Postglacial lava production in Iceland

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Abstract. All known postglacial lavas of Iceland ≥ 1 km³ are listed and labeled by age and volume. A plot showing the lava production per millennium reveals two pulses. The first and larger of these occurred 9,000-7,000 BP and the second extends over the last 2,000 years. When eruptions of lava shields and of crater rows are examined individually it becomes evident that they have different periods of activity. Most of the largest lava shields in Iceland were erupted in the first millennia after deglaciation. During the last 4,000 years, only three large lava shields have been erupted. The crater rows, on the other hand, do not show any clear relations to the deglaciation. Their lava production is marked by two pulses, the first 9,000-8,000 BP and the other during the last 1100 years. Between the production highs there is a prominent low, the mid-Holocene low, a 2,000-year period when no large fissure eruptions took place. The explosive plinian eruptions in the central volcanoes of Iceland exhibit a similar pattern to the crater rows, with greater activity in the early and late Holocene than in the mid Holocene but in the long run their frequency has increased with time. Glacier unloading and crustal rebound seem to stimulate eruptions of lava shields but their influences on crater rows and central volcanoes are small if any.

Keywords: Lava volume – Lava shields (shield volcanoes) – Crater rows – Plinian eruptions – Production rate – Iceland

Introduction

The aim of this paper is to evaluate the lava production of postglacial volcanism in Iceland and examine possible relationships between the production rate and deglaciation and ice unloading. Stratigraphic investigations in the Skagafjörður Valleys, outside the active volcanic zones of Iceland, revealed that compound lavas and lava shields are rare in the Neogene strata pile, but become abundant in the Pleistocene pile after the onset of glaciation (Article 4 in this thesis). This led to the following discussion on possible interaction between volcanism and the glacial isostasy together with rapid ice unloading.

Basaltic volcanism in Iceland is mainly confined to two types of volcanoes: crater rows and lava shields. Both types erupt only once and thus differ from central volcanoes with their repeated activity and varying magma production. The crater rows vary in length, from only a short fissure with a single crater up to 80 km, comprising hundreds of eruptive vents. The eruptions are accompanied by rifting episodes and can be hazardous, especially at the beginning. Sometimes they are associated with tephra falls, but they usually diminish with time and are rarely long-lasting (more than 1 year).

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Table 1. Iceland's largest postglacial lavas in volumetric order (≥ 1 km³)

Name	*Type*[1)]	*Age* [2)]	*Estim. age* [3)]	*Area km²*	*Volume km³*	*Ref.*
Þjórsárhraun THb	F	7800 ^{14}C	8600	967	25	1
Eldgjá	F	AD 934 H, I	1070	780	19.6	2, 16
Stóravítishraun	S	11080-11980 T	11300	460	18.4	7, 21
Skjaldbreiður	S	9600 S	9600	200	17	3, 4, 20
Trölladyngja	S	> 7000 S	7250	340	15	4
Laki	F	AD 1783 H	220	600	14.7	5
Kollóttadyngja	S	> 4500 S	8000	69.1	14.5	6
Skildingahraun	S	>11980 T	12200	250	10	7,25
Bárðardalshraun	F	> 10300 T	10300	450	8	7
Búrfellshraun Thi	F	3200 T	3200	440	6	9
Lambahraun	S	3700 ^{14}C	4100	160	6	7, 20
Heiðin há	S	7500 S	7500	150	6	8
Kerlingardyngja	S	> 4000 ?	6000		6	10
Kjalhraun	S	7800 T	7800	150	6	7, 20
Þráinsskjöldur	S	~12500 S	13000	130	5.2	11, 23
Hólmsárhraun	F	6800 ^{14}C	7600		5	2
Sandfellshæð	S	~12500 S	12500	120	4.8	11, 23
Þingvallahraun	S	9130 ^{14}C	10200	200	4	3
Ketildyngja – Laxárhr. E.	S	4300 T	4300	300	4	12, 19
Kinnarhraun	F	>10300	10800	250	4	7
Tungnárhraun TH-d	F	6000-7000 S	7000	270	3.8	13
Sigölduhraun TH-f	F	4000 S	3900	200	3.4	13
Hallmundarhraun	S	1100 T, ^{14}C	1100	225	3.4	7, 22
Hrútagjárdyngja	S	4000-5000 T	4500	80	3.2	11
Leitahraun	S	4560 ^{14}C	5200	100	3	11
Flatadyngja	S	3500-4500 T	4400	110.5	2.6	6
Laxárhraun yngra	F	2000 ^{14}C, T	2100	220	2.5	12, 19
Selvogsheiði	S	8200 S	8200	50	2.2	11
Frambruni	F	700 T	700	200	2	18
Gjástykkisbunga	S	11080-11980TS	11500	50	2	28
Búrfellshraun (Mývatn)	F	>2900T	3500	100	1.8	7, 25
Hekla 1766	F (C)	AD 1766 H	240	65	1.7	14
Litladyngja	S	2900-3500 T	3200	85.1	1.7	6
Rauðhólar – Sveinar	F	9500S	9500	150	1.5	24
Hágönguhraun	F	> 7000 S	8500	100	1.5	7
Veiðivötn	F	AD 1477 H	500		1.5	13
TH-c	F	6800 S	6800	120	1.4	13
Vatnaöldur	F	1100 T, I	1100		1.2	13
Hellisheiðarhraun A	F	9240 ^{14}C	10440	32	1.1	26,27
TH-e	F	6400 S	6400	260	1	13
Skuggadyngja	S	>4500 T	5900		1	25
Svartadyngja	S	> 4500 S	6800	38.7	1	6
Útbrunahraun	S	>10300	10500	85	1	7
Kröfluháls	F	>10000 S	10600	60	1	28
Surtsey	S	AD 1964 H	30		1	15

1) F = Fissure eruption, S = Lava shield, (C = Lava from a central volcano). 2) Measured age, ^{14}C = radiocarbon, T = tephrachronology, S = stratigraphy, I = ice core, H = historical, 3) Corrected and estimated ages are in calendar years before AD 2000. **References:** see next page.

