

Hot and heterogenous high-³He/⁴He components: New constraints from proto-Iceland plume lavas from Baffin Island

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S1. Supplementary Methods

S1.1. Rock preparation, crushing and powdering

Between 20 to 60 g blocks of the freshest interior portion of each sample were cut with a rock saw and sanded with silicon carbide paper to remove any surface contamination. The blocks were then cleaned by sonication in MilliQ H₂O ($\geq 18.2 \text{ M}\Omega \cdot \text{cm}$ de-ionized water). The 20 to 60 g rock blocks were crushed and powdered in an agate mill at the GeoAnalytical Lab at Washington State University (WSU) for major and trace element analyses. The agate mill was cleaned twice with silica between samples to avoid inter-sample contamination. For trace element analyses by ICP-MS, aliquots of powder were dissolved directly in acid in screw-top Teflon PFA vials on a hotplate without use of fusion flux (to reduce blank). For analysis of major (and a subset of trace) elements by X-ray fluorescence (XRF), sample powder was fused with lithium tetraborate to make beads.

For the 11 samples with volcanic glass, 300 mg of pristine glass was separated by hand picking for radiogenic isotopic analyses. For the 7 samples that do not have volcanic glass, additional portions of each sample were crushed with a hammer in a plastic bag and sieved. Between 300-400 mg of (0.5 to 1 mm) rock chips, targeting the freshest portions of the groundmass in the samples, were separated from the lavas for radiogenic isotopic analyses. The rock chips and glass were then cleaned by sonication in MilliQ H₂O. Rock chips were acid leached prior to dissolution, with no powdering step, due to the potential for blank contribution from the powdering apparatus (Takamasa and Nakai, 2009).

S1.2. Major and trace element analyses

The concentrations of major elements and select trace elements (Rb, Sr, Zn, Ni, Cr, V, Cu, Ga, Ba, Y, Nb, Zr) were determined by XRF at the WSU Geoanalytical Laboratory. Measurements of SiO₂, Al₂O₃, TiO₂, and P₂O₅ in basalts have a precision of 0.1 – 0.3% (1 σ)

of the amount present, and 0.4 – 0.7% (1σ) of the amount present for FeO, MgO, CaO, Na₂O, MnO and K₂O (Johnson et al., 1999).

Two USGS reference materials, BHVO-2 and BCR-2, were analyzed as unknowns together with the samples in this study. Major element analyses of two separate aliquots of the USGS reference material BCR-2 are within 2% of the preferred values from Jochum et al. (2016), with the exceptions of MgO (within 2.0 to 2.3%), Na₂O (2.3% for one of the aliquots), and P₂O₅ (4 to 5%). For BHVO-2 all major element analyses are within 1% except P₂O₅ (2.5%). A subset of the trace elements (Sr, Zn, Cu, Ga, Ba, Y, V and Rb) measured by XRF on the BCR-2 reference material are within 6% of the preferred measured values from Jochum et al. (2016) except for Ni (9%), Ga (10%), and Cr (21 to 44 %). The BHVO-2 XRF trace element measurements generally showed better agreement with the preferred literature values from Jochum et al. (2016), and are within 2% of the preferred Jochum et al. (2016) values, except for Ba (6%), Nb (11%), and Rb (19%).

A suite of trace elements (Cs, Rb, Ba, Th, U, Nb, Ta, La, Ce, Pb, Pr, Nd, Sr, Zr, Hf, Sm, Eu, Gd, Tb, Dy, Ho, Y, Er, Tm, Yb, Lu, Sc) were measured by inductively coupled plasma mass spectrometry (ICP-MS) at WSU and instrumental drift was corrected for using Rh, In, and Re internal standards. Knaack et al. (1994) previously reported the precision for trace element analysis using this method. For the BCR-2 and BHVO-2 reference materials analyzed in this study, most trace element concentrations are within 5% of the Jochum et al.'s (2016) preferred values for both reference materials (BCR-2 and BHVO-2). Analyses of the remaining trace elements (Cs, Th, U, Ta, Pb, Sm, Eu, Tb, Dy, Ho, and Er) agree to within 12% or better of Jochum et al.'s (2016) published values for both reference materials. Major and trace element data for aliquots of BHVO-2 and BCR-2 reference basalt powders, processed as unknowns with the Baffin Island samples within the same analytical session, are presented in Table 2.

S1.3. Olivine major and trace elements

Olivine grains from each sample were picked under a binocular microscope from 500-850 micron crushed whole rock fractions. Grains with visible alteration were avoided. Approximately 10 to 15 different grains from each sample were then placed into epoxy mounts, polished, and carbon coated for electron probe microanalysis on the Cameca SX-100 electron microprobe at the University of California Santa Barbara. Primary standards used were synthetic Mg_2SiO_4 (synthetic forsterite) for Mg, Si; Fe_2SiO_4 (synthetic fayalite) for Fe; MnO synthetic for Mn; Ni_2SiO_4 (synthetic) for Ni; diopside (Chesterman) for Ca; orthoclase MAD-10 for Al; and chromite (UC # 523-9) for Cr. Matrix correction was performed using ZAF or Phi-Rho-Z calculations and the mass absorption coefficients dataset were from FFAST.

S1.4. Helium isotopic analysis

Between 73 to 274 mg of the freshest olivine crystals, selected by visual inspection under a binocular microscope, were separated from the Baffin Island lavas for He isotopic analyses. Analyses were carried out at the Woods Hole Oceanographic Institution in the Isotope Geochemistry Facility following methods presented in Kurz et al. (2009; 2004). Samples were crushed *in vacuo*, and then analyzed on a dual-collection, statically operated He isotope mass spectrometer. Following crushing, powders from several olivine samples (AK-8b, AK-9, and DB-17) were selected for fusion *in vacuo*. The helium released by fusion from the sample with highest crush $^3\text{He}/^4\text{He}$ ratio (56.6 R_A), AK-9, has relatively high $^3\text{He}/^4\text{He}$ ratios (36.3 R_A) from fusion. The helium concentration measured by crushing in this sample is extremely low, resulting in large blank corrections, and the measurement is not considered to reflect mantle $^3\text{He}/^4\text{He}$. Sample DB-17, with 31.2 R_A by crushing, has low $^3\text{He}/^4\text{He}$ from the fusion experiment (6.4 R_A) and does not suggest a cosmogenic ^3He component. Finally, AK-8b (39.9 R_A) was also selected for $^3\text{He}/^4\text{He}$ analysis by fusion of crushed powders, and the fusion analyses yielded a $^3\text{He}/^4\text{He}$ of 20.8 R_A which is not consistent with a cosmogenic ^3He being responsible for the elevated $^3\text{He}/^4\text{He}$ in the crush experiment.

Helium gas concentrations varied from 6.15×10^{-11} to 2.3×10^{-8} cc ^4He STP/g for crush experiments, and in-run precision was ± 0.1 to ± 1.1 R_A (1σ) on the $^3\text{He}/^4\text{He}$ measurements. Additionally, two $^3\text{He}/^4\text{He}$ analyses were made on one sample (AK-13): one by crushing an olivine megacryst (28.8 R_A) and one by crushing multiple smaller olivine crystals (21.5 R_A). Helium isotopic compositions are summarized in Table 2.

S1.5. $\delta^{18}\text{O}$ methods

Oxygen isotopic compositions of olivines from a subset of the Baffin Island lavas in this study (Table 3) were analyzed by laser fluorination in the Stable Isotope Laboratory at the University of Oregon. Multiple olivine grains from a single rock sample were pooled for each oxygen isotopic analysis, with total olivine mass analyzed ranging from 0.9 to 1.7 mg. Oxygen isotopic analyses follow the methods described in Bindeman et al. (2008). A 35W CO_2 -laser was used, and olivines were reacted with purified BrF_5 to release oxygen. Gases were purified cryogenically using liquid N_2 and by using a Hg-diffusion pump to eliminate traces of F_2 gas formed by fluorination. Oxygen was then converted to CO_2 by reaction with platinum-graphite, and the yields were measured by a baratron gauge (all were at the 12.8 to 13.9 $\mu\text{mols/mg}$ range). Then the CO_2 was analyzed on a MAT 253 mass spectrometer. Internal precision varied from 0.07 to 0.10 ‰ (1 SD). The standards used with these analyses include San Carlos olivine ($\delta^{18}\text{O} = 5.25$ ‰), Gore Mt Garnet (UWG2, $\delta^{18}\text{O} = 5.80$ ‰, Valley et al., 1995) and OUG University of Oregon Garnet ($\delta^{18}\text{O} = 6.52$ ‰). Olivines from 13 lavas were analyzed, 11 of which had duplicate or triplicate analyses, where different olivines were selected for the replicate analysis: analyses of different olivine from the same hand sample agree to within 0.01 to 0.28 ‰. $\delta^{18}\text{O}$ of standards varied 0.01 to 0.14 ‰ over the course of the study, and were used to correct for day-to-day variability and absolute oxygen isotopic compositions on the SMOW scale.

