

Snæfellsnes—off-axis volcanism in Western Iceland: inferences on mantle lithology and temperature

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ABSTRACT

Volcanism in Iceland can be compositionally and spatially divided into two broad groups: tholeiitic basalts erupted from the active rift and smaller degree, alkaline to transitional-tholeiitic basalts erupted in off-axis areas. Investigating the melt generation processes for off-axis volcanism requires constraining parameters including mantle source lithology, temperature, and pressure. Here, we utilize trace elements in olivine macrocrysts and Al-in-olivine thermometry to independently constrain source lithology and maximum crystallization temperatures from post-glacial lavas on the off-axis Snæfellsnes Peninsula. High-precision trace element (Ni, Fe, Mn) analyses of olivine from 20 Snæfellsnes lava flows have similar concentrations to rift olivines indicating a dominantly peridotitic mantle source for both the depleted rift lavas and the enriched Snæfellsnes lavas. Al-in-olivine geothermometry data from 17 lava flows from primitive (Fo > 85 %) olivine macrocrysts show consistent maximum crystallization temperatures of ~1300 °C for Snæfellsnes, lower than the rift zone but higher than MORB.

KEYWORDS: Olivine; Al-in-Olivine Geothermometry; Trace Elements; Peridotite.

1 INTRODUCTION

Iceland is the archetype of a ridge-centered hotspot. Plate boundary rifting, enhanced by the added heat flux of a mantle plume, generates large volumes of depleted (low La/Sm, high εNd) tholeiitic melt along the active rifts [Jakobsson 1972]. Away from the axial rift zones are off-axis or flank zones (Figure 1), where melts are enriched (high La/Sm, low εNd) and of smaller volume [e.g. Thirlwall et al. 2004; Sigmarsson and Steinthórsson 2007; Sigmarsson et al. 2008; Peate et al. 2010]. The contrasting isotopic and trace element compositions between the axial and off-axis melts raise questions regarding the lithology of the enriched mantle component (i.e. pyroxenite vs. enriched peridotite) and whether it varies across Iceland. These questions are compounded by poorly understood off-axis melt generation mechanisms [e.g. Sigurdsson 1970; Walters et al. 2013; Jordan et al. 2022].

The Snæfellsnes Peninsula is ideal for investigating the nature of the enriched mantle component. Snæfellsnes is the most distant flank zone from the current inferred plume position beneath Vatnajökull glacier (Figure 1; Wolfe et al. 1997) and any actively rifting or propagating rift zones, and there is minimal crustal extension [Sigurdsson 1970; Walters et al. 2013]. The thicker lithosphere beneath Snæfellsnes leads to lower degrees of melting, which preferentially samples the enriched mantle component [e.g. Hards et al. 1995; Kokfelt et al. 2006; Peate et al. 2010]. Using independent methods of constraining mantle lithology and temperature is an essential step in constraining off-axis melt generation mechanisms in Iceland. This study uses trace element compositions of primitive olivine macrocrysts and spinel inclusions (Al-in-olivine thermometry: Wan et al. 2008) in primitive (> 8 % MgO) post-glacial (< 12 kyr) transitional to alkaline basalts on the Snæfells-

nes Peninsula (Figure 2), to investigate mantle source lithology [Sobolev et al. 2007; Herzberg 2011] and maximum crystallization temperatures using the Al-in-olivine method (T_{Al} ; Matthews et al. 2016; Spice et al. 2016).

2 SAMPLE PREPARATION AND ANALYTICAL METHODS

Whole rocks were crushed and sieved, and olivine macrocrysts were hand-picked from the 0.5–1 mm fraction, mounted in epoxy, and polished. Mineral compositions were analyzed on a JEOL JXA-8230 Electron Probe Microanalyzer (EPMA) in the Department of Earth and Environmental Sciences, University of Iowa. The energy dispersive spectrometer (EDS) was used to initially screen the olivines to target high forsteritic (Fo > 85 %) olivine, as the focus of the study is to infer source lithology and relative concentrations of minor elements can be influenced by co-crystallization of other phases in less primitive melts with lower Fo % olivines. The EPMA settings for the trace element analysis were 200 nA at 20 keV for olivine and 20 nA at 20 keV for spinel. The Al-in-olivine analyses required long dwell times to ensure detection limits low enough (~10–12 ppm) to accurately quantify Al_2O_3 in olivine to maximize reduction of thermometry uncertainties. Full details of methodology are included in [Supplementary Material 1](#). The complete analytical settings, standard reproducibility estimates, and error propagation for the datasets are provided in the [Supplementary Material 2](#).

