding figures were 22 000 m^3/sec, vol. weight 0.80 and 6000 m^3/sec (THORARINSSON 1954). Tephrochronological studies have revealed that the figures for the production rates of the initial phase of previous Hekla eruptions are similar. During the first hour or so of the

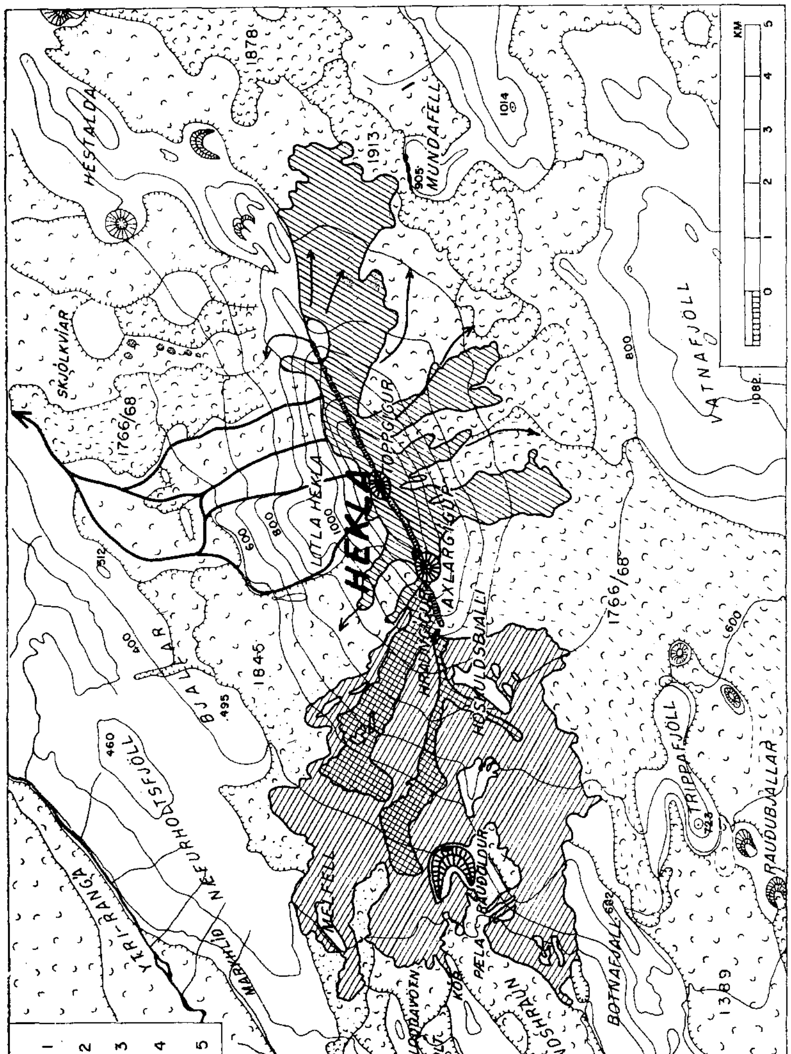

Fig. 5. The Hekla lavas of the 1947/48 eruption: 1: Lava flows March 29—April 6, 1947. 2: Lava flows April 6, 1947—April 21, 1948. 3: Older lava flows. 4: Craters. 5: Main courses of water floods. (From THORARINSSON 1956).

eruption that began on Febr. 13, 1693 the production of tephra averaged at least 60 000 m^3/sec (THORARINSSON 1967, p. 104).

The bulk of the tephra was whirled out from the crest craters of the volcano. The tephra producing initial phase was succeeded by a phase that after 8 o'clock was mainly lava producing. The fissure which splits the Hekla ridge lengthwise then opened up to a length of nearly 4.5 km and poured out lava in its entire length. Before midnight the lava had covered an area of some 18 km^2 and in accordance with T. EINARSSON (1949, p. 3) we can assume an average thickness of 5 m after reduction to compact lava. We then get a volume of 90 x 10^6 m^3 and lava production of about 1560 m^3/sec on the average. During this period the lava flow on the whole was rapidly decreasing, probably steadily and not in steps, and the max. production was probably about 4500 m^3/sec compact lava.

Calculating with a fissure width of 4 m viz. a vent area of 18 000 m^2 and assuming a steady flow from the entire 4.5 km length of the fissure we have an average upward migration of about 8 cm/sec during these 16 hours and a max. migration of about 25 cm/sec, both calculated for the depth of some few hundred meters where the density of the magma is similar to that of the lava.

An analysis of the Hekla lava is shown in Table 1. On March 31 EINARSSON estimated the viscosity of the lava in one of the craters to be somewhere between 10^6 and 10^7 poises (EINARSSON 1949 b, p. 4). Its SiO_2 content was then near 57%. In early November the SiO_2 content of the lava had dropped to about 55% and the viscosity was then measured 10^4 poises.