S1.6. Sr, Nd, Hf, and Pb isotopic analyses

Prior to dissolution, all samples were acid leached at the Ecole Normale Supérieure de Lyon (ENS Lyon) following the “light leach” method of Price et al. (2014). Wet chemistry,

including sample dissolution and separation of Hf and Pb, follows Blichert-Toft and Albarède (2009). Hf and Pb isotopic compositions were determined using the multi-collector (MC-)ICP-MS Nu Plasma 500 HR housed at ENS Lyon.

Hf isotopic ratios were corrected for mass fractionation assuming an exponential law and assuming a $^{179}\text{Hf}/^{177}\text{Hf}$ ratio of 0.7325. ^{173}Yb , ^{175}Lu , ^{181}Ta , and ^{183}W were monitored for isobaric interferences on masses 180 (^{180}W and ^{180}Ta) and 176 (^{176}Lu and ^{176}Yb), but corrections were nominal. The JMC-475 standard was analyzed repeatedly throughout Hf analytical sessions, and always overlap with the preferred value of 0.282163 ± 0.000009 (Blichert-Toft et al., 1997); samples were thus not renormalized for offset between measured and preferred $^{176}\text{Hf}/^{177}\text{Hf}$ values. New Hf-isotopic data are reported in Table 1.

Pb isotopic compositions were corrected for mass bias by Tl-addition, assuming an exponential law and a $^{205}\text{Tl}/^{203}\text{Tl}$ ratio of 2.388; ^{202}Hg was monitored to make the isobaric correction for ^{204}Hg on mass 204. Sample unknowns were corrected for the offset between measured and preferred (from Eisele et al., 2003) values for NBS981. External reproducibility is estimated based on repeat analyses of SRM981, and is 100 to 200 ppm for $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, and $^{208}\text{Pb}/^{204}\text{Pb}$, and 50 ppm for $^{207}\text{Pb}/^{206}\text{Pb}$ and $^{208}\text{Pb}/^{206}\text{Pb}$. New Pb-isotopic data are reported in Table 1.

Sr and the rare earth element (REE) fractions were collected from the HBr washes from the Pb chemistry at ENS Lyon described above. The Sr fractions were brought up and dried down in 8N HNO_3 twice to get rid of any residual HBr from Pb extraction. At UCSB, the Sr fractions were brought up and dried down in 8N HNO_3 twice to eliminate any residual HBr from Pb extraction at Lyon. Samples were then brought up in 3N HNO_3 at 120°C for 30 minutes, sonicated for 30 min, and then centrifuged for 4 to 5 minutes. Eichrom Sr-spec columns were made from custom cut and acid-cleaned 1 mL pipette tips each containing ~100 μL of Sr-spec resin (see Price et al., 2017). After Sr was collected from the first round of Sr-spec columns, each sample went through its respective Sr-spec column a second time for final collection of Sr. At UCSB, the REE fractions from Lyon were brought up and dried down in 8N HNO_3 twice to eliminate any residual HBr from Pb extraction. Samples were then brought up in 1N HNO_3 at 120°C for 30 minutes,

sonicated for 30 min, and then centrifuged for 4 to 5 minutes. Neodymium was separated from the REE fractions using a two-column procedure. First, Eichrom Tru-spec resin was added to custom cut and acid-cleaned 1 mL pipette tips and the REE fractions were passed through the resin and relevant REE fractions were collected (see Price et al., 2017). The collected REE fractions were then passed through LN resin column to purify Nd (see Price et al., 2017).

Strontium isotopic analyses were performed by thermal ionization mass spectrometry (TIMS) on a Thermo Scientific Triton Plus™ Multicollector Thermal Ionization Mass Spectrometer at the University of California Santa Barbara (UCSB). Approximately 500 ng of Sr (dissolved in 3 N HNO₃) was loaded with TaCl ion emitter onto zone refined Re filaments (99.999% pure, from H Cross USA) using a parafilm dam to control for sample location on the filament. The NBS987 Sr standard was measured every 3-4 samples during each of three analytical sessions. Analyses used 10¹¹ Ω resistors in the amplifier feedback loop, with a 3.3 picoamp gainboard, and typical beam intensities were 4 V (on 10¹¹ Ω resistors) on mass 88. Analyses consisted of ~75 minutes of analysis (21 minutes of which consisted of baseline measurements), with amplifier gains analyzed every three or four samples. Amplifier rotation was used for all analyses, and baselines were taken before each block (where five blocks—to rotate each amplifier through the five cups collecting intensities on masses 84, 85, 86, 87, and 88—constitute a full rotation of the amplifiers). The average ⁸⁷Sr/⁸⁶Sr value of the NBS987 Sr standards during the first analytical session was 0.710246 ± 0.000008 (2SD, N=4), 0.710248 ± 0.000013 (2SD, N=5) for the second analytical session, and 0.710248 ± 0.000013 (2SD, N=2) for the third analytical session. The measured ⁸⁷Sr/⁸⁶Sr ratios for all samples and USGS reference materials are corrected for the offset between preferred (0.710240) and measured ⁸⁷Sr/⁸⁶Sr values for NBS987 within each analytical session (i.e., a single barrel). The ⁸⁸Sr/⁸⁶Sr ratio was used to correct for mass fractionation using the exponential law and assuming a canonical ⁸⁶Sr/⁸⁸Sr ratio of 0.1194. Interference correction for ⁸⁷Rb was nominal and was performed by measuring ⁸⁵Rb and assuming a canonical ratio of ⁸⁷Rb/⁸⁵Rb = 0.386. At least one of two USGS reference materials (AGV-2 and BCR-2) was run with each analytical session, processed with Baffin

Island sample unknowns through column chemistry at UCSB. After correction to the preferred NBS987 value, the average measured $^{87}\text{Sr}/^{86}\text{Sr}$ for AGV-2 was $0.703968 (\pm 0.000007 \text{ 2SD, } N=3)$ and for BCR-2 was $0.705000 (\pm 0.000005 \text{ 2SE, } N=1)$ (Table 2). The AGV-2 and BCR-2 yielded $^{87}\text{Sr}/^{88}\text{Sr}$ ratios within error of values reported by Weis et al. (2006): 0.703973 ± 0.000010 (2SD, $N=10$) and 0.705005 ± 0.000011 (2SD, $N=13$), respectively, after renormalization of their data to the preferred NBS987 values used here. The total Sr procedural blanks were <60 pg.

