Reviewed research article

Delimiting Bárðarbunga and Askja volcanic systems with Sr- and Nd-isotope ratios

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Abstract — *Volcanic systems represent a fundamental component of the neovolcanic zones in Iceland. They are composed of a central volcano and a fissure swarm, or a combination of the two. The 2014–2015 rifting event at the Bárðarbunga volcanic system produced basaltic lava approximately 40 km to the north of the central volcano, within a fissure swarm commonly attributed to the Askja volcanic system, highlighting the complex tectonic structure of a region, directly above the Iceland mantle plume. New analyses of Sr- and Nd-isotope ratios from the new lava (Holuhraun), and the underlying older Holuhraun lava, show that they have identical values to those of the Bárðarbunga-Veiðivötn lavas and tephra erupted during the Holocene. Moreover, comparison with published high-precision radiogenic isotope data, reveals that Holocene lavas and tephra from the Bárðarbunga and Askja systems are characterized by contrasting Sr- and Nd-isotope ratios, with the notable exception of the Þjórsárhraun lava and two early Holocene lavas from the extreme west and east of the Veiðivötn fissure swarm. The* $^{87}Sr/^{86}Sr$ *and* $^{143}Nd/^{144}Nd$ *isotope ratios can thus be utilized to define the provenance of lava flows north of the Vatnajökull ice cap, ascertaining that the large lava fields of Krepputunguhraun and Fjallsendahraun (Frambruni) must also have originated within the Bárðarbunga volcanic system.*

INTRODUCTION

The neovolcanic zones in Iceland are composed of volcanic systems that, in turn, are composed of a fissure swarm, a central volcano or both (e.g. Sæmundsson, 1978). Examples are the Reykjanes fissure swarms without central volcanoes, Eyjafjallajökull central volcano without an associated fissure swarm and finally, the Krafla central volcano and its fissure swarm (e.g. Jóhannesson and Sæmundsson, 1998). Associating any particular eruption unit to a given volcanic system is of an importance when discussing eruption frequency and magma production rates for volcanic systems. It is also central when forecasting volcanic activity from real-time measurements. However, it is not always straight-forward to associate a lava flow or a tephra layer to its point of origin (e.g. Óladóttir *et al.*, 2011), especially when a large portion of the volcanic system is covered by a glacier (e.g. Einarsson and Björnsson, 1990). Additionally, volcanic systems in Iceland have been defined differently over the last decades. The extensive mapping of the Neogene volcanic pile in eastern Iceland revealed complex architecture of the central volcanoes with associated dike swarms that together formed a unity named volcanic system (summarized in Walker, 1974). Tectonic criteria and fissure mapping were applied by Sæmundsson (1978) when discussing active analogues for central volcanoes and fissure swarms within the neovolcanic zones of Iceland. A different approach based on major element composition of basalts and magma suites of each volcano were utilized by Jakobsson (1979) when defining the term volcanic systems in the Eastern Volcanic Zone. This latter approach has thus far not given a unique answer to the origin of several lava flow fields at the edge of Dyngjujökull, an outlet glacier of Vatnajökull. Further complications arise due to the fact that several volcanic systems at play in this region are partially covered by ice (Figure 1).

The complicated tectonic structure of the region N of Vatnajökull glacier, more or less directly above the Iceland mantle plume, was highlighted during the 2014–2015 rifting event. This event was characterized by two-week seismicity progressing over 40 km and up to 2 m spreading as monitored by Icelandic Meteorological Office and Institute of Earth Sciences, University of Iceland and collaborators (e.g. Sigmundsson *et al.*, 2015). The northward propagation of the rifting from the Bárðarbunga central volcano along the northern branch of the associated fissure swarm, caused seismicity in the neighbouring volcanic system of Askja several days before the fissure eruption at Holuhraun. This tectonic evolution caused uncertainty about where an eruption would occur, with an explosive eruption at Askja as a possible scenario. Fortunately, the magma came up through existing craters at the Holuhraun lava field, which had previously been associated with the southern fissure swarm of Askja (e.g. Einarsson and Sæmundsson, 1987), a proposition questioned by Hartley and Thordarson (2013). The question of illegitimate magma transferred from one volcano to another, such as observed at Galapagos and between Kilauea and Mauna Loa (e.g. Rhodes *et al.*, 1988; Geist *et al.*, 1998), and in this case from Bárðarbunga to Askja, is thus a possibility. Alternatively, as discussed by Hartley and Thordarson (2013) and developed below, the delimitation of the Bárðarbunga and Askja volcanic systems needs revision.