3 RESULTS

This study selected 17 post-glacial lava flows to represent the compositional range in terms of incompatible element ratios for Snæfellsnes (Figure 2) as well as spatial coverage along the peninsula (Figure 1). Post-glacial lavas contain olivine macrocrysts with a range of Fo contents. Primitive

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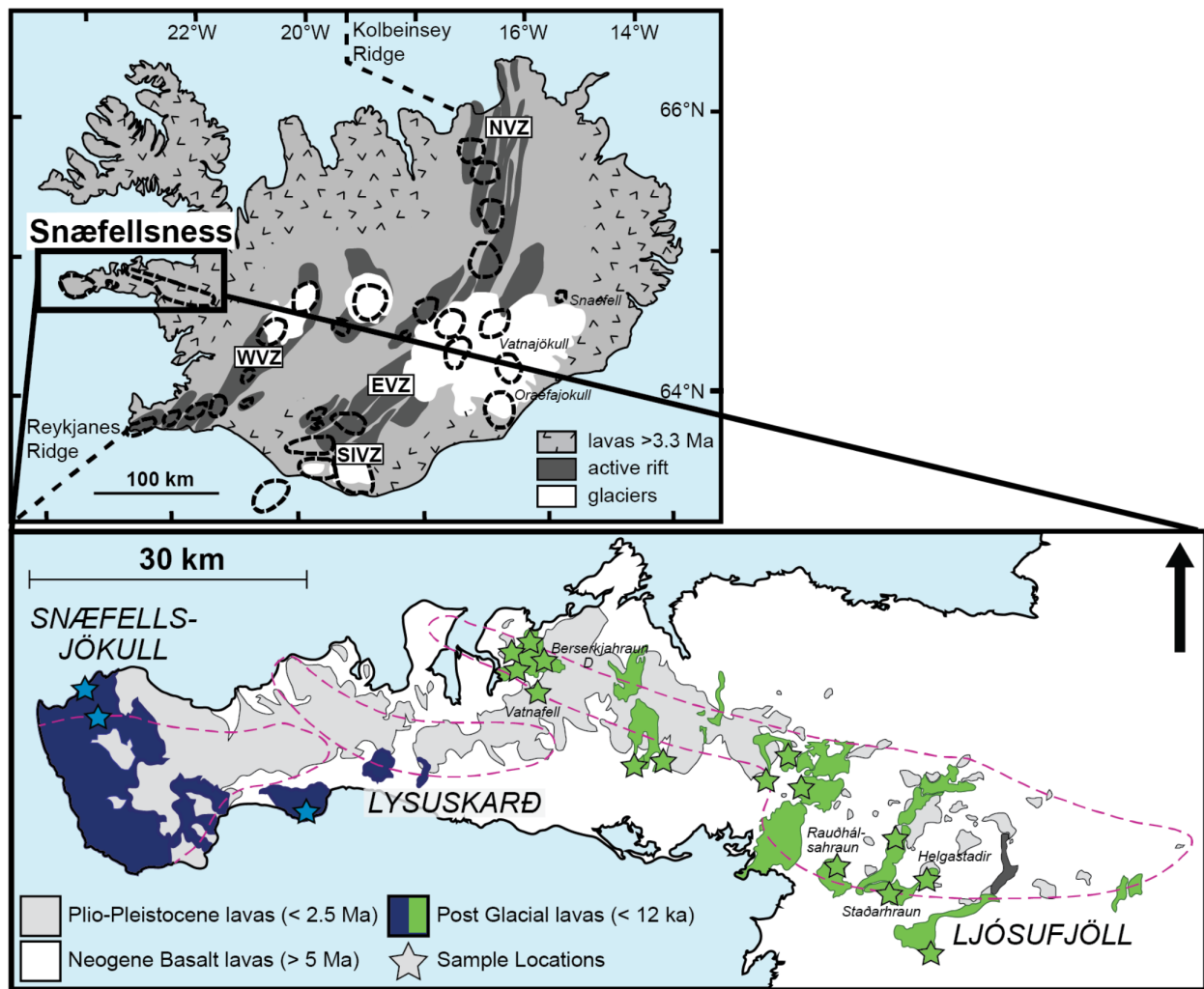


Figure 1: Overview tectonic map of Iceland from Burney et al. [2020]. Black dotted circles indicate central volcanoes. Currently the NVZ and EVZ are the most active volcanic zones accommodating most of the extension. NVZ–Northern Volcanic Zone, EVZ–Eastern Volcanic Zone, WVZ–Western Volcanic Zone, SIVZ–South Iceland Volcanic Zone. Snæfellsnes magmatism is arranged in three volcanic systems, each outlined by the dotted lines (Snæfellsjökull, Lysusgarð, Ljósufjöll: e.g. Jakobsson et al. 2008). Colored sections (blue and green) are post-glacial (<12 kyr) lavas. Stars mark the post-glacial flow locations sampled for this study. Neogene basalt lavas are composed of primarily tholeiitic lavas erupted from the now extinct Hunafloi–Snæfellsnes rift [e.g. Walters et al. 2013]. Plio-Pleistocene and post-glacial lavas are predominantly transitional to alkaline basalts [e.g. Jakobsson 1972; Jakobsson et al. 2008]. Adapted from Burney et al. [2020].

olivines ($Fo > 88\%$) were found in all but two flows, Vatnafell and Rauðukúla, which have maximum values of Fo 84.6 and 86.7 %, respectively.