Neodymium isotopic compositions were also run by TIMS at UCSB. Approximately 200 ng of Nd, dissolved in 1N HNO_3 , was loaded onto zone refined Re filaments (99.999% pure, from H Cross USA) using a parafilm dam. Analyses used $10^{11} \Omega$ resistors in the feedback loop of the amplifiers, with a 3.3 picoamp gainboard, and typical beam intensities were 2.5 V (on $10^{11} \Omega$ resistors) on mass 144. Analyses were typically ~75 minutes (21 minutes of which consisted of baseline measurements), with amplifier gains measured every three or four samples. Amplifier rotation was used for all analyses, and baselines were taken before each block (where five blocks—to rotate each amplifier through the five cups collecting intensities on masses 143, 144, 146, 147, and 150—constitute a full rotation of the amplifiers). Isotopic compositions were corrected for instrumental mass fractionation relative to $^{146}\text{Nd}/^{144}\text{Nd}$ of 0.7219 using the exponential law. Multiple JNdi Nd standards were run during each of four analytical sessions (i.e., where each analytical session consists of a single barrel) and gave the following averages: $^{143}\text{Nd}/^{144}\text{Nd}$ of 0.512100 ± 0.000004 (2SD, $N=5$); $^{143}\text{Nd}/^{144}\text{Nd}$ of 0.512100 ± 0.000005 (2SD, $N=4$); $^{143}\text{Nd}/^{144}\text{Nd}$ of 0.512101 ± 0.000005 (2SD, $N=6$); and $^{143}\text{Nd}/^{144}\text{Nd}$ of 0.512098 ± 0.000005 (2SD, $N=2$). The measured $^{143}\text{Nd}/^{144}\text{Nd}$ ratios for all USGS reference materials and unknowns are corrected for the offset between the measured and the preferred JNdi $^{143}\text{Nd}/^{144}\text{Nd}$ of 0.512099 (Garçon et al., 2018). The total procedural Nd blank was <5 pg. Interference correction for ^{144}Sm on ^{144}Nd was negligible, and was performed by measuring ^{147}Sm . Aliquots of the USGS reference material, BCR-2, were processed with unknowns through column chemistry at UCSB and run during each TIMS analytical session. Following renormalization to the preferred JNdi value within each analytical session, the

average measured $^{143}\text{Nd}/^{144}\text{Nd}$ for BCR-2 was 0.512623 ± 0.000006 (2SD, N=4) (Table 2). The average BCR-2 value from Weis et al. (2006) is 0.512618 ± 0.000012 (2SD, N=11) (after renormalizing their data to the preferred JNdi reference frame and using the La Jolla to JNdi conversion of 1.000503 from Tanaka et al. [2000]).

S2 Supplementary data treatment methods

S2.1. Filtering for crustal contamination

A primary goal of this study is to identify the mantle source composition of Baffin Island and West Greenland flood basalt lavas. Because these lavas traversed Precambrian continental crust *en route* to the surface, we used MgO contents and two trace element ratios, Nb/Th and Ce/Pb, to identify samples least impacted by crustal contamination to gain insight into primary isotopic ratios.

Lavas with low MgO concentrations erupted in continental settings often have signatures of crustal assimilation (e.g., Hoernle et al., 2015). Therefore, lavas with MgO <10 wt.% are excluded from consideration here (Figure 2). Mantle-derived lavas produced from high degrees of melting (where the degree of melting [F] is \gg than the partition coefficients [D] of the incompatible trace elements of interest) have relatively constant Nb/U and Ce/Pb (~ 47 and ~ 25 respectively; Hofmann et al., 1986). These ratios are useful for identifying assimilation of continental crust due to the low values of both ratios in upper (4.44 to 3.71; Rudnick and Gao, 2003) and bulk (6.15 to 3.91; Rudnick and Gao, 2003) continental crust. By comparison Nb/U and Ce/Pb ratios are significantly higher and relatively constant in global normal MORB (Nb/U = 44.0 ± 1.2 (1σ) and Ce/Pb = 24.0 ± 0.5 (1σ) using the Gale et al. [2013] database, and Nb/U = 46.5 ± 7.6 (1σ) and Ce/Pb = 24.3 ± 4.3 (1σ) using the Jenner and O'Neill [2012] database).

However, because U is mobile, the Nb/U ratio can be modified during weathering. We therefore use Nb/Th instead, as U and Th are similarly incompatible and Th is relatively immobile during weathering. Hence, like Nb/U, Nb/Th in melts should reflect the mantle ratio during high degrees of melting (Hofmann, 2003). Nb/Th is also relatively constant in oceanic lavas: Nb/Th = 14.3 ± 2.9 (1σ) (Gale et al., 2013) or 15.6 ± 2.6 (1σ) (Jenner and

O'Neill, 2012). Compared to MORB, Nb/Th is low in both upper (1.14, Rudnick and Gao, 2003) and bulk (1.43, Rudnick and Gao, 2003) continental crust. Therefore, like both Ce/Pb and Nb/U, the Nb/Th ratio is a sensitive tracer of continental crust assimilation in mantle-derived basalts erupted in continental settings.

We further consider the Baffin Island (this study, Jackson et al., 2010; Kent et al., 2004; Robillard et al., 1992; Starkey et al., 2009; Stuart et al., 2003; Yaxley et al., 2004) and associated West Greenland flood basalt lavas (Larsen and Pedersen, 2009; Starkey et al., 2009) to be contaminated if they have Nb/Th or Ce/Pb one standard deviation below the average of global MORB glasses by (Jenner and O'Neill, 2012; based on glass analyses made in the same lab). Thus, lavas with Nb/Th < 13.0 and/or Ce/Pb < 20.0 are excluded from consideration here.

We acknowledge the possibility that a crustal endmember could contaminate a given lava, yet remain undetected by the present trace element filters. For example, if the isotopic composition of the crustal endmember is significantly different from that of the primary melt, and concentration of that element is relatively high in the primary melt compared to the continental crust, it is conceivable that a very small fraction of continental crust could change the isotopic composition of the resulting lava yet have little impact on the whole-rock trace element ratios. We therefore conservatively refer to Baffin Island and West Greenland lavas with mantle-like Nb/Th (>13) and Ce/Pb (>20), and high MgO (>10 wt.%), as being "least contaminated", instead of "uncontaminated". Additionally, we cannot evaluate a potential continental signature in lavas that lack MgO, Ce/Pb, and Nb/Th data, hence such lavas are excluded from discussion. Oxygen isotopes provide another means of evaluating crustal assimilation. However, due to the lack of olivine $\delta^{18}\text{O}$ measurements from many Baffin Island-West Greenland lavas from previous studies, we do not use $\delta^{18}\text{O}$ as a filter for crustal contamination for the extensive dataset examined here. Instead, after filtering lavas for crustal assimilation using MgO, Nb/Th, and Ce/Pb, we examine the $\delta^{18}\text{O}$ of the least contaminated lavas to evaluate whether they have mantle-like compositions.

Finally, West Greenland lavas considered to be melts of a metasomatized source by (Larsen et al., 2003) are also excluded from further discussion (but shown in the figures

with separate symbols). We find such lavas to be enriched in Ba (i.e., Ba/Th > 100), hence all such lavas are excluded from consideration.

S2.2. Treatment of MORB geochemical database for comparison with Iceland plume lavas

We compare proto-Iceland plume lavas from Baffin Island-West Greenland with MORB using the database of Gale et al. (2013). In figures and subsequent discussion of radiogenic isotopic (Sr, Nd, Hf, Pb) compositions (see Sections 3.4 and 3.6), we exclude back arc basin lavas and MORB influenced by known hotspots (i.e., MORB samples located <500 km from known hotspots, following Gale et al. [2013] while employing the hotspot database of King and Adam [2014]). Additionally, for major element investigation of MORB in this study (Figures 2, 3, and Section 3.1), we use the Siqueiros MORB from Perfit et al. (1996) and Hays (2004). We filter Siqueiros MORBs with MgO < 10 wt. % to simplify calculation of primary liquids (by avoiding highly differentiated melts; Figure 3), and to facilitate direct comparison with Baffin Island and West Greenland lavas (which are also filtered to exclude MgO < 10 wt.%).