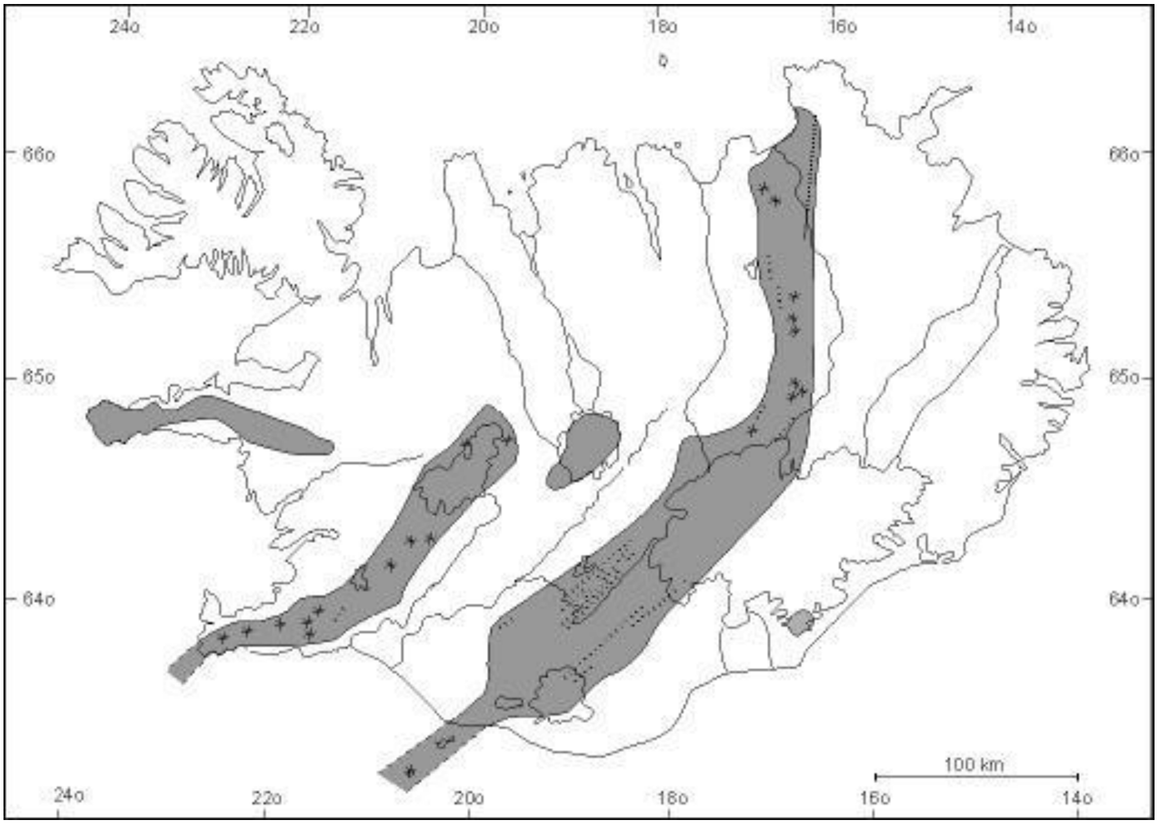

Fig. 1. Locations of the large lava eruptions (≥ 1 km³) in Iceland listed in Table 1. Lava shields are indicated by asterisks, crater rows by dotted lines. The grey areas are the active volcanic zones.

References for Table 1.

1 Hjartarson 1994, 2 Larsen 2000, 3 Sæmundsson 1992, 4 Kjartansson 1966, 5 Thordarson and Shelf 1993, 6 Sigvaldason et al. 1992, 7 Hjartarson unpubl., 8 Hjartarson 1999, 9 Vilmundardóttir et al. 1988, 10 Gudmundsson 2001, 11 Jónsson 1978, 12 Thorarinsson 1951, 13 Vilmundardóttir 1977, 14 Hjartarson 1995, 15 Thorarinsson 1968, 16 Thordarson et al. 2001, 17 Sigvaldason 2002, 18 Sigvaldason 1992, 19 Thorarinsson 1979, 20 Sinton and Grönvold 2001, 21 Sæmundsson 1973, 22 Jóhannesson 1989, 23 Sæmundsson 1995, 24 Sigurðsson 1975, 25 Sæmundsson pers. comm. 26 Jónsson 1989, 27 Kristjánsson et al. 2003, 28 Sæmundsson 1991.

Table 2. Holocene and late-glacial acid, plinian eruptions in Iceland

Eruption	Age	Age determination	Calendar age BP	Vol. (km³ magma)	Ref.
Askja 1875	125	Historical	125		1
Öræfajökull 1362	700	Historical	700	2	2
Hekla 1104	900	Historical	900		3
Snæfellsjökull	1750 +/- 150	^{14}C	1750		4, 7
Hekla H3	2820 +/- 70	^{14}C	2900	2.2	3
Hekla HSv	3600	Tephrachronology	3600		8
Snæfellsjökull	3960 +/- 100	^{14}C	4420		4, 7
Hekla H4	4030 +/- 120	^{14}C	4500	1.8	3
Hekla H5	6185 +/- 100	^{14}C	7000		3
Snæfellsjökull	8000	Tephrachronology	9000		4, 7
Askja (S)	11080 +/- 900	Tephrachronology	11080	1.5 +/- 0.5	6
Vedde (Z1)	11980 +/- 80	Ice core	11980	> 1	5

References: 1 Sigvaldason et al. 1992, 2 Thorarinsson 1958, 3 Larsen and Thorarinsson 1977, 4 Steinþórsson 1967, 5 Grönvold et al. 1995, 6 Sigvaldason 2002, 7 Flores et al. 1981, 8 Hjartarson 1995

The lavas consist of tholeiite (or transitional alkali basalt – alkali olivine basalt). The lava shields (shield volcanoes) are generally thought to be monogenetic (Walker 1971, Jakobsson et al. 1978, Rossi 1996) and most often emitted from a single circular crater. Rifting is rarely recognized. Their eruptions are thought to have been long-lasting but of low effusion rate. Practically no tephra is believed to have been produced. The lavas are of olivine tholeiite or picrite composition and occur mainly at the margins or outside the fissure swarms associated with the central volcanoes. It has been noted that many of the postglacial lava shields of Iceland are of early Holocene or late glacial age (Thorarinsson et al. 1959, Sigvaldason and Steinþórsson 1974, Jakobsson et al. 1978) and some relationship with glacial isostasy, together with rapid ice unloading, has been suggested (Gudmundsson 1986).