Radiogenic isotopes have proven useful in tracing the provenance of magma in Iceland. For example, the Sr- and Nd-isotope ratios reflect fractionations from their parental elements (Rb and Sm) and the time elapsed since the fractionation. Their respective half-lives, far exceed the young age of Icelandic crust (i.e. $\gg 10^9$ years vs. $>10^6$ years) and, therefore, limited crustal contamination will not affect the Sr- and Nd-isotope ratios in Icelandic basalts, which are principally mantle-derived. Mantle heterogeneity, and melts thereof, is thus directly sampled by basaltic volcanism. Nevertheless a given volcanic system (i.e. Jakobsson, 1979) appears to deliver magmas to the surface with relatively uniform Sr- and Nd-isotope ratios (e.g. Sigmarsson *et al.*, 1992; Furman *et al.*, 1995; Kokfelt *et al.*, 2009; Chekol *et al.*, 2011), an observation that may be helpful with delineating volcanic systems. An example where this approach was adopted on Icelandic volcanics, is the eruption at Gjálp in 1996 that produced magma originating at Grímsvötn volcano, despite a precursory seismicity at Bárðarbunga central volcano (Sigmarsson *et al.*, 2000 and references therein). In this paper, the aim is to further test this "fingerprinting" method on several recent craters and Holocene lavas from the complex intersection of Askja and Bárðarbunga fissure swarms in order to assign various eruptive units to their parental volcanic system.

GEOLOGICAL SETTING

The ice-covered central volcano of Bárðarbunga is located more or less directly above the presumed centre of the Iceland mantle plume. Several other central volcanoes are also found in the vicinity of Bárðarbunga (Figure 1) as identified on the most recent geological maps of active volcanic systems in this region that combine tectonic observations, including recent seismicity distribution and subglacial topography (Einarsson and Sæmundsson, 1987; Björnsson and Einarsson, 1990; Jóhannesson and Sæmundsson, 1998; Sigurgeirsson *et al.*, 2015). This region also marks the triple junction between the Northern Rift Zone (NRZ), the Eastern Rift Zone (ERZ) and the Mid-Iceland Volcanic Belt (MIVB), where the strike of the fissures changes direction from SW-NE to the South to progressively more N-S direction in the North. Associated with this change, appears to be an overlap in erupted magma compositions, or interfingering of fissure swarms belonging to two different volcanic systems. This region is characterised by very high magma production with, for example Bárðarbunga being one of the most productive volcanic systems in Iceland during the Holocene with estimated