S2.3. Radiogenic isotopic age corrections and calculation of modern mantle source compositions

In order to compare the isotopic compositions of the much older (~60 Ma) “least contaminated” Baffin Island lavas to the mid-Miocene and modern neovolcanic zone Iceland lavas, it is necessary to consider the influence of post-eruptive radiogenic ingrowth on the radiogenic isotopic compositions. Therefore, in Supplementary Table 3, the Sr, Nd, Hf, and Pb isotopic compositions are age-corrected to 60 Ma. This age correction gives the compositions of the Baffin Island mantle at 60 Ma; however, to facilitate comparison with modern Iceland lavas, the composition of the Baffin Island mantle source today (assuming it had not experienced melt extraction at 60 Ma) must be determined. To do this, we start with the initial values from the calculated radiogenic isotopic compositions of Baffin Island lavas at 60 Ma, which reflect the Baffin Island mantle source at the time of

flood basalt eruption. We then assume parent-daughter ratios for the Baffin Island mantle source to forward “age” the radiogenic isotopic compositions of the Baffin Island mantle source from 60 Ma to the present day (Supplementary Figure 2). The primary uncertainty in this calculation is the relevant parent-daughter ratios for each radiogenic isotopic system in the Baffin Island mantle source. In this regard, we note that the Nd isotopic compositions of the Baffin Island lavas provide a constraint on possible trace element compositions of the Baffin Island mantle source at 60 Ma. For example, the $^{143}\text{Nd}/^{144}\text{Nd}$ of the least contaminated Baffin Island lavas overlap with MORB (excluding back arc basins and samples <500 km from known hotspots) (see Section 3.4), but are more geochemically depleted (more radiogenic) than chondrites (0.512630; Bouvier et al., 2008). Therefore, the Baffin Island mantle source, prior to melt extraction at 60 Ma, was unlikely to have a trace element source more geochemically depleted than depleted MORB mantle (DMM), or more geochemically enriched than chondritic. Thus, the parent-daughter ratios for DMM (Workman and Hart, 2005) and bulk silicate Earth (BSE, or pyrolite; McDonough and Sun, 1995) are used to “bracket” the lower and upper limits, respectively, of the incompatible trace element composition of the Baffin Island mantle source, and thus the range of calculated radiogenic isotopic compositions of a present-day Baffin Island mantle source (see Supplementary Figure 2 for a schematic representation of this calculation). The difference in radiogenic isotopic compositions for the calculated Baffin Island mantle today, whether using DMM or BSE as trace element source compositions in the calculation, is minimal, and fields for the present-day mantle source isotopic compositions in relevant figures encompass the range of isotopic values arising from the DMM and BSE limits (Supplementary Table 3). In fact, the offset among measured, age-corrected, and calculated present-day Baffin Island mantle source fields is small in all isotopic spaces (see Supplementary Figure 3), with measured and calculated present-day Baffin Island mantle source isotopic compositions being most similar; of course, for the younger mid-Miocene Iceland lavas, the differences are even smaller (Supplementary Figure 3). We do not attempt to age-correct the $^3\text{He}/^4\text{He}$ data. Nonetheless, after excluding an influence of cosmogenic ^3He , measured $^3\text{He}/^4\text{He}$ ratios from olivine in vacuo crushing experiments will

most likely be lower than the original mantle source compositions due to eruptive degassing followed by post-eruptive generation of ^4He .

S3. Supplementary Discussion

S3.1. Modelled crustal assimilation scenarios

A goal of this modelling exercise to evaluate whether the Baffin Island and high $^3\text{He}/^4\text{He}$ Iceland mantle sources have different Pb-isotopic compositions, or whether the difference in their Pb-isotopic compositions is the result of continental crust to an Iceland-like high $^3\text{He}/^4\text{He}$ endmember to generate the Pb-isotopic compositions in the least contaminated Baffin Island lavas. Selecting the most representative basement composition for this test is challenging because the Pb isotopic compositions of the basement samples envelop the Baffin Island-West Greenland field (Figure 9), making it difficult to discern the direction of a contamination trend in Pb-isotopic space. Additionally, no single available basement sample can be mixed with the highest $^3\text{He}/^4\text{He}$ Iceland lava composition to produce the Pb isotopic compositions of the least crustally contaminated Baffin Island lavas. However, after many iterations of modelling individual and combined basement compositions, we find that combining basement samples 177375 (Karrat Group gneiss) and 113450 (Nordfjord shale), combined in equal proportions by mass, yields a successful crustal endmember composition. That is, the Pb isotopic composition of this crustal composition, when mixed with the highest $^3\text{He}/^4\text{He}$ Iceland lava, can successfully generate the $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$, and $^{208}\text{Pb}/^{204}\text{Pb}$ isotopic compositions of the least crustally contaminated Baffin Island lavas with 3% continental crust contribution; see black mixing line in Supplementary Figure 4). At face value, this would imply that the difference between Baffin Island and Iceland high $^3\text{He}/^4\text{He}$ lavas is simply the result of 3% addition of continental crust to an Iceland-like high $^3\text{He}/^4\text{He}$ endmember. However, there are geochemical consequences for this mixing scenario that make it untenable. For example, the hypothetical mixture of basement (3%) and the high- $^3\text{He}/^4\text{He}$ Iceland lava (97%) yields

a Ce/Pb of 11.0 and a Nb/Th of 8.7, values that are far lower than the Ce/Pb and Nb/Th ratios in the four least crustally contaminated Baffin Island lavas in this study (21.7 - 24.1 and 13.3 - 13.9, respectively). Additionally, this mixing scenario fails for Sr and Nd isotopes because it predicts higher $^{87}\text{Sr}/^{86}\text{Sr}$ and lower $^{143}\text{Nd}/^{144}\text{Nd}$ than observed in the four least contaminated Baffin Island lavas.

To solve the problems associated with $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ in the mixing model above, we develop a hypothetical uncontaminated Baffin Island endmember with lower $^{87}\text{Sr}/^{86}\text{Sr}$ and higher $^{143}\text{Nd}/^{144}\text{Nd}$. Therefore, we explore a mixing scenario where the hypothetical uncontaminated Baffin Island endmember has Pb isotopic compositions like the highest $^3\text{He}/^4\text{He}$ Iceland lava, but with lower $^{87}\text{Sr}/^{86}\text{Sr}$ and higher $^{143}\text{Nd}/^{144}\text{Nd}$, such that a mixture of this composition with basement will generate the observed Sr, Nd, and Pb isotopic compositions in the least contaminated Baffin Island lavas (see blue mixing line in Supplementary Figure 4). In order for the hypothetical uncontaminated Baffin Island melt with Iceland-like Pb isotopes to acquire, through crustal assimilation, the $^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$ and Pb-isotopic compositions observed in the least contaminated Baffin Island lavas, the $^{143}\text{Nd}/^{144}\text{Nd}$ must be relatively high (approximately 0.5134) and the $^{87}\text{Sr}/^{86}\text{Sr}$ must be very low (approximately 0.7025) (where the Sr and Nd isotopic compositions are chosen to “force” the model to successfully capture the Sr, Nd, and Pb isotopic compositions of the least contaminated Baffin Island lavas measured in this study; see blue mixing line in Supplementary Figure 4). The successful model also requires ~3% continental crust, but this also results in Ce/Pb (11.0) and Nb/Th (8.7) ratios in the hypothetical mixture that are much lower than observed in the least contaminated Baffin lavas (21.7 to 24.1 and 13.3 to 13.9, respectively). Thus, an important conclusion of this modelling exercise is that, even if we design a hypothetical uncontaminated Baffin Island endmember that will force the mixing model (i.e., mix continental crust with hypothetical uncontaminated Baffin Island lavas) to generate the Sr, Nd, and Pb radiogenic isotopic compositions measured in the least crustally contaminated Baffin Island lavas, such a mixing scenario can be rejected because the resulting Ce/Pb and Nb/Th ratios in the mixture are much lower than observed in these four lavas. We find this result to be true

for a range of continental crust compositions, owing to the high concentrations of Pb and Th, and low Ce/Pb and Nb/Th, in continental crust compared to the lavas: even small quantities of continental crust in Baffin Island lavas quantitatively reduce the Ce/Pb and Nb/Th ratios in crustally contaminated lavas. In summary, we cannot generate the Sr, Nd, and Pb isotopic compositions and Ce/Pb and Nb/Th ratios of the least contaminated Baffin Island lavas by mixing the Iceland high $^3\text{He}/^4\text{He}$ component with continental crust. The implication of this modelling exercise is that the Baffin Island source has distinct Sr, Nd, and Pb isotopic compositions from the Iceland high $^3\text{He}/^4\text{He}$ mantle. Indeed, the four least contaminated Baffin Island lavas are likely to have Sr, Nd, and Pb isotopic compositions very close to their original uncontaminated compositions, as evidenced by their mantle-like Nb/Th, Ce/Pb, and $\delta^{18}\text{O}$ compositions.