Earlier observations

Compound lavas from lava shields make up a considerable part of the total postglacial lava volume in Iceland. The ratio of the compound lavas to the total volcanic lava production has only been estimated for certain limited areas. Jakobsson et al. (1978) describe two volcanic systems on the western Reykjanes peninsula where they distinguish 56 lavas altogether: 42 fissure lavas and 14 lava shields. The volume of the fissure lavas is 3.2 km^3 and that of the lava shields 9.9 km^3. Consequently the crater rows are three times as numerous as the lava shields, and the lava shields are three times as voluminous as the crater rows. It is noteworthy that 67% of the total lava volume stems from two large eruptions, the Sandfellshæð and Þráinsskjöldur shield eruptions.

Gudmundsson (1986) examined 127 postglacial lavas on the Reykjanes Peninsula (including the area covered by Jakobsson et al. 1978). They belong to three volcanic systems and their total volume is 40-42 km^3. He found that the volume of the shields (29 km^3) is up to three times greater than that of the fissure lavas (11 km^3) and the largest shields are of an order of magnitude larger than the largest fissure lavas. Thus, although the fissures are far more numerous than shields, their total volume is much smaller. The proportion of the shields is ¾ or 75%. Additionally he reports that the production rate appears to have diminished during the later part of the postglacial period. This is due to the early formation of most of the lava shields and a low lava production in historical times, i.e. only 2.3 km^3 (in several eruptions between AD 940 and 1340). However the fissure lava/compound lava ratio differs greatly between areas. In the Eastern Volcanic Zone and the Snæfellsnes off-rift zone, compound lavas are virtually non-existent.

Sigvaldason et al. (1992) studied the postglacial lava production rate of the Dyngjufjöll area, Central Iceland. From their areal and volumetric measurements, the ratio of the compound lavas seems to be close to 50%.

They also found a very high production rate for the Dyngjufjöll volcanic system, compared to the present productivity, in the first millennia following the last deglaciation. Magma production in the period 10,000-4,500 years BP was 20-30 times higher than in the period since 2900 years BP. This high production rate coincides with the deglaciation of the area and they assume that rapid isostatic rebound and vigorous crustal movements, together with decreasing lithostatic pressure, might have triggered intensive volcanism (See also Sigvaldason 2002).

Vilmundardóttir and Larsen (1986) found a similar pattern in the volcanic development of the Veiðivötn system where half of the lava volume erupted during postglacial time was produced in the period 10,000-8,000 years BP.

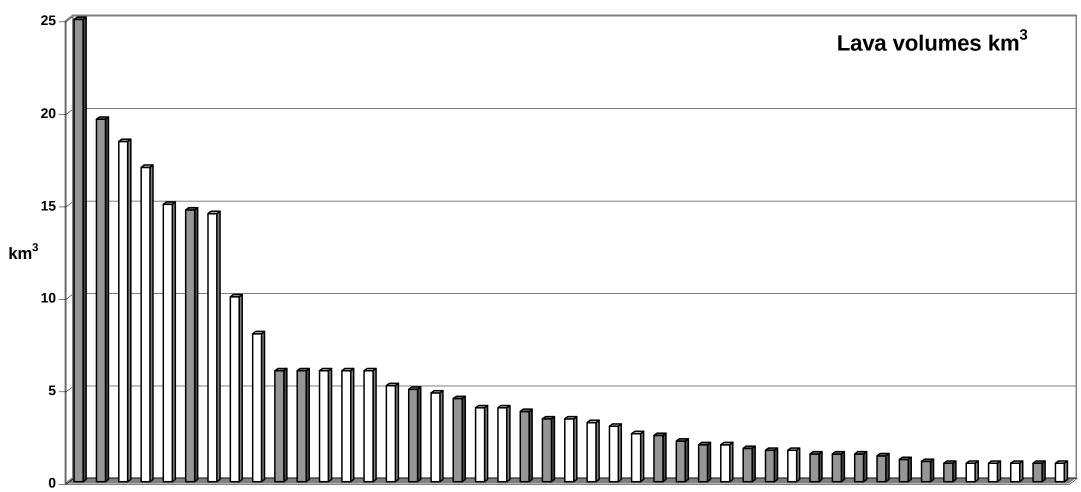

Fig 2. Volume distribution of 44 large Icelandic postglacial lavas (< 15,000 years) according to Table 1. The volume distribution between lavas from crater rows and lava shields seems to be even. Grey = fissure lavas from crater rows, white = compound lavas from lava shields.

The large Lavas

The studies mentioned above each cover one to three volcanic systems. If postglacial volcanism in Iceland is viewed as a whole, the picture is likely to become more general. The main problem is, however, that information about ages and lava volumes is in most cases uncertain and the uncertainty increases with increasing age. Large lavas have received more attention than small or intermediate ones and it is also, in general, easier to define their size, volume and age. The present investigation will focus on large lavas. Although such a focus inevitably leaves out some significant lavas which might affect the general trend, it is considered to give optimum results, and nonetheless a considerable fraction of total postglacial lava production is accounted for. Jakobsson (1972, 1979b) has estimated the total volume of postglacial extruded rocks in Iceland (lavas + tephra). His most recent estimate is 423 km^3.