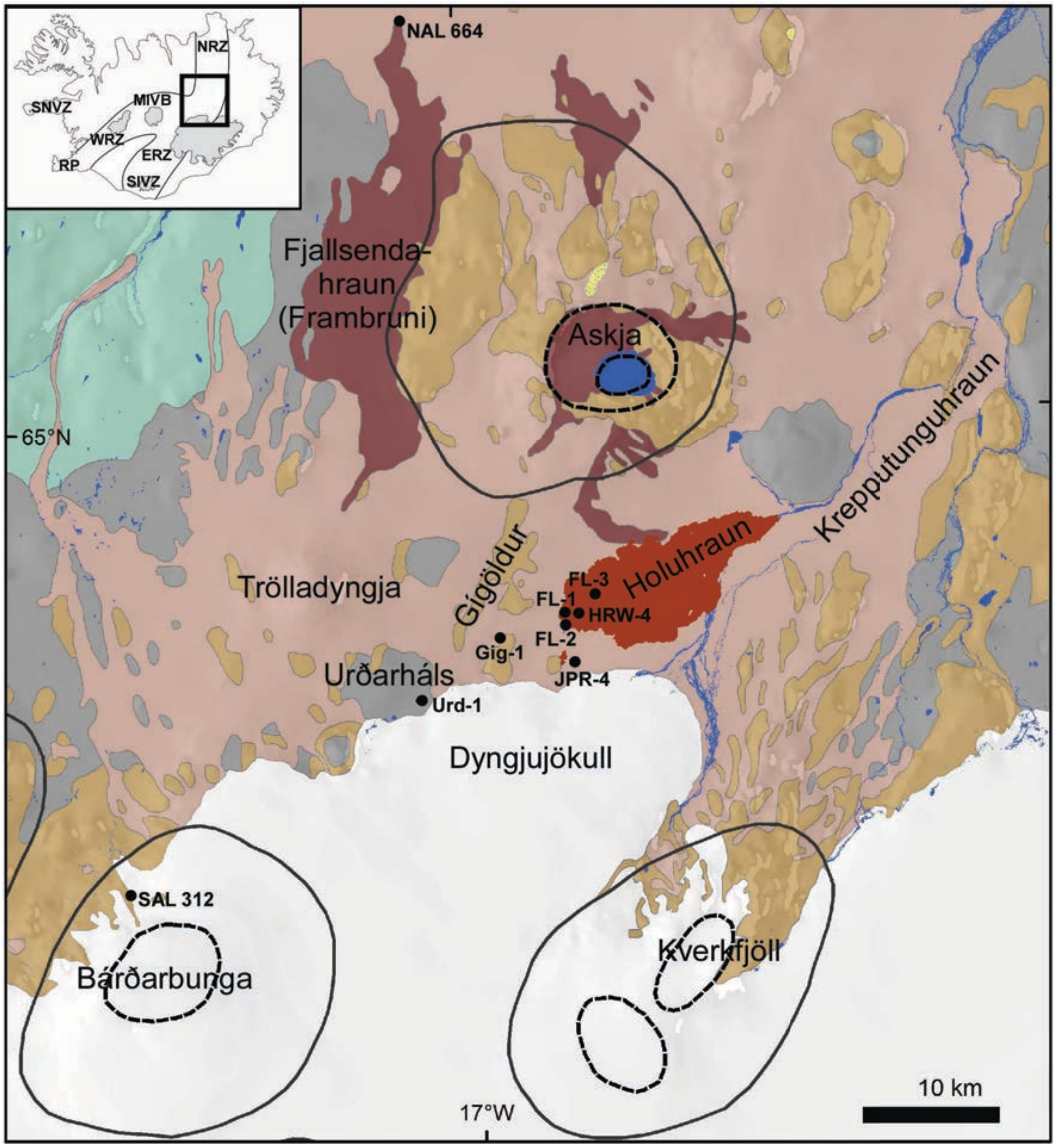

Figure 1. Geological map of the highland north of Vatnajökull glacier (modified from Jóhannesson and Sæmundsson (1998) showing sample locations and other localities discussed in the text. Basement rocks and interglacial lavas are shown in green and gray, respectively, subglacial formations in brown whereas Holocene lavas are shown in pink and historical lavas in purple. Insert: Iceland with its Neovolcanic zones; the Western (WRZ), Eastern (ERZ), and Northern rift zones (NRZ), the Mid-Iceland Volcanic Belt (MIVB) and off-axis zones: the South Iceland Volcanic Zone (SIVZ) and the Snæfellsnes Volcanic Zone (SNVZ). – *Kort af hálendinu norðan Vatnajökuls með náttúrunöfnum sem rædd eru í texta.*

10 km^3 of magma erupted during historical time (e.g. Thordarson and Larsen, 2007). The southwestern part of the Bárðarbunga volcanic system, referred to as the Veiðivötn fissure segment, has been subject to a number of studies in the past (e.g. Halldórsson *et al.*, 2008; Zellmer *et al.*, 2008; Manning and Thirlwall, 2014 and references therein). However, the northern part of the Bárðarbunga volcanic system, at the edge of Dyngjujökull, has been given less attention.

Holocene lava fields north of the Vatnajökull glacier, have been either attributed to the Askja or Bárðarbunga systems (e.g. Jóhannesson and Sæmundsson, 1998; Figure 1). For example, the Holuhraun lava field has been associated with both Askja (e.g. Sigurdsson and Sparks, 1978) and Bárðarbunga-Veiðivötn (Hartley and Thordarson, 2013). The Fjallsendahraun (Frambruni) lava field, with an estimated volume of approximately 4 km^3 (Thordarson and Larsen, 2007) has also been associated with the Bárðarbunga volcanic system. Finally, a significantly larger lava, Krepputunguhraun (>7 km^3, Thordarson and Self, 1998), mapped by Sigbjarnarson and colleagues (1988; 1995) has also been assigned to the Bárðarbunga volcanic system whereas Thordarson *et al.* (2013) prefer an origin from the Kverkfjöll volcanic system. Thus there is a need for an improvement in determining the provenance of volcanic formations north of Vatnajökull.