S3.2. Signals from ^{142}Nd

The ^{146}Sm – ^{142}Nd decay system is another short-lived isotopic system that has produced isotopic anomalies in modern mantle-derived rocks (Horan et al., 2018; Peters et al., 2018). ^{146}Sm has a half-life of 103 Ma, and therefore was extant for only ~500 million years following Solar System formation. Due to the lithophile nature of Sm and Nd (assuming the core is not highly enriched in sulfur; Kiseeva and Wood, 2015), the presence of ^{142}Nd anomalies in modern plume-derived lavas would record the preservation of an early silicate differentiation event. Pairing of ^{182}W and ^{142}Nd can provide additional constraints on the timing and processes that produced Hadean signatures preserved in hotspot lavas. However, Baffin Island lavas from two studies do not show resolvable $\mu^{142}\text{Nd}$ differences from the terrestrial standard: de Leeuw et al. (2017) measure an average $\mu^{142}\text{Nd}$ of -1.4 ± 6.3 ppm (2SD, $N = 15$), and (Rizo et al., 2016) measured an average $\mu^{142}\text{Nd}$ of 4.0 ± 5.4 ppm (2SD, $N = 7$) (where $\mu^{142}\text{Nd} = 10^6 \times [^{142}\text{Nd}/^{144}\text{Nd}_{\text{sample}} - ^{142}\text{Nd}/^{144}\text{Nd}_{\text{terrestrial standard}}] / ^{142}\text{Nd}/^{144}\text{Nd}_{\text{terrestrial standard}}$, and the terrestrial standard is JNdi). Furthermore, Andreasen et al. (2008) and Debaille et al. (2007) did not identify resolvable $\mu^{142}\text{Nd}$ anomalies in lavas from Iceland, including mid-Miocene lavas. A question that arises is whether the Iceland lavas with $\mu^{182}\text{W}$ anomalies have $\mu^{142}\text{Nd}$ anomalies: while Andreasen et al. (2008) did not

identify $\mu^{142}\text{Nd}$ anomalies in Iceland lavas, none of the Iceland samples containing $\mu^{182}\text{W}$ anomalies (Mundl et al., 2017; Mundl-Petermeier et al., 2019) were analyzed for $\mu^{142}\text{Nd}$ (and none of Iceland lavas analyzed for high-precision $^{142}\text{Nd}/^{144}\text{Nd}$ have been characterized for $^3\text{He}/^4\text{He}$).

Nonetheless, it is important to use the lack of resolvable $^{142}\text{Nd}/^{144}\text{Nd}$ anomalies as a constraint for any model for the origin of the Baffin Island mantle source. The least crustally contaminated Baffin Island lavas have superchondritic $^{143}\text{Nd}/^{144}\text{Nd}$ ($\epsilon^{143}\text{Nd} = +9.0$ to $+9.7$) and primitive Pb isotopic compositions that fall on or near the 4.50 Ga Geochron, and the Pb isotopic compositions are consistent with an early (~ 4.50 Ga) differentiation event that fractionated U from Pb. If U/Pb fractionation resulted from silicate differentiation, then silicate melt extraction from the mantle at 4.50 Ga would also have been expected to produce superchondritic Sm/Nd responsible for the positive (geochemically depleted) $\epsilon^{143}\text{Nd}$ in the residual mantle that became the source of Baffin Island mantle, and the superchondritic Sm/Nd would generate anomalously high $^{142}\text{Nd}/^{144}\text{Nd}$ (because differentiation occurred during the lifetime of ^{146}Sm). But no ^{142}Nd anomalies relative to the terrestrial standard are observed in Baffin lavas.

However, it is possible that the $^{142}\text{Nd}/^{144}\text{Nd}$ in the Icelandic plume source is distinct from the ambient upper mantle, but has been overprinted by mixing with upper mantle. The Iceland plume first erupted at Baffin Island and West Greenland in a rift environment as the Labrador Sea was spreading (Keen et al., 2012). Therefore, if a high $^3\text{He}/^4\text{He}$ mantle sampled by the Iceland plume interacted with local DMM ($\mu^{142}\text{Nd} = 0$) in the rifting environment, then plume's ^{142}Nd anomaly (if indeed there is one) could be greatly attenuated by mixing (de Leeuw et al., 2017). For example, if the Baffin Island lavas represent a mixture of the moderately high- $^3\text{He}/^4\text{He}$ plume mantle like that found in Reunion ($\mu^{142}\text{Nd} = 7.0 \pm 1.9$) and DMM ($\mu^{142}\text{Nd} = 0$), then mixing of these two reservoirs in 25:75 (Reunion:DMM) mixture would yield $^{142}\text{Nd}/^{144}\text{Nd}$ ($\mu^{142}\text{Nd} = 2.9$) indistinguishable from the terrestrial standard, assuming Nd concentrations for the two mantle sources of 1.25 ppm and 0.581 ppm, respectively (McDonough and Sun, 1995; Workman and Hart, 2005). This result is consistent with the lack of resolvable $^{142}\text{Nd}/^{144}\text{Nd}$ in Baffin Island lavas.

In this mixing scenario, the high- $^3\text{He}/^4\text{He}$ signature of the mixture (i.e., like that in the least crustally contaminated Baffin lavas) is not significantly overprinted by low $^3\text{He}/^4\text{He}$ of DMM if the plume mantle has at least ten times higher concentration of He compared to the DMM (e.g., de Leeuw et al., 2017) and the plume has a $^3\text{He}/^4\text{He}$ of 50 R_A and DMM is 8 R_A . For example, in the 25:75 mixing scenario, the $^3\text{He}/^4\text{He}$ of the mixture is 40.3 R_A (or 48.8 R_A) if the plume mixing endmember has 10 (or 100) times higher helium concentrations than the depleted upper mantle. If the $^3\text{He}/^4\text{He}$ of the plume is higher than 50 R_A , then achieving even higher $^3\text{He}/^4\text{He}$ in the mixture is feasible at even lower mixing proportions of the plume endmember.

Another possible model for Baffin Island lavas having $^{142}\text{Nd}/^{144}\text{Nd}$ similar to the terrestrial standard is discussed in de Leeuw et al (2017), who suggest that some, but not all (Bouvier and Boyet, 2016), of the $^{142}\text{Nd}/^{144}\text{Nd}$ difference between Earth and chondrites may still be attributed to ^{146}Sm decay in the early Earth's mantle. The Earth and enstatite chondrites appear to have the same nucleosynthetic mix for several elements including oxygen, Cr and Ti, but the $^{142}\text{Nd}/^{144}\text{Nd}$ of the accessible Earth is on the order of 8 to 10 ppm higher than the average measured for enstatite chondrites (Burkhardt et al., 2016; Gannoun et al., 2011). This difference in $^{142}\text{Nd}/^{144}\text{Nd}$ of the accessible Earth relative to enstatite chondrites could be the result of superchondritic Sm/Nd in the accessible Earth. For example, if we assume that the accessible Earth has $^{142}\text{Nd}/^{144}\text{Nd}$ that is 8 ppm higher than bulk Earth with enstatite chondrite-like $^{142}\text{Nd}/^{144}\text{Nd}$, then global differentiation of the silicate Earth at 4.4 Ga to from an incompatible element depleted reservoir with superchondritic Sm/Nd ($^{147}\text{Sm}/^{144}\text{Nd} = 0.2123$) would yield $\mu^{142}\text{Nd} = 0$ and a modern "PREMA-like" $^{143}\text{Nd}/^{144}\text{Nd} = 0.513105$. These $\mu^{142}\text{Nd}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ compositions match Baffin Island lavas (and, in particular, the $^{143}\text{Nd}/^{144}\text{Nd}$ of the least crustally contaminated lavas). In other words, if the bulk-Earth has $\mu^{142}\text{Nd} = -8$, then $\mu^{142}\text{Nd} = 0$ reflects an early-formed depleted mantle source that also would have superchondritic $^{143}\text{Nd}/^{144}\text{Nd}$ today. Global-scale differentiation of the Earth could be caused by a Moon-forming impact, which may have occurred as late as 4.4 Ga (e.g., Carlson, 2019). This leaves open the interpretation of Jackson et al. (2010) and Jackson and Carlson (2011), with the only

difference being that the early differentiation event is no longer limited to the first 30 Ma following terrestrial accretion by the assumption that the bulk-Earth has $\mu^{142}\text{Nd} = -20$, as would be the case if it had the same isotopic composition as ordinary chondrites, but instead can be pushed to later times following terrestrial accretion using an enstatite chondrite composition. The lack of correlation of $^{142}\text{Nd}/^{144}\text{Nd}$ and $^{182}\text{W}/^{184}\text{W}$ in high $^3\text{He}/^4\text{He}$ lavas is most easily explained if the event that fractionated Sm/Nd occurred after ^{182}Hf was dead as Hf/W also would be expected to fractionate during a magma ocean scenario. Additionally, ocean island basalts with reported $\mu^{142}\text{Nd}$ anomalies (i.e., $\mu^{142}\text{Nd} > 0$ or $\mu^{142}\text{Nd} < 0$), like those at Reunion (Peters et al., 2018), may reflect the range of Sm/Nd ratios in different reservoirs produced by the global differentiation event.