Lava sizes are defined as follows:

Small lava	$< 0.1\ km^3$
Intermediate lava	$\geq 0.1 - < 1\ km^3$
Large lava	$\geq 1\ km^3$

Table 1 is the basis for the following discussion, and was prepared especially for this purpose. Information on lava ages and volumes is scarce and patchy in the geological literature, exceptions being the papers of Jónsson (1978) and Jakobsson et al. (1978) on the Reykjanes Peninsula. Information on the age and volume of a certain lava often comes from two different sources. The methods used for estimating lava sizes are as different and numerous as the authors. The same can be said about their age: the resolution is sometimes inconsistent, but Icelandic tephrachronology provides a valuable method of dating and makes possible reliable age estimates. Here, for the first time, a record of the volumes of the largest Icelandic lavas appears. Future observations will very likely revise the order and the ages slightly but the main trends are expected to hold.

Forty-five large postglacial lavas are listed in Table 1, totalling 247 km^3 of rocks, or 58% of the estimated total volume of eruptives. They are distributed fairly evenly over the volcanic belts of Iceland, with the exception of the Snæfellsnes off-rift zone where no large lavas are found (Fig. 1). Twenty-one of them are from fissure eruptions (108 km^3) and twenty-four from lava shields (139 km^3). Here the ratio of the shields makes up 139 km^3/247km^3 = 0.56 or 56% of the total volcanic production. The largest shields are similar in size (or a little smaller) to the largest fissure lavas (Fig. 2). This outcome is similar to that for the Dyngjufjöll region (Sigvaldason et al. 1992) but is considerably different from the pattern on the Reykjanes Peninsula (Jakobsson et al. 1978, Gudmundsson 1986).

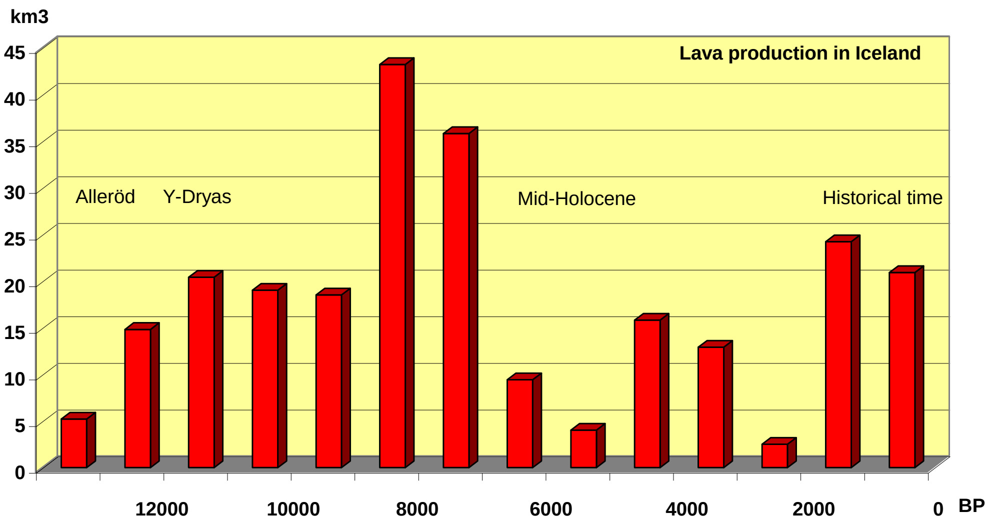

Fig. 3. Production of large lavas in Iceland per millennium. Two (or three) pulses appear, the first one in the early Holocene and the second in historical time with the great eruptions of Eldgjá and Laki.

Fig. 3 illustrates the production of large lavas per millennium. Some pulses appear, the largest one in the early Holocene and the second largest covering the last 2,000 years. However, the pulses constitute very few, though large, lavas and statistically they are not very convincing.

Although resolution of the age data in Table 1 is rather poor, the division between early and late Holocene is thought to be reasonably good. Early Holocene production (≥ 6000 years BP) is 164 km^3 and late Holocene (and late glacial) production is 80 km^3, i.e. the ratio is roughly 2:1. This ratio does not agree with the immense eruptive pulse estimated by Jull and McKenzie (1996). They suggested a 30-fold increase in magma production in the first millennium after the deglaciation, as will be discussed later.

Production of the Shields

Fig. 4 shows individual large postglacial eruptions, with sizes plotted against age. Here the two main pulses are prominent and the high productivity in early Holocene and historical time is evident, as is a distinct Mid-Holocene minimum. The obvious difference between shields and fissure rows is seen more clearly in Figs. 5 and 6. The lava production of the lava shields started as soon as the glaciers retreated inland from the shore line and culminated already in late glacial times. In the Mid-Holocene the production of the lava shields decreased. During the last 4,000 years only three of them have erupted, which might be similar to the Neogene frequency of such volcanism, and no small shields have erupted. Therefore it is a fair statement that the period of the shields lasted from 13,000 to 4,000 BP, i.e. for 9,000 years.

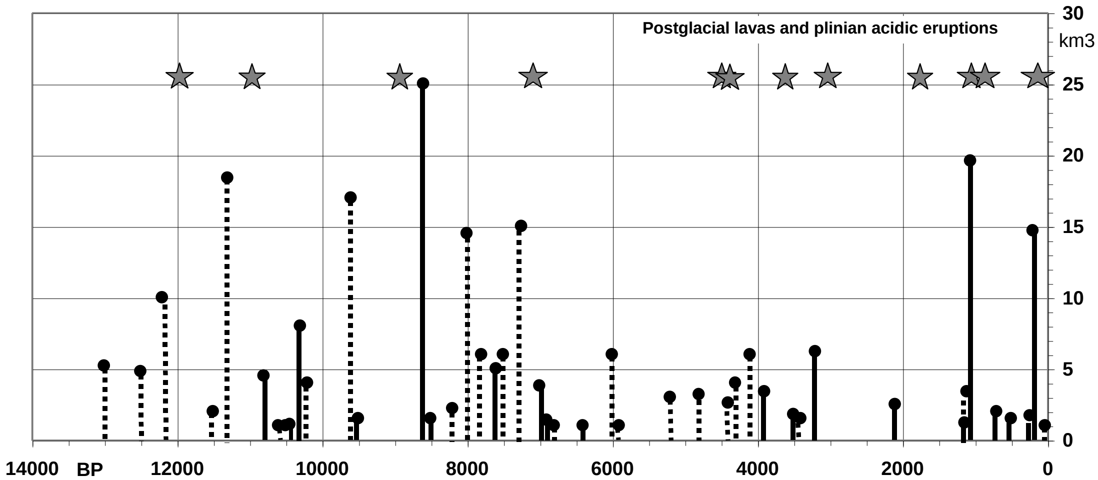

Fig. 4. Large lava eruptions in Iceland in postglacial time. Acidic plinian eruptions are also shown. Dashed lines = lava shields, solid lines = crater rows, stars = acidic plinian eruptions. Lava production is highest in the early Holocene but declines in the mid-Holocene, with a prominent peak in historical times. The frequency of acidic plinian eruptions seems to be increasing towards present times.