SAMPLES

For the purpose of delimiting lava flow fields at the intersections of Bárðarbunga and Askja volcanic systems, we selected (i) a short crater row lying W-E on the eastern flank of the interglacial lava shield, Urðarháls (sample Urd-1; Figure 1; unit Urh in Sigbjarnarson, 1988), (ii) a large crater row further east, extending S-SW from Dyngjufjöll forming large craters named Gígöldur from which a pillow lava fragment was collected (Gig-1; unit Gb in Sigbjarnarson, 1988), (iii) the older Holuhraun (HRW-04, see Hartley and Thordarson, 2013) and (iv) the Fjallsendahraun (or Frambruni) lava field (NAL-664) at Suðurárbotnar. In addition, we included one sample from a nunatak on the flank of the Bárðarbunga central volcano (SAL-312). Finally, four samples from the first three months of the 2014 eruption at Holuhraun (Fl-1, -2, -3 and JPR030914-4) were included in this study.

All the lava samples are of basaltic to intermediate composition with a normative composition ranging from 1.68 ol to 6.33 qz in the nunatak (SAL-312), which is the only lava located within the Bárðarbunga central volcano (Figure 1). Only a few plagioclase and clinopyroxene crystals are visible in hand specimens. The samples are fresh looking without any sign of alteration as judged from inspection under the binocular microscope.

ANALYTICAL METHODS

Lava samples were crushed in stainless steel (Clermont-Ferrand) or pure Mn-steel (Reykjavík) jaw crushers before reduction to a fine powder in agate mill. Five samples (Fl-1-3, Urd-1 and Gig-1) were processed in Clermont-Ferrand and additional four (JPR030914-4, HRW-04, NAL-664 and SAL-312) in Reykjavik using the following methods:

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The powder was dissolved and Sr and Nd isolated using established methods (Pin *et al.*, 1994; Pin and Zalduegui, 1997). Their isotope ratio was obtained on a Triton mass spectrometer in a static mode and corrected for mass fractionation by normalization to ^{88}Sr/^{86}Sr and ^{146}Nd/^{144}Nd of 0.1194 and 0.7219, respectively. The international standards NIST-987 and JNd-1 gave ^{87}Sr/^{86}Sr and ^{143}Nd/^{144}Nd equal to 0.710240 ± 10 (2SD, n = 28) and 0.512105 ± 14 (2SD, n = 27), respectively, during the period of analyses. These values are within error of the accepted standard values.

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Methods adopted in Reykjavík, are similar to those initially described by Halldórsson *et al.*, (2008) with modifications and improvements following Marske *et al.* (2007) that will be detailed elsewhere. The Sr and Nd isotopic compositions of samples were measured using a Nu Plasma multi-collector inductively-coupled plasma mass-spectrometer (MC-ICP-MS). Strontium isotope values were normalized to a

^{86}Sr/^{88}Sr = 0.1194 with an exponential law to correct for mass fractionation. Rubidium-87 and ^{86}Kr interferences were closely monitored and corrected for following the correction scheme of Konter and Strom (2014). Over the analytical period the NIST SRM-987 standard reproduced with a ^{87}Sr/^{86}Sr ratio of 0.710244 $\pm$ 56 (2SD, n = 5) and values reported here are normalized to a NIST SRM-987 ^{87}Sr/^{86}Sr ratio of 0.710248. Neodymium isotope analyses were corrected for instrumental mass fractionation to the natural ^{146}Nd/^{144}Nd = 0.7219. For Nd isotope analysis, the La Jolla Nd isotope standard was used to bracket each sample. Over the analytical period, it gave a ^{143}Nd/^{144}Nd ratio of 0.511853$\pm$13 (2SD, n = 5) and all data reported here have been normalized to a ^{143}Nd/^{144}Nd ratio of 0.511858. The measured ^{143}Nd/^{144}Nd ratio for the La Jolla standard in Reykjavík, corresponds to a JNd-1 value of 0.512110 (Tanaka *et al.*, 2000).

RESULTS AND COMPARISON WITH PUBLISHED DATA

The new results (Table 1, Figures 2 and 3) were compared to (i) recent high-precision thermal-ionization mass spectrometric (TIMS) results of Kokfelt *et al.* (2006), Kuritani *et al.* (2011) and Manning and Thirlwall (2014), and (ii) Sr isotope ratios of Halldórsson *et al.* (2008) measured with multi-collection inductively coupled plasma mass spectrometry (MC-ICP-MS). Encompassing a relatively narrow range of ^{87}Sr/^{86}Sr (0.70307–0.70324) and ^{143}Nd/^{144}Nd (0.513024–0.513074) ratios, our results are in good agreement with published Sr and Nd isotope data from the ERZ and the NRZ (e.g. Kokfelt *et al.*, 2006, Halldórsson *et al.*, 2008, Kuritani *et al.*, 2011; Manning and Thirlwall, 2014 and references therein; Figure 1). However, in order to define Sr- and Nd- isotope composition characteristic for lavas and tephras from the Bárðarbunga and Askja volcanic systems, we will critically evaluate published results in the following sections. We first note that publications without standard values are of little value for this study and have thus been omitted in our compilation.