Askja 1961

The eruption which to the writers knowledge gives the most reliable information about the rate of upward migration is the fissure eruption in Askja, Central Iceland, which began on Oct. 26, 1961. A detailed description of this eruption is found in the monograph Askja on Fire (THORARINSSON 1962, cf. also THORARINSSON and SIGVALDASON 1961). The eruption started at about 14:30 IMT, but observations indicate that lava production on a big scale did not begin until about 15:00 IMT. Between 22:40 and 23:40 the writer was in an aeroplane over the volcano and from photos taken and sketches made it proved possible to map rather exactly the extent of the lava flow (Fig. 6). It was then 5.8 km^2 and its average thickness after cooling probably about 3 m. (In THORARINSSON's and SIGVALDASON's paper the thickness is estimated at 4 m which is probably too much). Thus the average production of lava between 15:00 and 23:00 was approximately 600 m^3/sec, and since the flow was obviously on the vane during the hour we watched it from the plane, the maximum flow can be assumed to have been considerably greater than the average flow during these $8^1/_2$ hours and the writer has estimated the max. rate of lava production to have been not less than 1000 m^3/sec of solid lava or about 2000 m^3/sec of flow from the vent. The lava fountains reached about 500 m height.

The fissure that opened up in the Askja caldera and poured out this lava was about 800 m in length, but it could be stated with certainty that practically all the lava had been emitted from the eastern half of the fissure, that is, from a fissure 400 m in length. Assuming a fissure width of 4 m at the depth where the vol. weight of the magma is similar to that of solidified lava flow, we get 35 cm/sec as an average speed of the upward flow and about 60 cm/sec for the maximum flow.

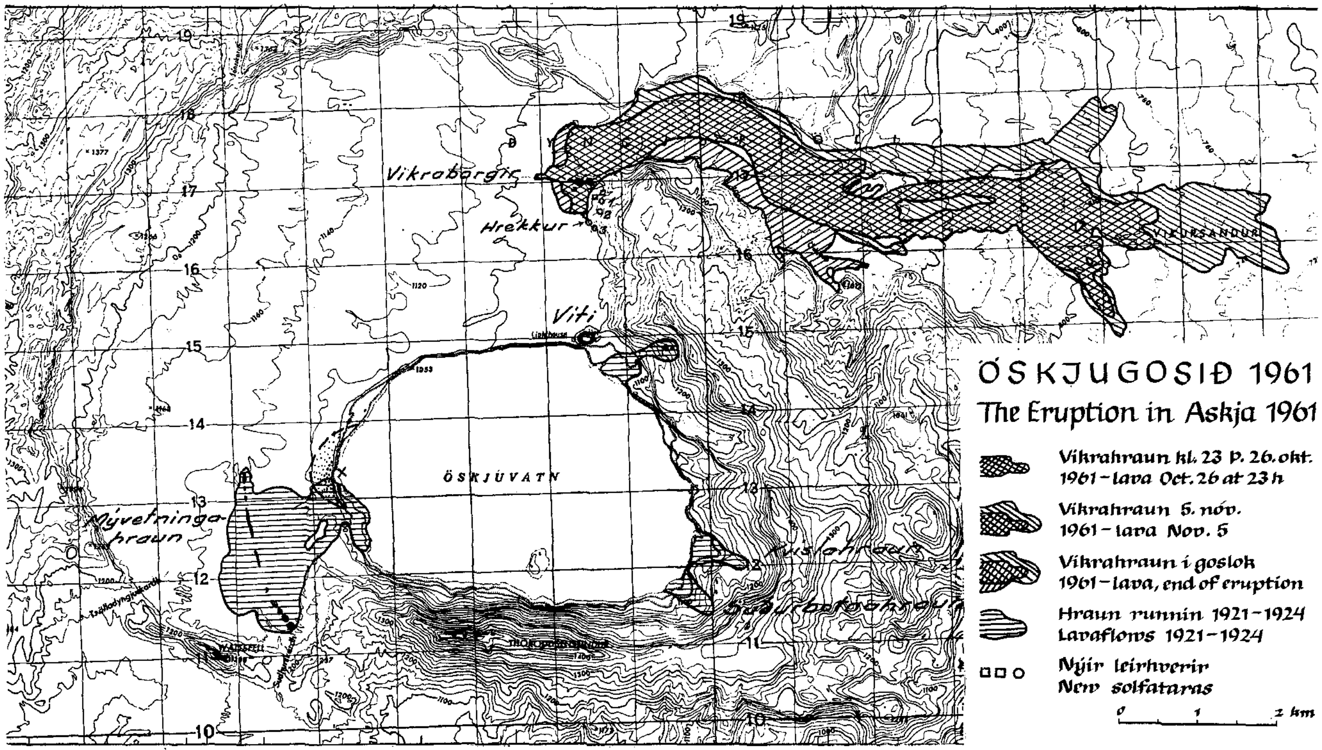

Fig. 6. Map of Askja showing the 1961 lava flow and the lava flows from the 1920ies. Lake Öskjuvatn occupies the caldera formed after the 1875 eruption. From THORARINSSON 1963.