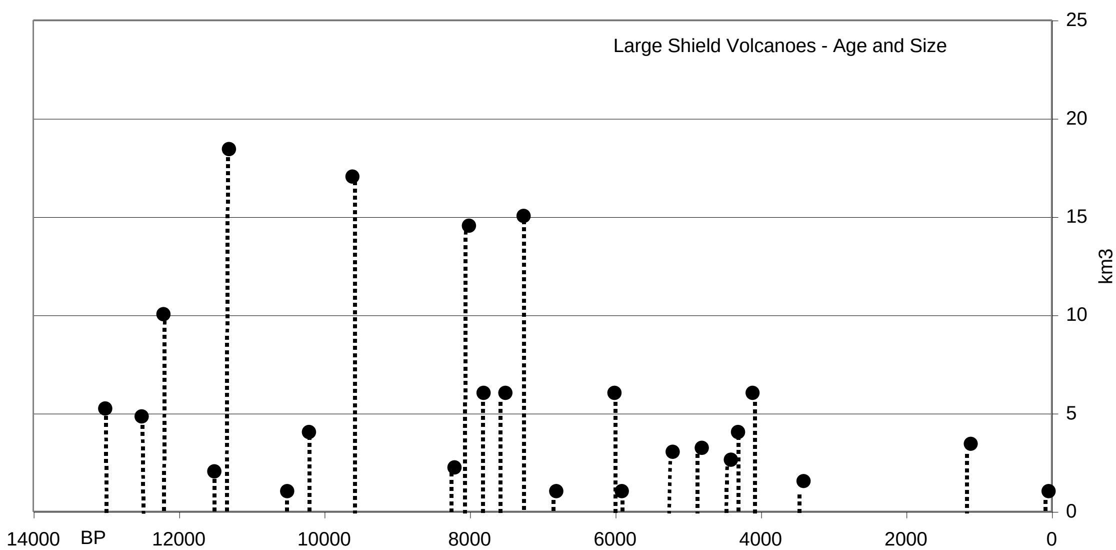

Fig. 5. Size and timing of large postglacial shields. Their productivity of compound lavas culminates in late glacial times with a constant decline during the Holocene.

A relationship between lava shields, glacial retreat and unloading might be proposed on the basis of this evidence. However, the occurrence of shield volcanism during and after deglaciation might also be fortuitous. Lava shields and compound lavas are rare in the Neogene lava pile of Skagafjörður but become abundant in the Pleistocene pile (Article 1 in this thesis; see also the Appendix 5.2.3.). This difference has also been recorded in the Plio-Pleistocene strata pile of Fnjóskadalur, North Iceland (Jancin et al. 1985).An increasing abundance of shields during late Pleistocene is also evident in the Reykjavík region (Torfason et al. 1997, 1999, 2000). An increasing number of lava shields in the volcanic pile of these regions, after the onset of glaciations, supports the idea about relationship between shields and deglaciations.

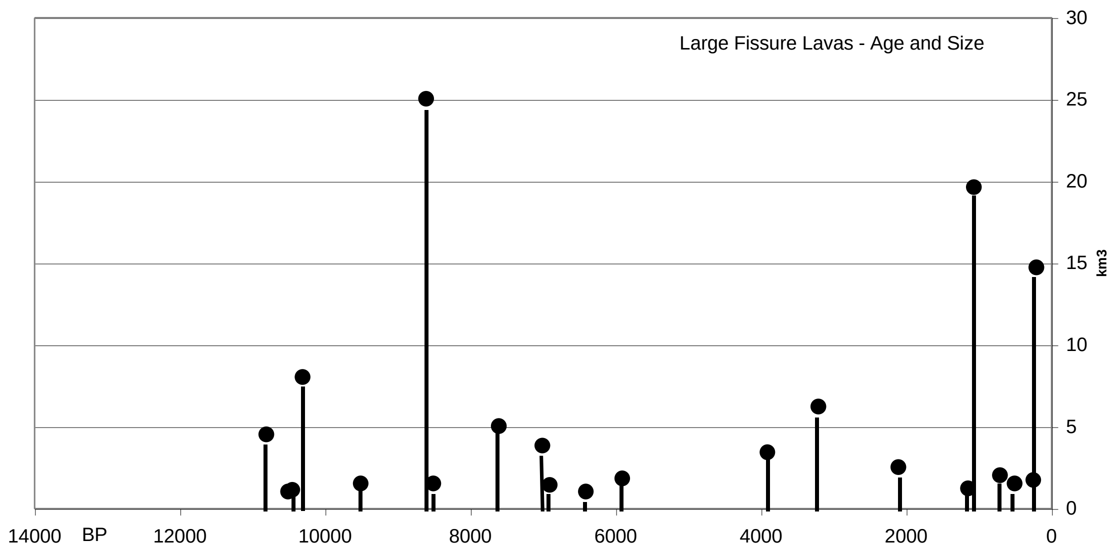

Fig. 6. Size and timing of large postglacial fissure lavas. Their productivity culminates in the early Holocene and in historical time with a distinct decline in the mid-Holocene.