Bárðarbunga range

In their thorough study of Veiðivötn basalts, Manning and Thirlwall (2014) excluded historical basalts (Vatnaöldur and Veiðivötn) analysed by Zellmer *et al.* (2008), considering that they represent mixed magmas with Torfajökull rhyolites. The results from Zellmer *et al.* (2008) have higher ^{87}Sr/^{86}Sr than those of Sigmarsson *et al.* (2000) and Halldórsson *et al.* (2008) for the same eruptions and are thus eliminated from the compilation of Veiðivötn basalts. Indeed, on the basis of Pb isotopes, Halldórsson *et al.* (2008) argued that although most samples from these single fissure eruptions, revealed values identical to Bárðarbunga, samples in close proximity to the Torfajökull volcanic system have radiogenic Pb isotope ratios, which represent mixing of magmas of the Veiðivötn fissure swarm with those of the Torfajökull volcanic system.

Table 1. Analytical results and sample locations. – *Mæliniðurstöður samsætuhlutfalla og staðsetning sýna.*

Sample #	Longitude (W)	Latitude (N)	^{87}Sr/^{86}Sr	$\pm$2 SE	^{143}Nd/^{144}Nd	$\pm$2 SE
Fl-1	16.850	64.873	0.703118	7	0.513059	5
Fl-2	16.851	64.864	0.703112	6	0.513069	4
Fl-3	16.804	64.885	0.703115	6	0.513068	6
JPR030914-4	16.840	64.840	0.703122	15	0.513072	9
HRW-04	16.831	64.872	0.703105	15	0.513074	15
SAL-312	17.538	64.692	0.703070	16	0.513074	15
NAL-664	17.087	64.271	0.703089	14	0.513058	10
Urd-1	17.081	64.818	0.703220	7	0.513027	3
Gig-1	16.954	64.858	0.703246	7	0.513024	4

Internal errors are given on the last significant digits.

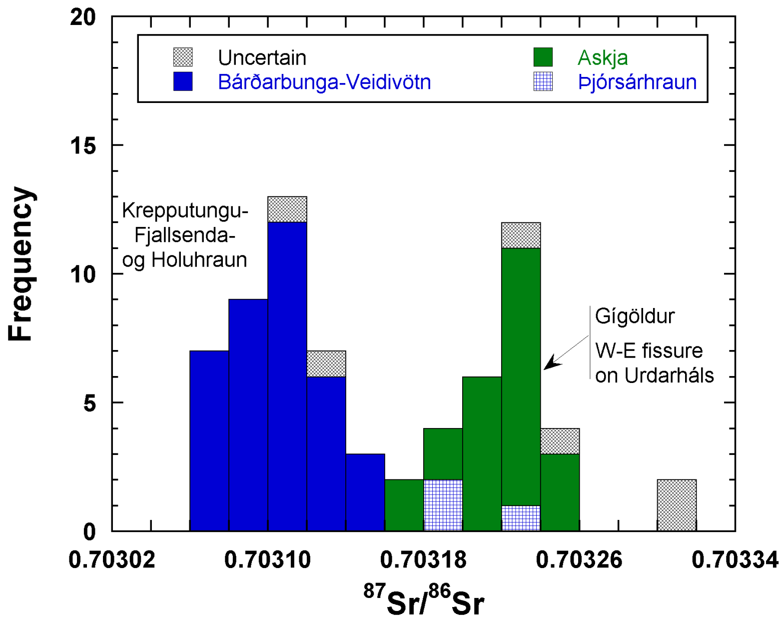

Figure 2. Strontium isotope ratio of Recent lavas from the Bárðarbunga-Veiðivötn and Askja volcanic systems demonstrating the connection of Holu-, Krepputungu- and Fjallsendahraun (Frambruni) lavas to the Bárðarbunga magma system. External analytical errors are represented by the width of the columns. Same symbol as for the Þjórsár lava is used for two old Veiðivötn lavas. "Uncertain" refers to lavas that have not been correlated to a given volcanic system (see text for further discussion). – *Samsætuhlutföll Sr í nútíma basalti frá eldstöðvakerfum Bárðarbungu-Veiðivatna og Öskju sýna að Holuhraun og Krepputunguhraun eiga rætur sínar að rekja til kvikukerfis Bárðarbungu. Sömu tákn eru notuð fyrir tvö af elstu hraunum Veiðivatnareinarinnar og Þjórsárhraun sem skera sig úr mengi annara Veiðivatnabasalta. Sér tákn er notað fyrir hraun sem ekki hafa verið rakin til ákveðinna eldstöðvakerfa.*