An analysis of the lava is given in Table 1. The viscosity during the first day I would estimate at 10^4 poises.

The calculations, estimates and assumptions presented above are summarized in the following Table.

Table 2

	Lakagígar 1783	Hekla 1947	Askja 1961
Length of fissure, m	10 000	4 500	400
Assumed width of fissure, m	4	4	4
Time-span, hours	1 200	16	8½
Average prod. of lava, m^3/sec	2 200	1 560	600
Average prod. of lava per 100 m fissure, m^3/sec	22	35	150
Estim. max. prod. of lava, m^3/sec	22 000	4 500	1 000
Estim. max. prod. of lava per 100 m fissure, m^3/sec	220	115	250
Aver. upward migration of magma, cm/sec	6	8	35
Estim. max. upward migration of magma, cm/sec	60	25	60
SiO_2 content of lava	50	57	50
Estimated viscosity of lava near the craters, poises	10^3 to 10^4	10^6 to 10^7	10^4

As mentioned above the figures for the upward migration of magma are estimated for such a depth below the surface that the density of the magma is approximately the same as that of the solidified lava flow, which means a depth of a few hundred meters. It must be underlined again that the figures are only approximations and the longer the time-span and the longer the fissures, the more likely the figures are to be too low. However, they are based on sufficient factual information to be of some value.

Askja 1875

As a comparison I want to deal with one example of the uprush of magma through a circular vent. There is only one Icelandic eruption where we know the diameter of the vent sufficiently exactly for an attempt at an approximation of the speed of uprush. This is the Askja eruption March 28—29 1875. Contrary to the 1961 eruption this was a purely explosive eruption and the tephra was rhyolitic (cf. Table 1). From reliable contemporary records we can work out that the bulk of the tephra was produced in 8½ hours. Using isopach maps of the tephra fall in Iceland and Norway-Sweden I have calculated that the volume of tephra as freshly fallen was about 2 km^3, corresponding to nearly 0.5 km^3 of dense rhyolitic rock (THORARINSSON 1963). It has been regarded as nearly certain that all this tephra came from the circular crater Víti (Figs. 6—7). The diameter of this crater at 60 m depth is about 70 m, area thus about 4000 m^2, which may be regarded as an absolute maximum for the conduit farther down. Assuming, that all the tephra came through a vent of that width we have an average production of about 65 000 m^3/sec, or like that of Hekla 1947 during the first half an hour, and about 17 000 m^3/sec calculated as dense rock, which means that at the depth where the magma had about the same density as rock the speed of the upward movement was about 4.5 m/sec. The production at its maximum was certainly considerably higher than the average and these calculations have led the present writer to doubt seriously that all the tephra really came through the Víti crater. We cannot exclude the possibility that some material was whirled out from fissures that may have opened up in the Askja caldera floor short south of the Víti crater, but that part of the floor had already collapsed when Askja, in July 1875, was visited for the first time after the great paroxysm.

Fig. 7. The Víti crater formed March 28—29 1875, and to its left Lake Öskjuvatn in the collapse caldera formed after the eruption. Photo P. Jónsson.

The highest speed of uprush measured in the Surtsey eruption while it was phreatic is about 150 m/sec. Cautious estimates of the gas content of the Askja magma lead to figures for the uprush in the Víti crater that are two to three times higher and uprush of that velocity would in all probability have eroded and widened the Víti crater much more than to its present width. In this connection it is of interest to note that the tephra that fell in East Iceland during the first hour of the tephra fall was fine dust, but after that a coarse grained pumice began to fall. The bottom layer of the tephra from the tremendous rhyolitic eruption of Öraefajökull in 1362 is also very fine-grained (Thorarinsson 1958). This means that during the first hour or so of these eruptions the vesiculation of the magma was so rapid that the magma was expelled as spray.

In the Askja eruption at least some spray may have been expelled from fissures south of the Víti crater, but there is hardly a doubt that the pumice was expelled from Víti.