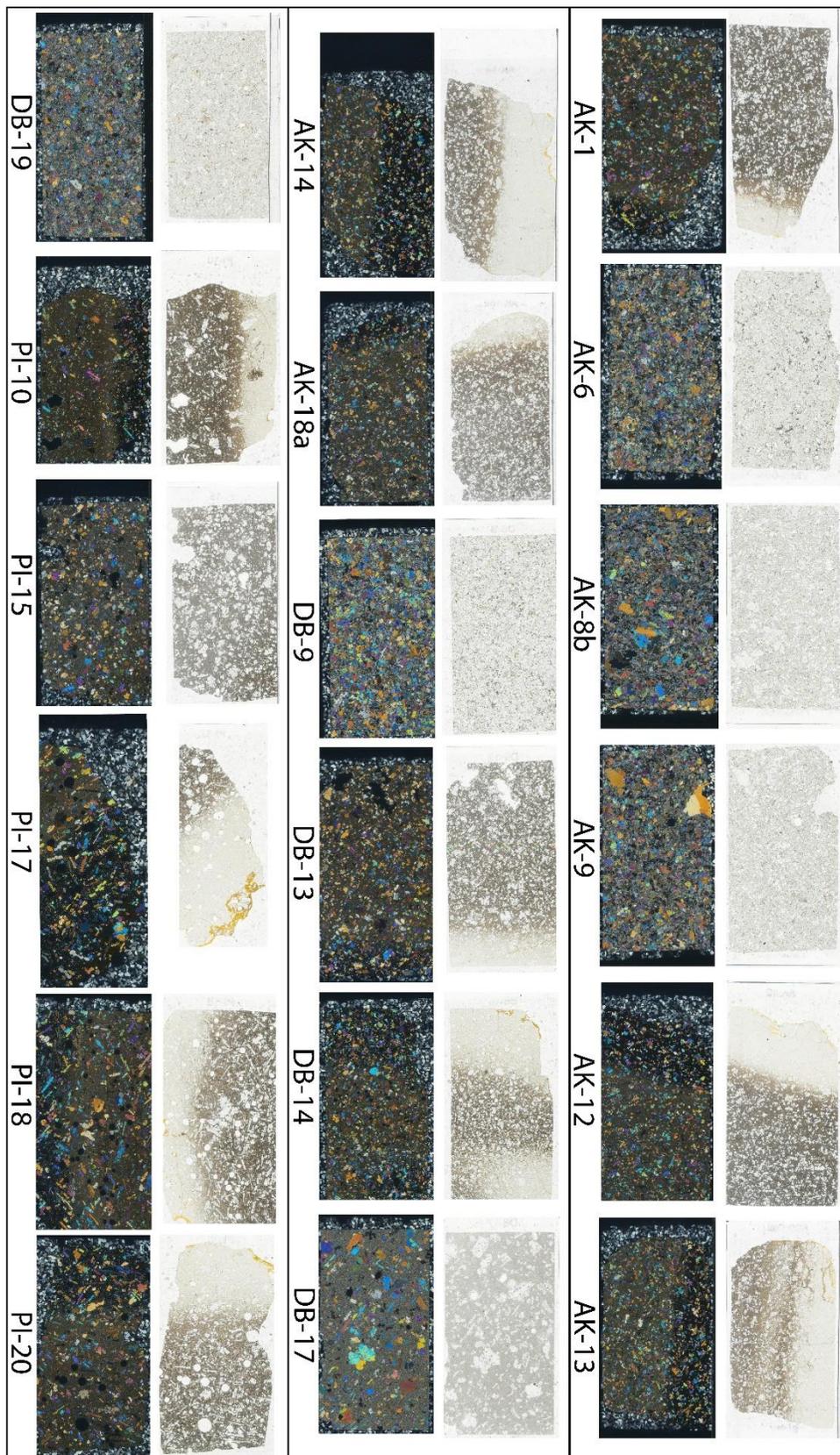


Figure S1. Thin sections (1" x 1 7/8") of the eighteen new Baffin Island lavas in this study are shown in plain polarized light and cross polarized light. Glassy margins are visible in a number of samples including: AK-8b, AK-12, AK-13, AK-14, AK-18a, DB-13, DB-14, PI-10, PI-17, PI-18, PI-20.