Production of Crater Rows

The eruptions from crater rows show a different pattern from that of the lava shields (Fig. 6). No large lavas of late glacial age are known. Productivity culminates in the early Holocene, three thousand years later than the main pulse of the compound lavas, then a distinctive decline takes place between 6,000 and 4,000 years BP, after which a prominent peak appears during historical times (< 1,100 years BP). No effects of ice melt and glacial isostasy appear.

The best-known acidic plinian eruptions of the Holocene and late glacial times in Icelandic central volcanoes are shown in Table 2 and Fig. 3. These seem to exhibit a similar pattern to that of the fissure eruptions and do not seem to be influenced by the deglaciation. The longest interval between such eruptions coincides with the mid-Holocene decline. The last 2,000 years seem to have been exceptionally active as regards both large fissures and central volcanoes.

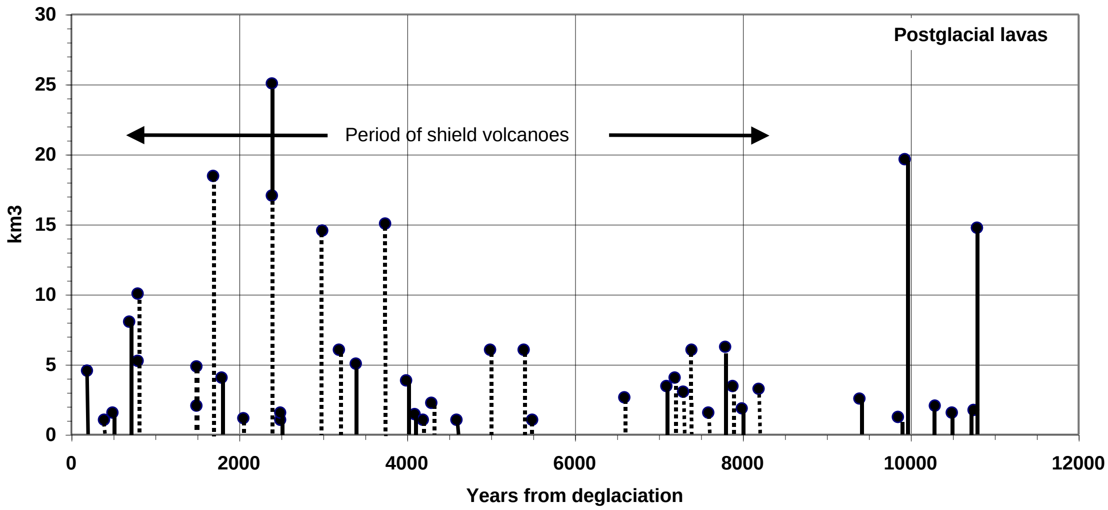

Fig. 7. Time of eruptions plotted against the time since the deglaciation of each area. The shield eruptions group within 8,000 years of the deglaciation. (The Surtsey eruption is omitted from the figure).

Discussion

In his study of the petrology of recent basalts in the Eastern Volcanic Zone, Jakobsson (1979a) plotted the frequency of basaltic eruptions during postglacial time. His diagram shows two periods of high frequency of eruptions, i.e. 0-2,000 BP and 5,000-8,000 BP. Jakobsson also noted that the eruption frequency of each volcanic system inside the Eastern Volcanic Zone conforms to this same pattern, and moreover, where accurate age determinations are available from volcanic systems outside the zone, they fall within either of the two periods. Jakobsson's observations indicate that the activity in the volcanic systems harmonizes with the fluctuations in the frequency and volumes of the large lavas discussed here in the present paper. These two independent observations support each other.

The conclusion of the present discussion is that the high lava production following the last deglaciation is essentially due to eruptions of lava shields. The interrelation between the shields and deglaciation becomes still clearer if allowances are made for the time difference between local deglaciations in different parts of the country. Four to five thousand years may have passed between the ice retreat from the outer Reykjanes Peninsula and the final retreat from the Central Highlands near Vatnajökull (Ingólfsson 1998). If a correction is made for this and the timing of an eruption of a lava shield is calculated as the time from the deglaciation of the area, the shield eruptions group within 8,000 years of the local deglaciation (Fig. 7). The overall lava production shows, in the same manner, a distinct pulse culminating c. 2,000 years after the ice retreat.

Glacier unloading and crustal rebound stimulate eruptions of lava shields but seem to have little effect on the crater rows and central volcanoes.

This outcome is supported by Gudmundsson's (1986) mechanical eruption model and investigation on the Reykjanes Peninsula. The late glacial-early Holocene eruption pulse of the lava shields is striking and if the production rate of the crater rows is examined it seems to be around 1 km^3/kyr on average during the postglacial period but over 2 km^3/kyr during the last millennium. No early Holocene pulse appears for the crater rows on the Reykjanes Peninsula.

On the other hand this contradicts the development in the Veiðivötn system (Vilmundardóttir and Larsen 1986), and the Dyngjufjöll system (Sigvaldason et al. 1992, Sigvaldason 2002) and partly contradicts the results of the calculations of Jull and McKenzie (1996) regarding the effect of deglaciation on mantle melting.

The Veiðivötn volcanic system is the most productive one in Iceland. Its production pattern is governed by the overwhelming size of the Great Þjórsá lava (25 km^3) and the timing of maximal production depends entirely on this single event. No lava shields have been recognized near Veiðivötn. Ignoring the Þjórsá lava, the production rate in the Veiðivötn system seems to be rather even during the Holocene.

The production pattern of the Dyngjufjöll system displays a clear maximum in the period 10,000-4,500 years BP, both with respect to shields and fissure lavas and also the production of acidic eruptives (Sigvaldason et al. 1992, Sigvaldason 2002). The age resolution of the lavas before 4,500 BP is very poor but even so it can be stated that the lava shields follow the general trend of maximum emission in early postglacial times. On the other hand, Sigvaldason's (2002) statements on the relationship between the great plinian eruption in Dyngjufjöll and glacial rebound in the area are not convincing. The distribution of plinian eruptions in time (Table 2, Fig. 4) does not support such a relationship in general. The timing of the great Askja eruption at the Pleistocene/Holocene boundary seems incidental. In the same manner it can be stated that the early Holocene production pulse of the fissure lavas in the Askja volcanic system was not caused by glacial rebound but rather by the activity of the central volcano combined with its colossal caldera collapse.