Multiple spinel inclusions are common in individual olivines. Some olivines contain recrystallized melt inclusions with microlites or spinels. In general, the olivines exhibit small Fe-rich overgrowth/diffusion rims and have no obvious internal zoning with respect to major elements. Analyses were conducted in the macrocryst cores, away from the diffusion rims.

Evolved olivines ($Fo < 85\%$) generally have lower Cr (~150 ppm) and Ni (~1350 ppm; Figure 3) contents, and higher Mn (~2000 ppm) contents, while more primitive olivines ($Fo > 85\%$) have higher Cr (~500 ppm), Ni (~2350 ppm; Figure 3),

and Mn (~1200 ppm) contents. However, variations in Ca concentrations between primitive and evolved populations is less clear, with most of the values between 1800 and 2300 ppm.

Aluminum-in-olivine crystallization temperatures (T_{Al}) were calculated using the updated calibration provided in Coogan et al. [2014]. The compositional parameters for the spinel calibration datasets are outlined in Wan et al. [2008] and Coogan et al. [2014]. Spinels outside of these compositional limits were not included in thermometry calculations (see Supplementary Material for details).

With few exceptions, each olivine and spinel pair were analyzed three times. Olivine-spinel pairs with an Al_2O_3 ratio (i.e. Al_2O_3 olivine/ Al_2O_3 spinel) that exceeded the sample average 95 % CI were excluded from final thermometry cal-