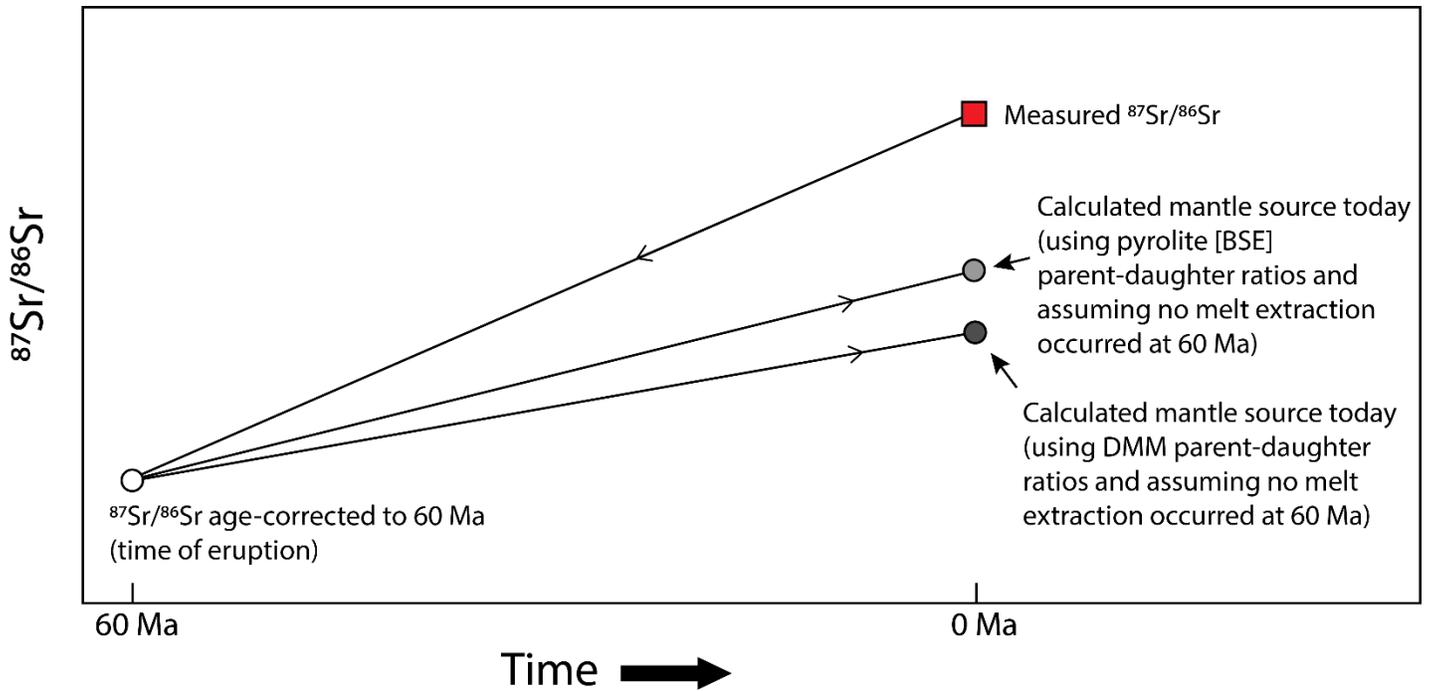


Figure S2. A schematic diagram illustrating the relationship between the measured $^{87}\text{Sr}/^{86}\text{Sr}$, age-corrected (to 60 Ma) $^{87}\text{Sr}/^{86}\text{Sr}$, and calculated present-day mantle source $^{87}\text{Sr}/^{86}\text{Sr}$. The age-corrected $^{87}\text{Sr}/^{86}\text{Sr}$ is calculated using the measured Rb/Sr and isotopic composition of the Baffin Island lavas and an eruption age of 60 Ma. In order to calculate the Baffin mantle source today, the age-corrected $^{87}\text{Sr}/^{86}\text{Sr}$ at 60 Ma is taken to be the starting mantle source composition. Assuming this mantle source did not undergo melt extraction at 60 Ma to generate Baffin Island lavas, the age-corrected $^{87}\text{Sr}/^{86}\text{Sr}$ is then “forward aged” from 60 Ma to 0 Ma using two different mantle source trace element compositions: For a depleted mantle scenario, the Rb/Sr from DMM [Workman and Hart, 2005] is used to calculate what the $^{87}\text{Sr}/^{86}\text{Sr}$ of the Baffin mantle source today would be if it had not experienced melt extraction at 60 Ma; for the other scenario, the Rb/Sr from pyrolite [McDonough and Sun, 1995] is used to calculate the $^{87}\text{Sr}/^{86}\text{Sr}$ of the Baffin mantle source today (see Supplement Section S.2.3). Of course, the Rb/Sr ratio of the Baffin Island mantle source is unknown, but the range of source trace element compositions captured by pyrolite and DMM provide upper and lower Rb/Sr limits on the possible range of the time evolution of radiogenic isotopic compositions of the Baffin Island mantle source. This is because the Baffin Island source is clearly more geochemically depleted than pyrolite (as evidenced by the geochemically depleted Sr, Nd, and Hf isotopic compositions in Baffin lavas), but not more depleted than DMM (again, as evidenced by the same radiogenic isotopic compositions).

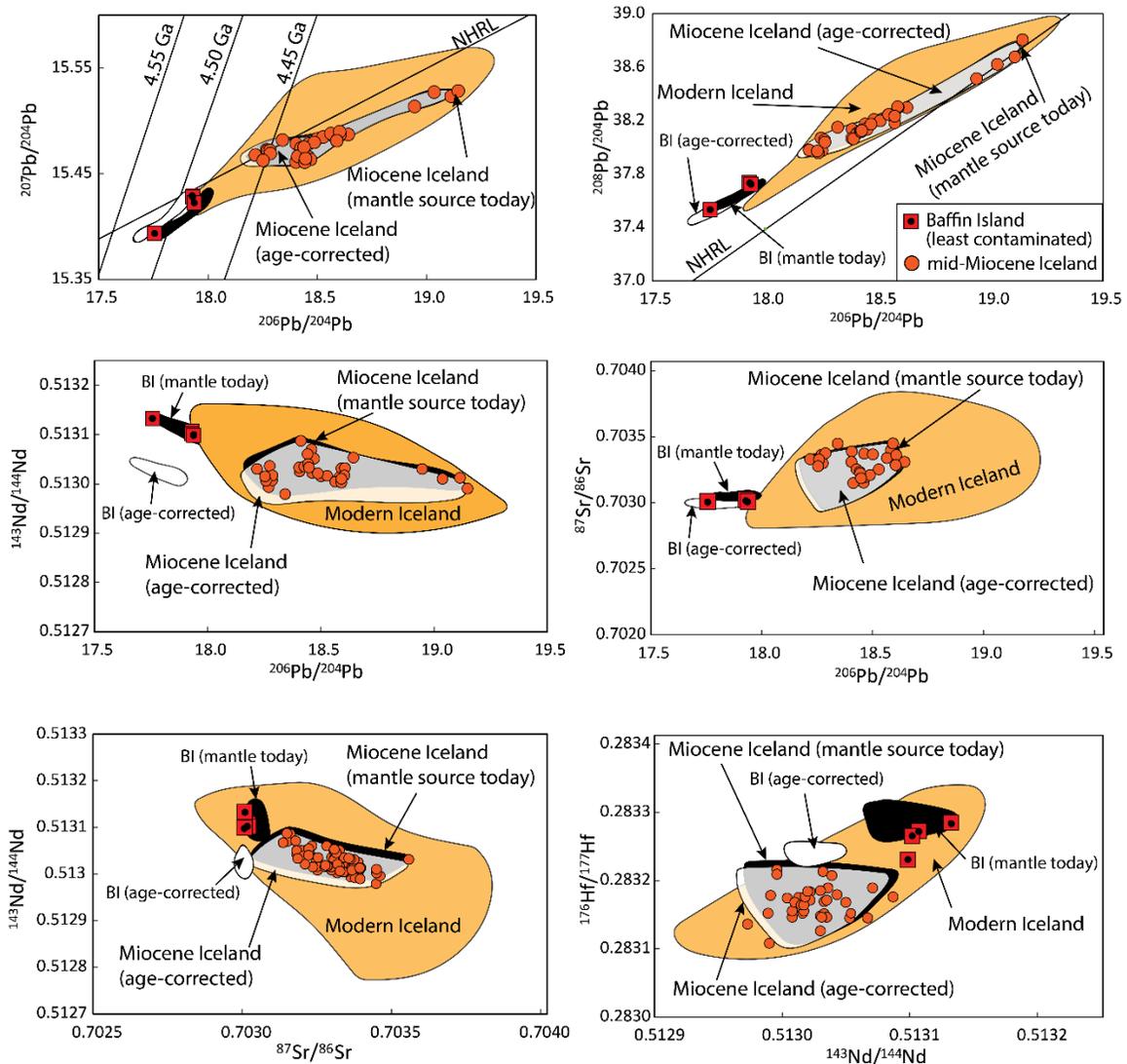


Figure S3. The measured isotopic ratios for Baffin Island (BI, red squares), and Miocene Iceland (orange circles), are shown with the field for their respective age-corrected data (white fields) and range of calculated mantle sources today (black fields). Only data with paired isotopic and parent-daughter trace element compositions (required for age correction and mantle source calculations) are shown. In all isotopic spaces, there is overlap between the measured ratios and the range of “calculated mantle today” ratios. Use of either measured or calculated present day radiogenic isotopic compositions for Baffin Island lavas does not change the conclusions of this study (see Section 3.4 of the text), but we argue that age-corrected radiogenic isotopic compositions of Baffin Island

lavas are difficult to meaningfully compare to radiogenic isotopic compositions in modern Iceland lavas. For Miocene to modern Iceland lavas, the offset among measured, age-corrected, and calculated mantle source today compositions is insignificant.