Older results from Hémond *et al.* (1993) agree perfectly with the results shown in Figures 2 and 3 after readjustment to the same standard values. The only isotope ratios from Bárðarbunga that disagree with ours are those attributed to the Tungnaárhraun lava by Kempton *et al.* (2000) with $^{87}Sr/^{86}Sr$ equal to 0.70327. Our analysis of the Búrfellshraun (Tungnaárhraun) gave 0.70312±1, confirmed by the results of Manning and Thirlwall (2014) who obtained $^{87}Sr/^{86}Sr$ equal to 0.70311±1. Earlier less precise Nd isotope ratios, such as those of Sigmarsson *et al.* (2000), are excluded from this compilation. Three lavas from the Veiðivötn fissure swarm have significantly higher $^{87}Sr/^{86}Sr$ than other lavas from the same volcanic system (Figure 2). These are amongst the oldest Veiðivötn lavas, namely Þjórsárhraun, Jökulheimahraun and Skeifuhraun (or Fellsendahraun; see maps in Vilmundardóttir *et al.*, 2000 and Jakobsson, 1979). Notably, these basalts were produced in the early Holocene after a large isostatic rebound followed the rapid ice melting, which possibly affected the melting regime at the origin of these basalts. Indeed, a detailed study of Sr isotopes in plagioclase crystals and the groundmass of the Þjórsárhraun lava revealed lower $^{87}Sr/^{86}Sr$ for the crystals, which was proposed to reflect mixing between mantle melts and earlier-formed mafic intrusions, highligths the complex origin of this large lava unit (Halldórsson *et al.*, 2008).

Based on the filtering criteria adopted, the range, median, mean and standard deviation for both Sr and Nd isotope ratios of Bárðarbunga-Veiðivötn lavas

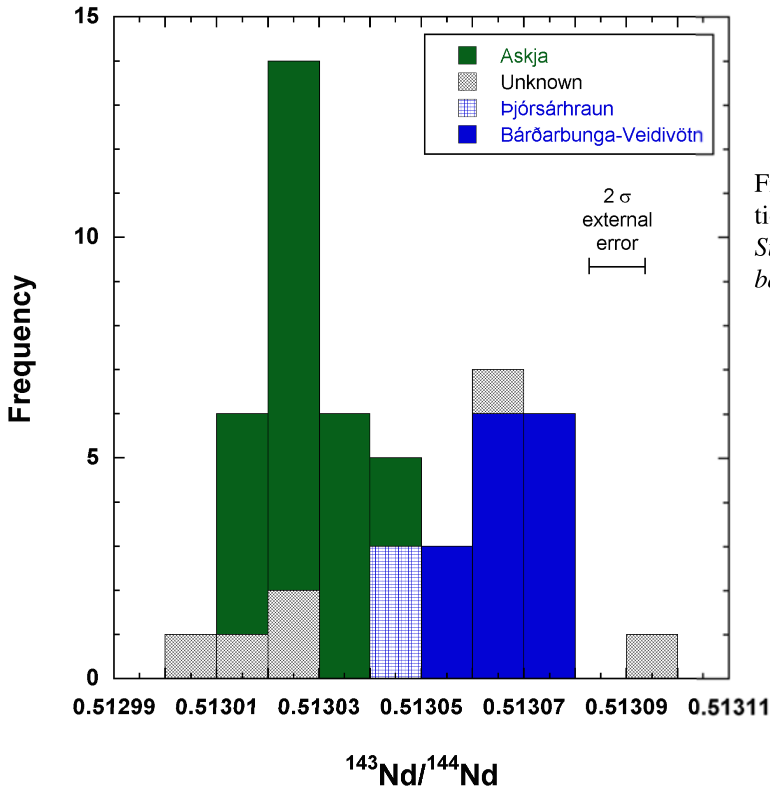

Figure 3. Histogram of Nd isotope ratios in same basalts as in Figure 2. – *Súlurit fyrir Nd samsætuhlutfall í sömu basöltum og á 2. mynd*

and tephra are given in Table 2, excluding the three old lavas from the Veiðivötn area. Restricted spread in isotope composition is evident with $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ in the narrow ranges of 0.70307–0.70315 and 0.51306–0.51307, respectively.