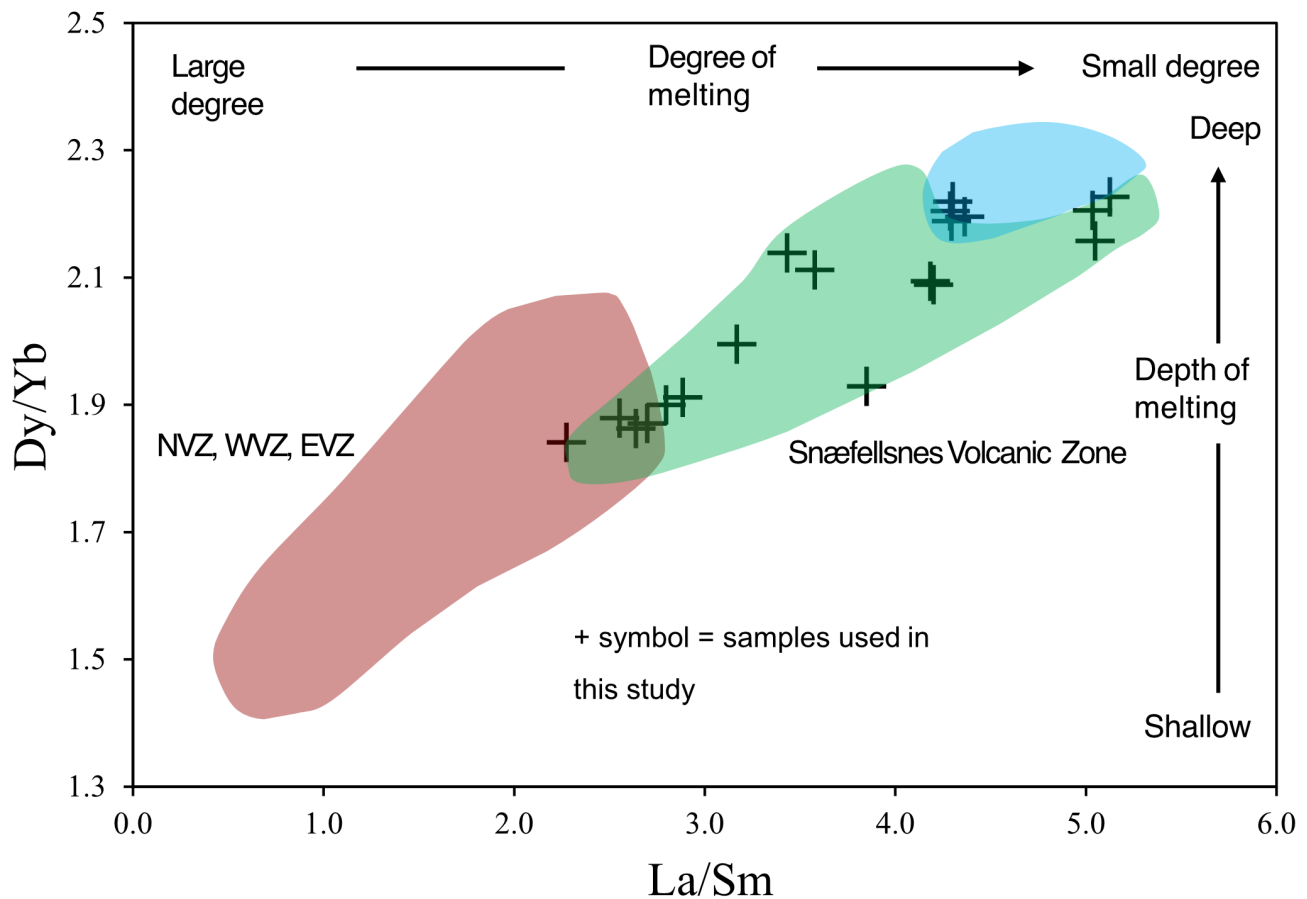


Figure 2: Published range of whole rock REE compositions for the Northern, Western, and Eastern Volcanic Zones (NVZ, WVZ, EVZ; red field), and the off-axis Snæfellsnes Volcanic Zone (SVZ; blue field) (data sources: [Breddam et al. 2000](#); [Chauvel and Hémond 2000](#); [Kempton et al. 2000](#); [Skovgaard et al. 2001](#); [Smit 2001](#); [Stracke et al. 2003](#); [Kokfelt et al. 2006](#); [Brandon et al. 2007](#); [Martin and Sigmarsson 2007](#); [Nielsen et al. 2007](#); [Debaille et al. 2009](#); [Peate et al. 2009](#); [Peate et al. 2010](#); [Koornneef et al. 2012](#); [Shorttle et al. 2013](#); [Sims et al. 2013](#); [Maruszczak 2018](#)). The ‘plus’ symbols indicate the samples selected for olivine trace element and thermometry analysis in this paper. Samples were selected to cover the compositional and spatial range of post-glacial SVZ basalts.

culations. [Coogan et al. \[2014\]](#) reported the accuracy of the Al-in-olivine thermometer as ± 20 – 22 °C, therefore, any of the calculated errors < 20 °C have been set at 20 °C to reflect the inherent uncertainty in the thermometer. A total of 139 olivine-spinel pairs were analyzed from 17 flows, and calculated T_{Al} temperatures, ranging from 1182–1351 °C, are provided in the [Supplementary Material 2](#), and their variation with host olivine Fo % is presented in [Figure 5](#). The highest T_{Al} crystallization temperatures (> 1310 °C) are found in three flows (Rauðhalsahraun, Staðarhraun, Helgastadir) in eastern Ljósufjöll ([Figure 1](#)), with the maximum T_{Al} of 1351 ± 20 °C found in the Helgastadir flow.

4 DISCUSSION

4.1 Mantle lithology

Uniquely constraining the lithology of the enriched mantle beneath Snæfellsnes is difficult because whole rock compositions can be affected by melting conditions (i.e. degree and depth of melting, mantle temperature, melt-rock reactions; e.g. [Short-](#)

[tle and MacLennan 2011](#); [Lambart 2017](#); [Brown et al. 2020](#)), and there is substantial variability in the isotopic signature of subducted and recycled materials [e.g. [Thirlwall et al. 2004](#); [Kokfelt et al. 2006](#); [Sobolev et al. 2007](#)].

It has been argued that the minor element compositions of primitive high-Fo olivine macrocrysts can be used to infer the presence of olivine-free, pyroxenite lithologies in the mantle source of basalts [[Sobolev et al. 2005](#); [2007](#)]. These models determined that pyroxenite-derived melts are characteristically enriched in Ni but depleted in Ca and Mn, while primary melts sourced from predominantly peridotite would show the inverse [[Sobolev et al. 2007](#)]. This suggests that the composition of primitive olivines can be potentially used to infer mantle source lithology. However, there are caveats to this approach as studies have shown that mineral-melt partitioning for Ni and Mn are also strongly temperature and pressure dependent [e.g. [Matzen et al. 2017](#)]. Furthermore, Ni in particular is influenced by crustal processes (e.g. magma recharge and mixing) that can lead to overestimates of the proportion of pyroxenite-derived melts [[Gleeson and Gibson 2019](#)].