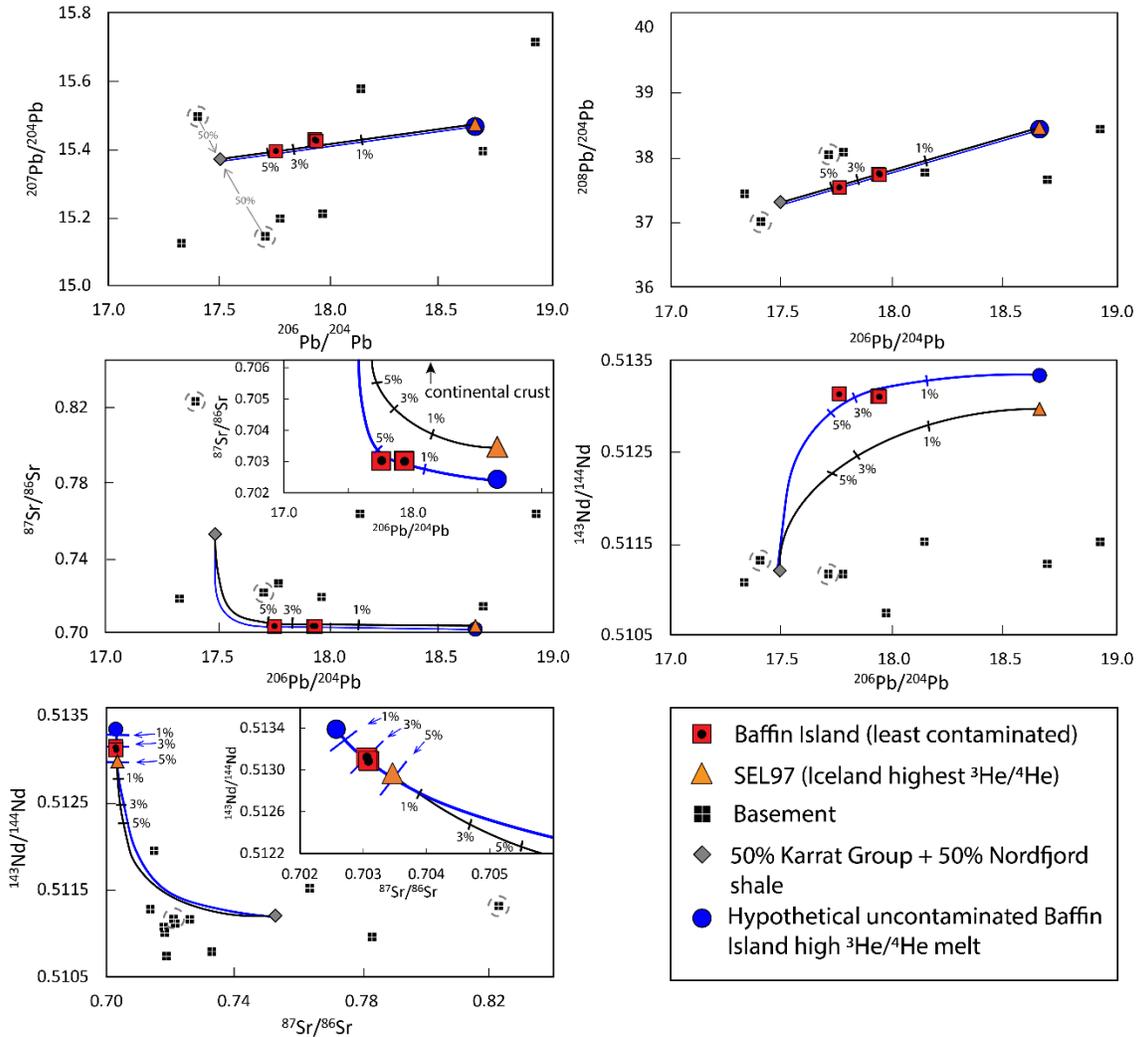


Figure S4. Two mixing models are shown here (see Section 4.1 of the text). The basement endmember is a mixture of 50% Karrat Group gneiss sample 177375 combined with 50% Nordfjord shale sample 113450 [radiogenic isotopic compositions and trace element concentrations are in *Larsen and Pedersen, 2009*]. The two basement samples that are mixed are outlined in dashed grey circles. Black lines show the mixing scenario between the basement endmember and the highest $^3\text{He}/^4\text{He}$ lava from Iceland that has measured Sr-Nd-Pb isotopic compositions (SEL97). The isotopic compositions for SEL97 can be found in *Hilton et al. [1999]* and trace element concentrations are reported in *Jackson et al. [2008]*. While the Pb isotopic compositions of the least crustally contaminated Baffin Island lavas can be generated by assimilation of ~3% of the basement endmember into an Iceland high $^3\text{He}/^4\text{He}$ melt, the mixing model fails to capture the Baffin Island lavas in Sr-Pb, Nd-Pb, or Sr-Nd isotopic spaces. Therefore, blue

lines show the mixing scenario between the basement and a hypothetical uncontaminated Baffin Island high $^3\text{He}/^4\text{He}$ melt that, while unlike any measured Baffin Island lava, is designed (to have lower $^{87}\text{Sr}/^{86}\text{Sr}$ and higher $^{143}\text{Nd}/^{144}\text{Nd}$) to make a successful mixing model such that a mixture of this composition with basement will generate observed isotopic compositions in the least contaminated Baffin Island lavas (see Section 4.1 of the text): the Pb isotopic composition of the hypothetical uncontaminated melt is the same as that in SEL97, but the $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of the hypothetical uncontaminated Baffin Island high $^3\text{He}/^4\text{He}$ end member are 0.7025 and 0.5134, respectively (where values are chosen to generate a successful isotopic mixing model). In order for the hypothetical uncontaminated melt mixing model to generate the least crustally contaminated Baffin Island compositions in all isotope spaces (i.e., blue line), the Sr concentration required for the hypothetical uncontaminated melt is 400 ppm, and the Nd concentration required is 15 ppm. The blue line shows that mixing the hypothetical uncontaminated Baffin melt with ~3% of the basement endmember can generate all of the radiogenic isotopic compositions observed in least crustally contaminated Baffin Island lavas. However, the Ce/Pb and Nb/Th of the mixture would be much lower (~11 and ~9, respectively) than observed in the least crustally contaminated Baffin Island lavas (21.7 to 24.1 and 13.3 to 13.9, respectively), allowing us to reject such a model.

Supplementary Table 1: Baffin Island sample notes

Sample no.	Name		Easting	Northing	Elevation (m)
Akpak Point					
NTS: 16K/13/14, NAD 27, UTM Zone 20					
AK-1	Pillow Fragment	lower pillows	554821	7423575	80
AK-6	Beach Stone - Flow Interior		554975	7424264	1
AK-8b	Flow Interior	summit Flow	553724	7422689	895
AK-9	Flow Interior		553468	7422641	860
AK-12	Pillow Fragment	lower pillows	554924	7424118	
AK-13	Pillow Fragment	lower pillows	554924	7424118	
AK-14	Pillow Fragment	lower pillows	554924	7424118	
AK-18a	Pillow Fragment	lower pillows	554924	7424118	
Durban Island					
NTS: 16 M/1 & N/4, NAD 27, UTM Zone 20					
DB-9	Flow Base		533580	7440411	345
DB-13	Pillow Fragment	upper pillows	533409	7440566	435
DB-14	Pillow Fragment	upper pillows	533409	7440566	435
DB-17	Flow Base	second subaerial flow	533409	7440566	460
DB-19	Flow Interior		536577	7441613	625
Padloping Island					
NTS: 16 M/1 & N/4, NAD 27, UTM Zone 20					
PI-10	Pillow Fragment	lowermost pillows	524244	7451382	25
PI-15	Pillow Fragment	upper pillows	523777	7450813	340
PI-17	Pillow Fragment	upper pillows	523777	7450813	340
PI-18	Pillow Fragment	upper pillows	523777	7450813	340
PI-20	Pillow Fragment	upper pillows	523777	7450813	340

Table S1.

1. All the exposures are remnants of flat lying successions of lavas exposed as cliffs along the coast.
2. Elevation is equivalent to stratigraphic position at any one of the three sampling sites (i.e., Akpat Point, Durban Island, Padloping Island), but cannot be used for cross comparison between sampling sites.
3. The samples without elevations (AK-12, 13, 14 and 18a) were collected on the beach from large blocks that had fallen from the cliff.

Table S2. Major and trace oxide compositions of olivines measured by electron probe microanalysis.

Table S3. Measured, age-corrected, and calculated Baffin "mantle source today" isotopic compositions. 1. Isotopic ratio labels: (m) = measured basalt values; (60 Ma) = age corrected basalt to 60 Ma; "calc'd mantle today, BSE traces" = isotopic composition

calculated using parent and daughter elemental concentrations of pyrolite from *McDonough and Sun* [1995]; "calc'd mantle today, DMM traces" = isotopic composition calculated using parent and daughter elemental concentrations from depleted mantle in *Workman and Hart* [2005].