A remarkable consequence of the Askja eruption in 1875 was the formation of a collapse caldera within Askja. This caldera was formed after the paroxysm of March 28—29 by repeated engulfment and is situated entirely south of the Víti crater which did not collapse (cf. Fig. 7). The volume of this caldera has now been thoroughly measured by S. Rist (THORARINSSON 1963) and is 1.9 km³, or about the same as the volume of

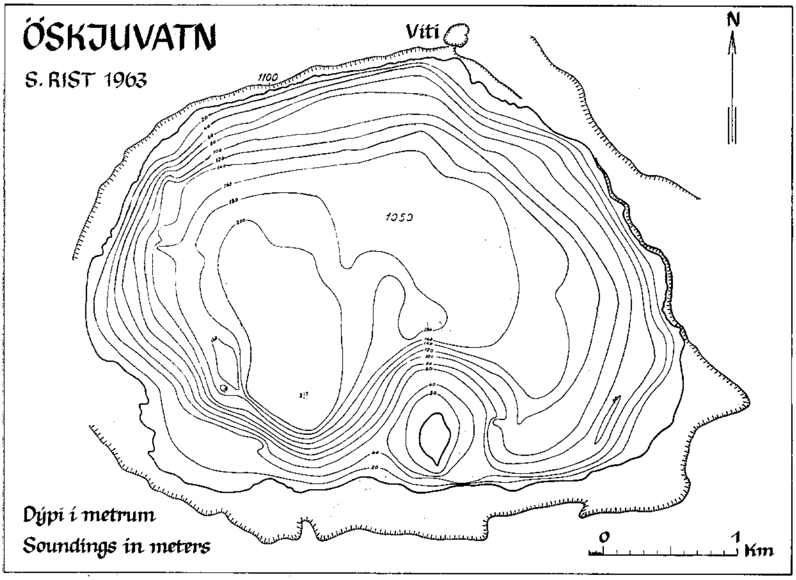

Fig. 8. Bathymetric map of Öskjuvatn based on echo soundings by S. RIST, July 1963. (From THORARINSSON 1963).

the expelled tephra as freshly fallen, but the tephra had a vol. weight not higher than 0.7. A priori one would think it likely that the volume of the collapse caldera should roughly correspond to the volume of the chamber emptied by the eruption. We are here led into speculations about the possible conditions in a magma chamber at a shallow depth, but these speculations are beyond the scope of this paper.

References

ANDERSON, T.: Volcanic studies in many lands. — London, pp. 122—134, pl. 63—69, 1903.

BODVARSSON, G., and WALKER, G. P. L.: Crustal drift in Iceland. — Geol. Journ. Royal Astr. Soc. **8**, 3, 285—300, 1964.

EINARSSON, T.: Rate of production of material during the eruption. — The eruption of Hekla 1947—1948, **IV**, 2, 1—18, 1949 a.

—: The flowing lava. Studies of its main physical and chemical properties. — The eruption of Hekla 1947—1948, **IV**, 3, 1—70, 1949 b.

GODFREY, J. H. ED.: Iceland, Geophysical Handbook Series B. R. 504, Cambridge 1942.

HEINER, K. S., et al.: The geochemistry of four Icelandic basalts. — Norsk Geol. Tidsskr., **46**, 427—437, 1966.

HELLAND, A.: Lakis Kratere og Lavaströme. — Kristiana 1886.

HOPPE, H. J.: Chemische und mikroskopische Untersuchungen an isländischen Gesteinen. — Chemie der Erde, **11**, 457—479, 1938.

KJARTANSSON, G.: Geological map of Iceland Sheet 6, South Iceland.

MOORE, J. G.: Petrology of Deep-sea Basalt near Hawai. — Am. Journ. Sci., **263**, 1, 40—52, 1965.

RECK, H.: Isländische Masseneruptionen. — E. Kohens Geol. u. Pal. Abh., Neue Folge, **IX**, 3, 60—93, 1910.

SAPPER, K.: Über einige isländische Vulkanspalten und Vulkanreihen. — Neues Jahrb. Min. Geol. Paleont. Berlin, **XXVI**, 5—24, 1908.

THORARINSSON, S.: The approach and beginning of the Hekla eruption. Eyewitness' accounts. The eruption of Hekla 1947—1948. — **II**, 1, 1—23, 1950.

—: The tephra fall from Hekla on March 29th 1947. — The Eruption of Hekla 1947—1948. **II**, 3, 1—78, 1954.

—: Hekla on fire. — Hanns Reich Verlag, München 1956.

—: The Öraefajökull eruption of 1362. — Acta Nat. Isl., **II**, 2, 1—100, 1958.

—: Eldur í Öskju. — Askja on fire. — Almenna bókafélagid, Reykjavík 1963.

—: The eruptions of Hekla in historical times. — The eruption of Hekla 1947—1948. **I**, 1—170, 1967.

THORARINSSON, S., and SIGVALDASON, G.: The eruption in Askja 1961. — Am. J. Sci., **260**, 641—651, 1962.

WALKER, G. P. L.: Geology of the Reydarfjördur area, Eastern Iceland. Quart. Journ. Geol. Soc. London, **114**, 367—393, 1959.

—: 1960: Zeolite zones and dyke distribution in relation to the structure of the basalts of Eastern Iceland. Geol. J., **68**, 5, 515—528, 1960.