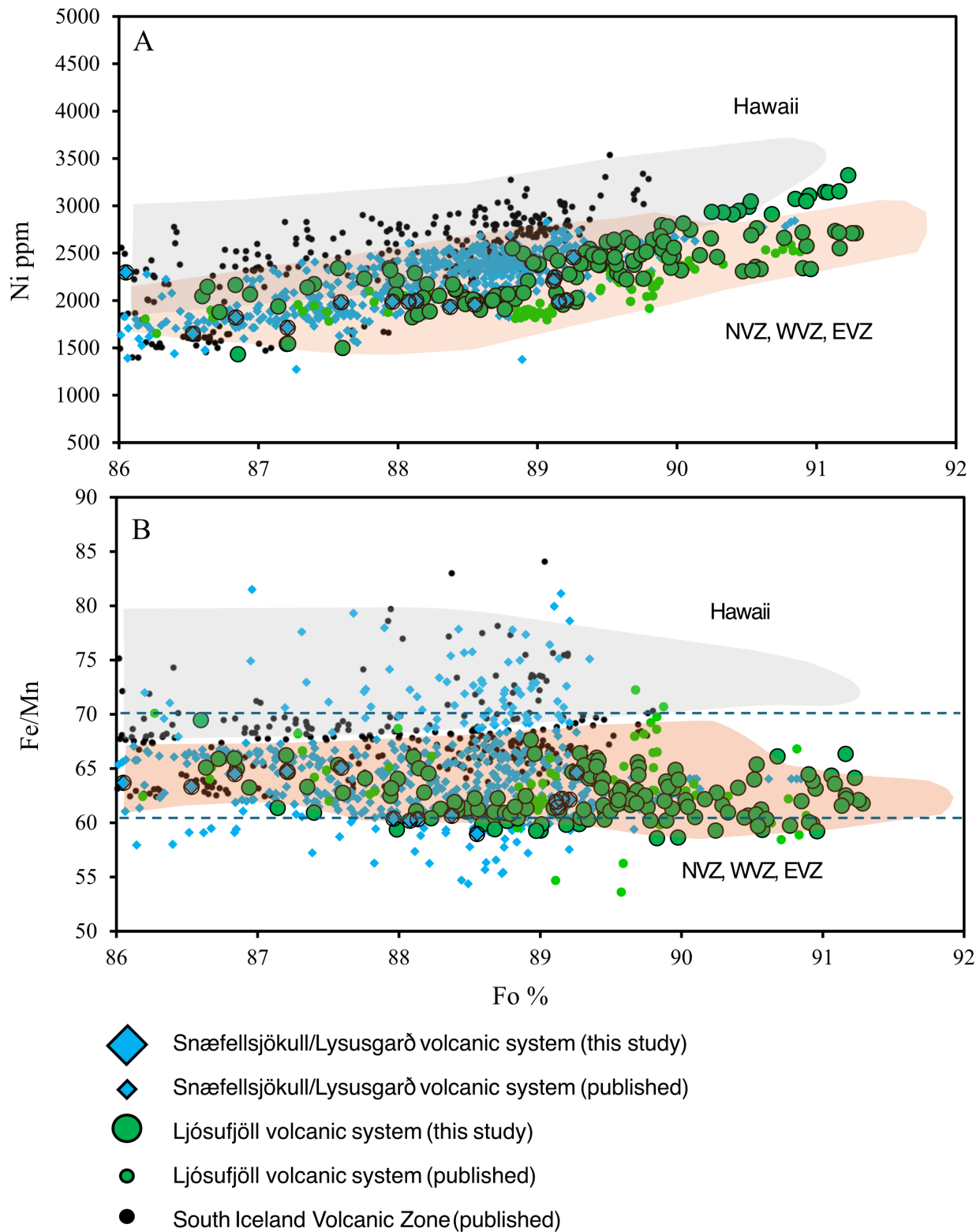


Figure 3: [A] Fo % vs. Ni ppm. [B] Fo % vs. Fe/Mn. The gray field represents data from Hawaii [Sobolev et al. 2007; Lynn et al. 2017]. The red field represents data from the Eastern Volcanic Zone (EVZ; Spice et al. 2016; Nikkola et al. 2019; Rasmussen et al. 2020), the Northern Volcanic Zone (NVZ; Sobolev et al. 2007; Matthews et al. 2016; Spice et al. 2016; Nikkola et al. 2019; Rasmussen et al. 2020), and the Western Volcanic Zone (WVZ; Sobolev et al. 2007; Neave et al. 2018; Nikkola et al. 2019; Rasmussen et al. 2020). Published data for Snæfellsnes basalts are from Sobolev et al. [2007], Nikkola et al. [2019], and Rasmussen et al. [2020]. The dashed lines Fe/Mn = 60 and 70 are the lower and upper bounds for olivines crystallizing from peridotite [Herzberg 2011]. The variation in some of the samples for the South Iceland Volcanic Zone are eruptions of different ages [Nikkola et al. 2019; Rasmussen et al. 2020].