Jull and McKenzie (1996) calculated the effect of deglaciation on mantle melting beneath Iceland. They found that the average melting rate and magma production increased by about 30 times its steady-state value when a 2,000 m thick glacier disappeared in 1,000 years. They also state that this can only happen because melt generation is reduced for about 60,000 years after the ice load is applied. The observations and arguments presented above do not support the existence of such a high-intensity eruptive pulse. Part of the explanation is the short deglaciation period in the model of Jull and McKenzie. Instead of a 1,000-year period of glacier retreat, 5,000 years would have been more appropriate, which would then give a much smaller increase in the eruptive pulse.

Conclusions

Forty-five large postglacial lavas ($\geq$ 1 km^3) are listed in volumetric order in Table 1 together with the best available information on their age. These lavas make up 247 km^3 of rocks, or 58% of the estimated total postglacial volume of eruptives in Iceland. Twenty-one of them are from fissure eruptions (108 km^3) and twenty-four from lava shields (139 km^3). The largest shields are similar in size to the largest fissure lavas.

A diagram showing the lava production per millennium reveals two pulses. The first and larger one occurred between 9000 and 7000 BP (calendar years) and the second extends over the last 2,000 years. When eruptions of lava shields and crater rows are examined individually, it becomes evident that they have different periods of activity. Most of the largest lava shields in Iceland were erupted in the first millennium after deglaciation. During the last 4,000 years only three large lava shields have been erupted. It can be suggested that the period of the shields lasted from 13,000 to 4,000 BP, i.e. for 9,000 years. On the basis of this evidence, a relationship between lava shields, glacial retreat and unloading might be suggested; on the other hand, the occurrence of shield volcanism during and after deglaciation might also be fortuitous. Lava shields and compound lavas are rare in the Neogene lava pile of Iceland but seem more abundant in the Quaternary pile. An increasing number of lava shields in the volcanic pile after the onset of the Pleistocene glaciations supports statements about a relationship between shields and glacial unloading.

The crater rows, on the other hand, do not show any clear correlation to deglaciation. Their lava production is marked by two pulses, the first 9,000-8,000 BP and the other during the last 1,100 years. These pulses are primarily due to three exceptional eruptions, firstly the Great Þjórsá Lava (25 km^3) and secondly the historical Eldgja and Laki eruptions (19.6 km^3 and 15 km^3 each). Between the production highs there is a prominent low, the mid-Holocene low, a 2,000-year period when no large fissure eruption took place. The explosive plinian eruptions in the central volcanoes of Iceland exhibit a similar pattern to that of the crater rows, with more activity in the early and late Holocene than in the mid Holocene, but in the long run their frequency has increased with time. Glacier unloading and crustal rebound seem to stimulate eruptions of lava shields but their influences on the crater rows and central volcanoes are small, if any.

References

Flores RM, Jónsson J and Jóhannesson H (1981) A short account of the Holocene tephrachronology of the Snæfellsjökull central volcano, western Iceland. (Ljósu öskulögin frá Snæfellsjökli), Jökull 31:23-30

Grönvold K, Oskarsson N, Johnsen SJ, Clausen HB, Hammer CU, Bond G and Bard E (1995) Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. Earth Planet Sci Lett 135:149-155

Guðmundsson AT (2001) Íslandseldar. Mál og menning, Reykjavík, pp 1-450

Gudmundsson A (1986) Mechanical Aspects of Postglacial Volcanism and Tectonics of the Reykjanes Peninsula, Southwest Iceland. J Geophys Res 91:12711-12721

Hjartarson Á (1994) Environmental changes in Iceland following the Great Þjórsá Lava Eruption 7800 14C years BP. In: Environmental Change in Iceland. Ed. J.Stötter & F.Wilhelm, Munchen, pp 147-155

Hjartarson Á (1995) Hekla and its surroundings (Á Hekluslóðum). Árbók Ferðafélags Íslands 1995, Reykjavík1-236

Hjartarson Á (1999) The geology of Ölfus, overview. (Yfirlit um jarðfræði í Ölfusi og grennd). ÁH 99/06, Orkustofnun, Reykjavík, pp 1-11 + map

Ingólfsson Ó (1998) Isavsmältning och israndlinjer på Island. In Andersen and Pedersen: Israndslinier i Norden. TemaNord 1998:584. Nordisk Ministeråd, København, pp 109-124

Jakobsson SP (1972) Chemistry and distribution pattern of recent basaltic rocks in Iceland. Lithos 5:365-386

Jakobsson SP (1979a) Petrology of recent basalts of the Eastern volcanic zone, Iceland. Acta Naturalia Islandica 26, pp 1-103

Jakobsson SP (1979b) Outline of the petrology of Iceland. Jökull 29:57-73

Jakobsson SP, Jónsson J and Shido F (1978) Petrology of the Western Reykjanes Peninsula, Iceland. J Petrol 19:669-705

Jancin M, Young KD, Voight B, Aronson JL and Sæmundsson K (1985) Stratigraphy and K/Ar ages across the west flank of the northeast Iceland axial rift zone, in relation to the 7 Ma volcano-tectonic reorganization of Iceland. J Geophys Res 90, 9961-9985

Jóhannesson H (1989) The age of Hallmundarhraun lava. (Aldur Hallmundarhrauns í Borgarfirði). Fjölrit Náttúrufræðistofnunar Íslands no 9. pp 1-12

Jónsson J (1978) Geological map of Reykjanesskagi. (Jarðfræðikort af Reykjanesskaga). OS-JHD 7831, Orkustofnun, pp 1-333 + maps

Jónsson J (1978) On the geology of Hveragerði and surroundings. (Hveragerði og nágrenni. Jarðfræðilegt yfirlit). Rannsóknarstofnunin Neðri Ás, skýrsla nr. 50, pp 1-55