Askja range

When compiling published results for the Askja volcanic system, it becomes clear that three samples have most likely been erroneously associated with Askja. These are samples H25, collected along the track from Hrossaborg to Herðubreiðarlindir, just south of Ferjuás, and H24, collected east of Herðubreiðartögl (Kokfelt *et al.*, 2006). Both these are olivine tholeiites that display the highest $^{87}Sr/^{86}Sr$ and lowest $^{143}Nd/^{144}Nd$ of all the analyses examined here and major element composition significantly less evolved than the Askja basalts (Kokfelt *et al.*, 2006). Their origin remains unknown but we note that they have near identical values to those reported from Kverkfjöll by Hémond *et al.* (1993). A single Mg-rich and relatively old (>6000 a) basalt (sample# IA1709) collected just south of Herðubreiðartögl by Kuritani *et al.* (2011) is of unknown origin, displaying both low and high $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$, respectively. Before associating these curious basalts to Askja, a more thorough study of the Dyngjufjöll basalts is needed. Alternatively, the Askja basalts exhibit a much larger range in radiogenic isotope ratios than any other volcanic system studied so far in Iceland. Excluding these three anomalous basalts, Table 2 gives the range, median, mean and standard deviation for both Sr and Nd isotope ratios for Askja. The respective ranges are 0.70316–0.70326 and 0.51301–0.51304, only slightly but nevertheless significantly different from those observed for Bárðarbunga volcanic system.

Table 2. Statistics. – *Tölfræðileg gögn.*

Volcanic system	Bárðarbunga	Askja
Range in $^{87}Sr/^{86}Sr$	0.70307–0.70315	0.70316–0.70326
n	37	23
Median	0.70311	0.70322
Mean	0.70311	0.70322
Standard Deviation	2.22×10^{-5}	2.23×10^{-5}
Range in $^{143}Nd/^{144}Nd$	0.51306–0.51307	0.51301–0.51304
n	15	25
Median	0.51307	0.51303
Mean	0.51307	0.51303
Standard Deviation	1.59×10^{-6}	7.74×10^{-6}

n denotes number of analyses from this study and published results of Kokfelt *et al.* (2006), Kuritani *et al.* (2011) and Manning and Thirlwall (2014).

DISCUSSION

The irregular geographical variations of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ in basalts at the northern edge of Vatnajökull glacier illustrate the complex overlapping of eruptive fissures belonging to Bárðarbunga and Askja volcanic systems. However, a critical evaluation of published results for Sr- and Nd-isotope composition in lavas from Bárðarbunga-Veiðivötn and Askja volcanic systems reveals marked difference between isotope ratios in products from these volcanic systems. This allows determining the provenance of both recent and older lava fields in this complex region as well as discussing the delimitation of these volcanic systems.

Source provenance of the Holuhraun lava fields

The four 2014–2015 Holuhraun samples and a sample of the older Holuhraun unit fall within the ranges of Sr- and Nd-isotope ratios observed in Bárðarbunga lavas, strongly suggesting an affiliation with the magma system of Bárðarbunga. The results confirm the limited spread of both Sr- and Nd-isotope ratios in Bárðarbunga-Veiðivötn volcanics. This is further supported by similar high-field-strength element concentrations and ratios of the older Holuhraun unit and Veiðivötn basalts (Hartley and Thordarson, 2013).

Source provenance of the Krepputunguhraun and Fjallsendahraun lava fields

The provenance of Krepputunguhraun has been a matter of debate. Based on the presence of large plagioclase phenocrysts Sigbjarnarson (1988, 1995) proposed an origin from the Bárðarbunga volcanic system, possibly from the Gígöldur crater row, whereas Guðmundsson *et al.* (2013) preferred an origin at the Kverkfjöll volcanic system. Kokfelt *et al.* (2006) measured its composition in a sample collected at Hvannalindir. Its Sr- and Nd-ratios are very different from those of Gígöldur and Kverkfjöll (Figures 2 and 3; Hémond *et al.*, 1993), but they are well within the range measured for Bárðarbunga-Veiðivötn products thus confirming its provenance. In addition, we note that the large Krepputunguhraun (∼500 km^2, Sigbjarnarson, 1988; >7 km^3, Thordarson and Self, 1998), which is approximately 8000 years old, is partly overlain by the younger Trölladyngja shield volcano and both these large formations have near-identical Sr- and Nd-isotope ratios (Kokfelt *et al.*, 2006).