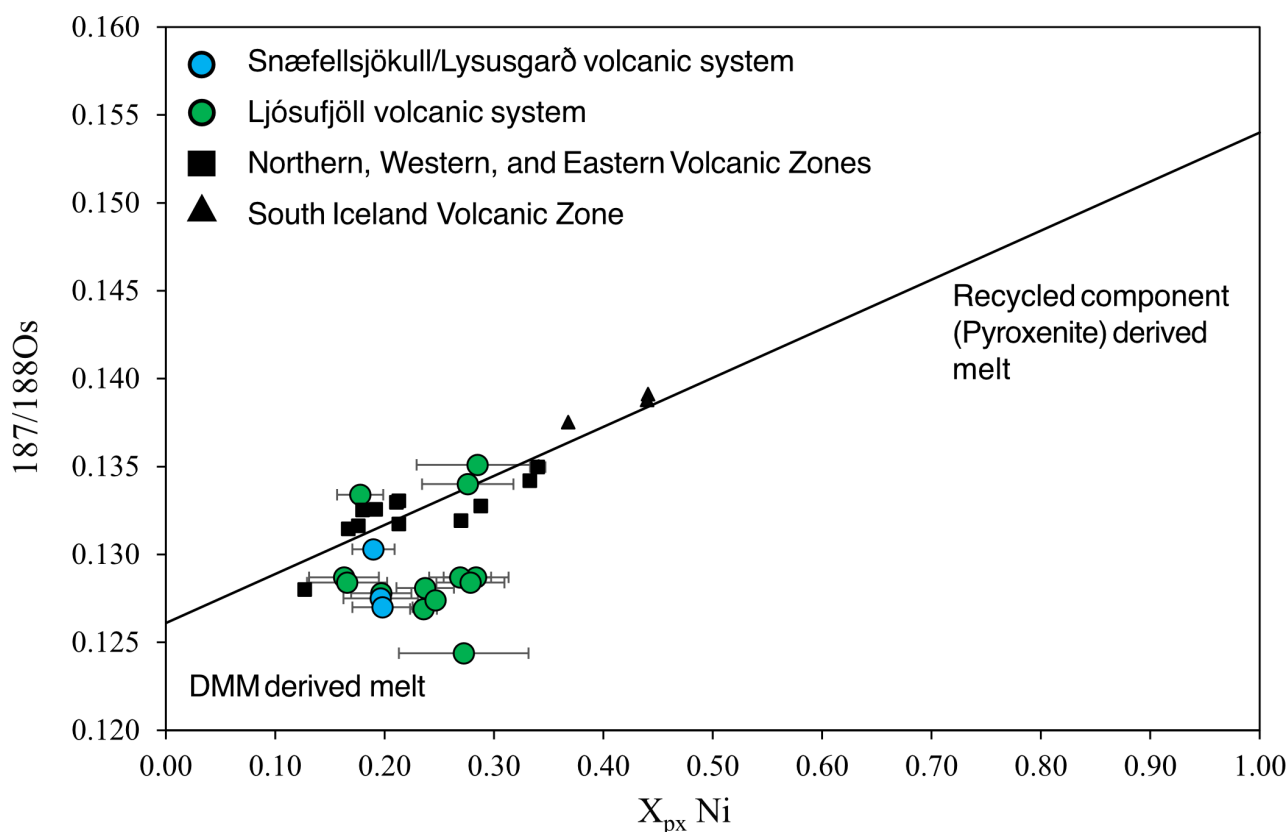


Figure 4: $X_{\text{px-Ni}}$ vs. $^{187}\text{Os}/^{188}\text{Os}$. The solid line represents the best fit line for NVZ, WVZ, EVZ and SIVZ after Sobolev et al. [2008]. Sobolev et al. [2008] argued that the best-fit line is a mixing line between the depleted/primitive mantle and recycled crust mantle components ($X_{\text{px-Ni}} = 10.54 \times \text{NiO}/(\text{MgO}/\text{FeO}) - 0.4368$). $X_{\text{px-Ni}} = 0$ and $^{187}\text{Os}/^{188}\text{Os} = 0.126$ represent the peridotite endmember, and $X_{\text{px-Ni}} = 1$ and $^{187}\text{Os}/^{188}\text{Os} = 0.155$ represent the pyroxenite endmember. Errors for the data are equal to or less than the size of the symbol unless otherwise indicated. Os isotope data for the samples of this study are from Smit [2001].

Fo % vs. Ni (Figure 3A) shows the difference between Hawaiian olivines from Koolau, an archetype for pyroxenite-sourced melts [Sobolev et al. 2007; Lynn et al. 2017], and Icelandic olivines [Sobolev et al. 2007; Matthews et al. 2016; Spice et al. 2016; Neave et al. 2018; Nikkola et al. 2019; Rasmussen et al. 2020]. There is some overlap between the two fields, yet Icelandic olivines have consistently lower Ni concentrations than Hawaiian olivines, apart from olivines from the South Iceland Volcanic Zone (SIVZ), as noted by Rasmussen et al. [2020]. Gleeson and Gibson [2019] showed that magma recharge and mixing processes can produce olivines with higher Ni contents at lower Fo that can fall within the Hawaii pyroxenite-melt dominated field. However, this shift is not seen in the Ni concentrations of Snæfellsnes olivines that fully overlap with olivines from the tholeiitic primary rift zones (Northern and Western Volcanic Zones; NVZ and WVZ) and indicate peridotitic mantle sources in both settings.