Jull M and McKenzie D (1966) The effort of deglaciation on mantel melting beneath Iceland. J Geophys Res 101:21815-21828

Kjartansson G (1966) The volumes of lava shields. (Rúmmál hraundyngna). Náttúrufræðingurinn 36:125

Kristjánsson BR, Jónsson SS, Sæmundsson K and Hafstað ÞH (2003) Grunnvatnsborholur á Hellisheiði og nágrenni : greining jarðlaga í HK-holum 2001-2002, Orkustofnun, Rannsóknasvið, OS-2003/003 pp 1-60

Larsen G (2000) Holocene eruptions within the Katla volcanic system, south Iceland: Characteristics and environmental impact. Jökull 48:1- 28

Larsen G and Thorarinsson S (1977) H4 and other acid Hekla tephra layers. Jökull 27:28-45

Rossi MJ (1996) Morphology and mechanism of eruption of postglacial shield volcanoes in Iceland. Bull Volcanol 57:530-540

Sigurðsson O, Zóphóníasson S, Hannesdóttir L, Þorgrímsson S 1975: Dettifdossvirkjun, jarðfræðiskýrsla, OS-ROD-7526, Orkustofnun, Reykjavík, pp 1-62 + maps

Sigvaldason GE (1992) Recent hydrothermal explosion craters in an old hyaloclastite flow, central Iceland. J Volcanol Geotherm Res 54:53-63

Sigvaldason GE (2002) Volcanic and tectonic processes coinciding with glaciation and crustal rebound: an early Holocene rhyolitic eruption in the Dyngjufjöll volcanic center and the formation of the Askja caldera, north Iceland. Bull Volcanol 64:192-205

Sigvaldason GE and Steinþórsson S (1974) Chemistry of tholeiitic basalts from Iceland and their relation to the Kverkfjöll hot spot. In Kristjánsson (ed.): Geodynamics of Iceland and the North Atlantic Area. D. Reidel , Hingham, Mass, pp 155-164

Sigvaldason GE, Annertz K and Nilsson M (1992) Effect of gracier loding/deloding on volcanism: postglacial volcanic production rate of the Dyngjufjöll area, central Iceland. Bull Volcanol 54:385-392

Sinton J and Grönvold K (2001) Post-Glacial Eruptive History of the Western Volcanic Zone, Iceland. (Poster)

Steinþórsson S (1967) Two new C14 dates on Snæfellsjökull tephra layers.(Tvær nýjar Cl4-aldursákvarðanir á öskulögum úr Snæfellsjökli). Náttúrufræðingurinn 37:236-238

Sæmundsson K (1973) Straumrákaðar klappir í kringum Ásbyrgi. Náttúrufræðingurinn 43:52-60

Sæmundsson K (1992) Geology of the Thingvallavatn area. In: ed. Jónasson 1992, Ecology of oligotrophic, subarctic Thingvallavatn, pp 1-434

Sæmundsson K (1995) Um aldur stóru dyngnanna á utanverðum Reykjanesskaga. In: Björn Hróarsson, Dagur Jónsson og Sigurður Sveinn Jónsson (eds) 1995: Eyjar í eldhafi. Gott mál, Reykjavík, pp.165-172

Thorarinsson S (1951) Laxárgljúfur and Laxárhraun a tephrochronological study. Geografiska annaler 1951:1-89

Thorarinsson S (1958) The Öræfajökull eruption of 1362. Acta Naturalia Islandica II, pp 1-100

Thorarinsson S (1968) The last stages of the Surtsey eruptiuon. (Síðustu þættir Eyjaelda). Náttúrufræðingurinn 57:113-135

Thorarinsson S (1979) The postglacial history of the Mývatn area. Oikos 32:17-28

Thorarinsson S, Einarsson T. and Kjartansson G (1959) On the geology and geomorphology of Iceland. Geografiska Annaler 41:143-153

Thordarson Th and Self, S (1993) The Laki (Skaftar fires) and Grimsvotn eruptions in 1783-1785. Bull. Volcanol. 55:33-63

Thordarson Th, Miller DJ, Larsen G, Self S. and Sigurdsson H (2001) New estimates of sulfur degassing and atmospheric mass-loading by the 934 AD Eldgja eruption, Iceland. J Volcanol Geotherm Res 108:33-54

Torfason H, Hjartarson Á, Jóhannesson H, Jónsson J and Sæmundsson K (1997) Bedrock map, Viðey 1613 III NV-B, 1:25.000. Landmælingar Íslands, Orkustofnun, Hafnarfjarðarbær, Garðabær, Kópavogsbær, Seltjarnarnesbær and Reykjavíkurborg.

Torfason H, Hjartarson Á, Jóhannesson H, Jónsson J and Sæmundsson K (1999) Bedrock map, Vífilsfell 1613 III SA-B, 1:25.000. Landmælingar Íslands, Orkustofnun, Hafnarfjarðarbær, Garðabær, Kópavogsbær, Seltjarnarnesbær and Reykjavíkurborg.

Torfason H, Hjartarson Á., Jóhannesson H, and Friðleifsson IB (2000) Bedrock map, Mosfellssveit 1613 III NA, 1:25.000. Landmælingar Íslands, Orkustofnun, Hafnarfjarðarbær, Garðabær, Kópavogsbær, Seltjarnarnesbær and Reykjavíkurborg.

Vilmundardóttir EG (1977) Tungnárhraun. OS ROD 7702, Orkustofnun, pp 1-156 + map

Vilmundardóttir EG and Larsen, G (1986) Productivity pattern of the Veiðivötn fissure swarm, southern Iceland,in postglacial time. Preliminary results. 17. Nordiska Geologmötet , Helsingfors

Vilmundardóttir EG, Snorrason SP, Larsen G and Guðmundsson Á (1988) Bedrock map. Sigalda – Veiðivötn 1:50.000

Walker GPL (1971) Compound and Simple Lava Flows and Flood Basalts. Bull Volcanol 35:579-590