A single sample from Fjallsendahraun (Frambruni), analysed for Nd isotope ratio by Koornneef *et al.* (2012), is similar to those of Askja basalts. However, our Hf-Pb isotope measurements of this lava (Halldórsson, unpublished) are indistinguishable from

Veiðivötn basalts (Manning and Thirlwall, 2014). In addition, both Sr- and Nd-isotope of this lava (Table 1) fall within the range of Bárðarbunga-Veiðivötn volcanics. Further studies of this large lava are needed but the Hf isotope data of Koornneef *et al.* (2012) together with our Sr and Nd isotope ratios agree with the tectonic lineation that strongly suggest an origin from the Bárðarbunga magma system.

Gígöldur and Urðarháls craters: eruptive fissures associated with Askja?

The single sample of the large Gígöldur crater row (sample Gig-1) has isotope ratios suggesting an affiliation within Askja volcanic system (Table 1, Figures 2 and 3). In addition, the neighbouring W-E trending eruptive fissure on the eastern side of interglacial Urðarháls lava shield (sample URD-1) also produced basalts with isotope ratios akin to Askja volcanic system. Further work on these impressive and highly peculiar crater rows is needed before detailed discussion of their origin. In principle, however, this either suggests an inter-fingering relationship between the two volcanic systems, or that the two magmatic systems at depth erupt through the same tectonic fractures. The results presented here are only based on some of the most recent products in the region north of Vatnajökull that tend to support the former proposition. However, the latter explanation, which may operate on a longer time scale cannot be eliminated yet. Taken together with the complex tectonic settings in this region, namely the intersection of the two dominant tectonic lineaments of Iceland (e.g. Jónsson *et al.*, 1991), it is clear that further studies of older lavas above the Iceland mantle plume centre would be valuable.

Bárðarbunga: the largest magma producer in Iceland?

Magma production at the Bárðarbunga volcanic system is thought to be amongst the highest in Iceland. However, in their compilation of lava volume estimates over historical time, Thordarson and Larsen (2007) concluded that Bárðarbunga was only the fourth highest producer of magma. We note, however, that when adding the volumes of the Great Þjórsárhraun and the multiple lava fields of Tungnaárhraun (e.g. Vilmundardóttir *et al.*, 2000), together with Krepputunguhraun and Fjallsendahraun to the shield-volcanoes, such as Trölladyngja, Bárðarbunga is likely to get the first place as the highest magma production volcanic system during the Holocene in Iceland. In addition, there are hints (from Sr- and Nd isotope ratios; Carpentier and Sigmarsson, unpublished results) that the large ($\sim$5 km^3) Bárðardalur lava flow (Hjartarson, 2004), also belongs to this very large volcanic system. Finally, improved volumetric data and age determinations are needed for quantitative treatment and comparison of the magma productivity between different volcanic systems above the mantle plume.

CONCLUSIONS

Isotope ratios of Sr and Nd are relatively uniform for a given volcanic system above the Iceland mantle plume and the delineation of these systems can be readily achieved with radiogenic isotope ratios. The large Krepputunguhraun and Fjallsendahraun (Frambruni) lava fields, as well as the very recent Holuhraun and the older Holuhraun lava field, are shown to have originated within the Bárðarbunga volcanic system. These results amplify the magma productivity at Bárðarbunga during the Holocene, but also emphasize the complex inter-fingering of eruption fissures at the junction of Askja and Bárðarbunga volcanic systems.

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ÁGRIP

Eldstöðvakerfi eru grunneining í gosbeltum Íslands. Megineldstöð og sprungurein, eða hvort um sig, geta talist eldstöðvakerfi. Rekhrinunni 2014 í Bárðarbungu-Veiðivatnakerfinu lauk með sprungugosi í rein sem hefur verið talin til eldstöðvakerfis Öskju. Samsetning basaltsins sem upp kom er hins vegar mjög svipuð þeirri sem einkennir Veiðivatnareinina. Samsætumælingar Sr og Nd í þremur sýnum frá gosinu í Holuhrauni gefa sömu hlutföll ^{87}Sr/^{86}Sr og ^{143}Nd/^{144}Nd og mælst hafa í nútíma gosbergi Bárðarbungu-Veiðivatnakerfisins. Ólík hlutföll mælast í hraunum Öskjukerfisins og einnig í Þjórsárhrauni og tveim gömlum hraunum á jöðrum Veiðivatnareinarinnar. Ólík samsætuhlutföll í gosefnum aðliggjandi eldstöðvakerfa koma að notum við að finna hvaðan goseiningar eru ættaðar, sem er grundvöllur fyrir mati á gostíðni og kvikuframleiðni hvers eldstöðvarkerfis.

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