Fe and Mn exhibit different partitioning behavior in mantle minerals, meaning Fe/Mn ratios are sensitive to, and fractionated by, differences in source modal mineralogy. Davis et al. [2013] found $K_D^{\text{Mn-Fe}}$ is < 1 in olivine and > 1 in clinopyroxene, orthopyroxene, and garnet, which means that olivines crystallizing from a melt derived from a peridotite source will have a relatively low Fe/Mn ratio (~60-70: blue

dotted lines on Figure 3B). Conversely, the compatibility of Mn in residual pyroxenite will produce melts that crystallize olivines with higher Fe/Mn ratios (i.e. Hawaiian basalts $> \sim 70$; Figure 3B; Sobolev et al. 2005; 2007; Herzberg 2011; Matzen et al. 2017). Additionally, Fe/Mn is generally insensitive to clinopyroxene fractionation [Herzberg 2011], and fractional crystallization trends should show relatively invariant Fe/Mn as Fo decreases [e.g. Rasmussen et al. 2020]. The Snæfellsnes olivines of this study all have $\text{Fe}/\text{Mn} < 70$, and plot on a horizontal trend on Figure 3B coincident with the olivine data from the main rift zones (NVZ, WVZ), again consistent with a predominantly peridotite mantle source. Rasmussen et al. [2020] included data from six Snæfellsnes flows in their survey of olivine minor element compositions from rift and flank zone settings. They concluded that samples with a clear signal for a more pyroxenitic mantle source were only found in the SIVZ, and that the data on the Snæfellsnes flows indicated a predominantly peridotitic source. They tested the idea from Gómez-Ulla et al. [2017] that the peridotitic ‘signature’ in the Snæfellsnes samples might have been imposed through re-equilibration of deep-sourced melts with dunite channels in the lithosphere, but ruled this out based on the comparable Ca/Al in olivines from Snæfellsnes and the SIVZ.

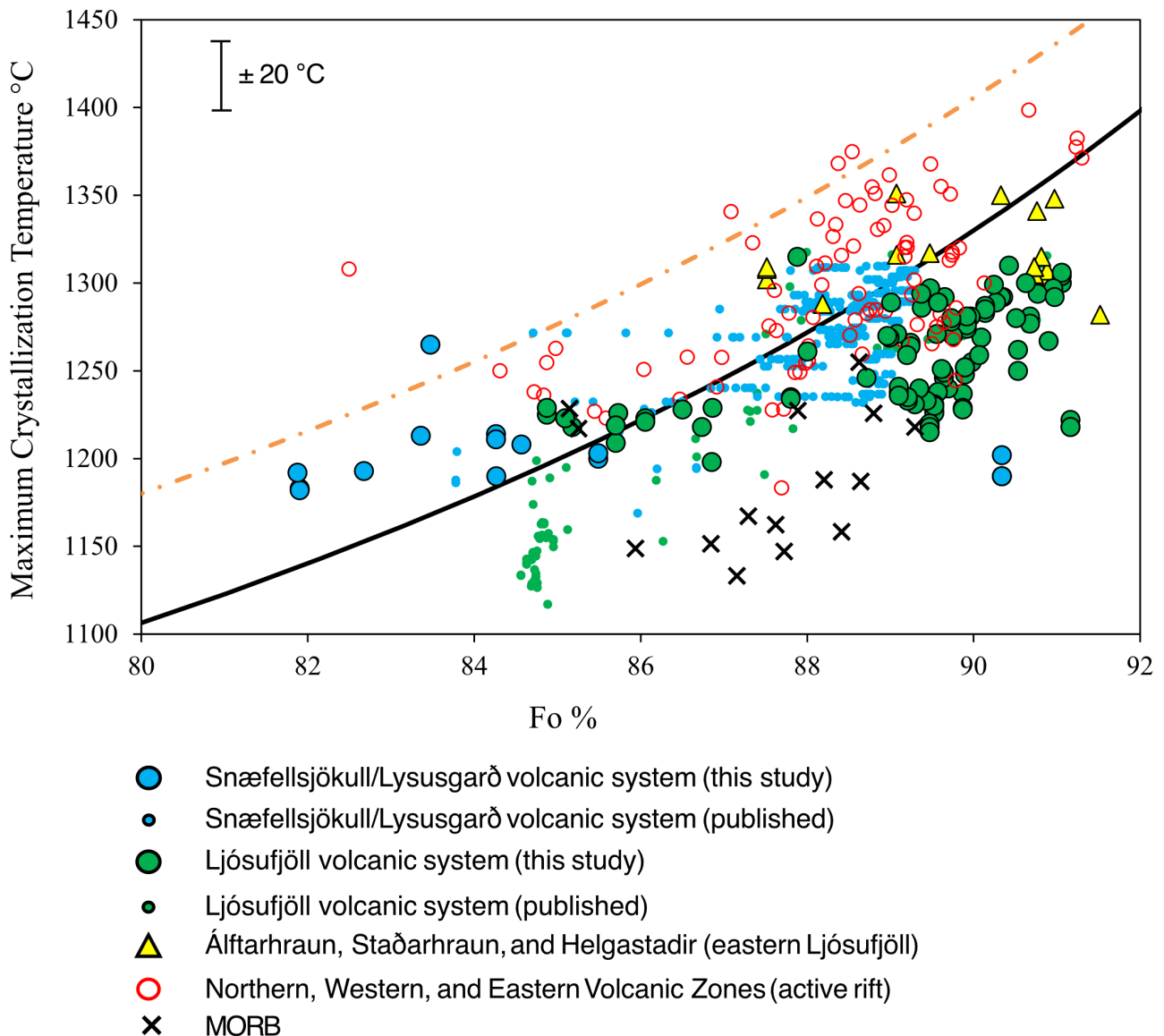


Figure 5: Fo % vs. Al-in-ol maximum crystallization temperatures (°C). Each point represents the temperature from a single olivine-spinel pair. The solid and dotted lines represent the cooling trends of olivine crystallizing from melts derived from a garnet peridotite (KR4003; [Walter 1998](#)) and an enriched peridotite (KG1; [Kogiso et al. 1998](#)). Both trends assume olivine as the only crystallizing phase and were calculated using Petrolog3 [[Danyushevsky and Plechov 2011](#)] after [Matthews et al. \[2016\]](#) (Figure 5 therein). Rift data are from [Matthews et al. \[2016\]](#) and [Spice et al. \[2016\]](#). Snæfellsnes Volcanic Zone data from [Burney et al. \[2020\]](#) and [van der Meer et al. \[2021\]](#). MORB data from [Coogan et al. \[2014\]](#).

Mantle sources containing recycled oceanic crust should have elevated $^{187}\text{Os}/^{188}\text{Os}$ values compared to typical depleted MORB mantle (DMM) as a result of the time-integrated high Re/Os of basaltic crust. Therefore, [Sobolev et al. \[2008\]](#) argued that there should be a positive correlation between $^{187}\text{Os}/^{188}\text{Os}$ and the estimated proportion of pyroxenite-derived melt ($X_{\text{px-Ni}}$) calculated from olivine minor elements ($X_{\text{px-Ni}} = 10.54 \times \text{NiO}/(\text{MgO}/\text{FeO}) - 0.4368$; [Sobolev et al. 2007](#)). [Sobolev et al. \[2008\]](#) showed that a suite of Icelandic rift-zone lavas (NVZ, WVZ, EVZ) plotted on a linear trend (Figure 4) that was modeled as mixing between melts from a depleted mantle source ($^{187}\text{Os}/^{188}\text{Os} = 0.125$; $X_{\text{px-Ni}} = 0$)

and a recycled ocean crust component ($^{187}\text{Os}/^{188}\text{Os} = 0.140$ to 0.155 ; $X_{\text{px-Ni}} = 1$). Many of the post-glacial lava samples from Snæfellsnes chosen for this study (labeled YS98-) came from the Ph.D. thesis collection of [Smit \[2001\]](#), who had measured their whole rock $^{187}\text{Os}/^{188}\text{Os}$. We calculated $X_{\text{px-Ni}}$ values for these samples, and these data are plotted on Figure 4.

The Snæfellsnes lavas and the rift zone (NVZ, WVZ) samples have the same range in calculated $X_{\text{px-Ni}}$ values, 0.17–0.34, and the same maximum $^{187}\text{Os}/^{188}\text{Os}$ values of 0.135 (Figure 4). Most of the Snæfellsnes samples have lower $^{187}\text{Os}/^{188}\text{Os}$ than the rift zone samples ranging down to 0.124, but this is still within the range for DMM (0.123 to 0.126;

Shirey and Walker 1998). If melt from a recycled oceanic crust component was a meaningful contributor to the renewed volcanism on Snæfellsnes, then these samples would be expected to have higher $^{187}\text{Os}/^{188}\text{Os}$ than the rift zone lavas, at similar or higher values than Skridufell in the EVZ. Instead, both the olivine trace and major element compositions, and the unradiogenic Os isotope compositions of the Snæfellsnes samples are consistent with melting of a predominantly peridotite source and show no evidence of a distinct recycled oceanic crust component.

It is unclear as to whether the composition of modeled pyroxenite [Sobolev et al. 2005; 2007] is derived from intact recycled crust or a multi-step reaction resulting in an olivine-free pyroxenite. The Sobolev et al. [2007] model is designed to differentiate between a peridotite and an olivine-free pyroxenite. Herzberg et al. [2014] noted that when adding a Si-rich melt derived from recycled eclogite to a peridotite, ~40 % is the critical threshold to produce a nearly olivine-free pyroxenite. Several studies [e.g. Herzberg et al. 2016; Neave et al. 2018; Rasmussen et al. 2020] argued that the olivine compositions of the rift zone lavas (NVZ and WVZ) are inconsistent with melting of an olivine-free mantle lithology, indicating a primarily peridotite source. Sobolev et al. [2007] suggested that the Iceland rift zones might contain up to 10 % recycled oceanic crust, but this was much less than in pyroxenite-dominated mantle sources like that for Koolau in Hawaii. Similarly, various mantle melting models for the Iceland rift zones [e.g. Shorttle et al. 2014; Brown et al. 2020] have argued for 4–8 % pyroxenite in the mantle source. Lambart [2017] inferred ~10 % recycled crust in the Icelandic model from melting models, but argued that the enriched component in the basalts was contributed through melting of olivine-bearing hybrid lithologies formed by solid-state reaction between recycled oceanic crust and peridotite. A similar conclusion can be reached for the Snæfellsnes lavas, as the compositions of the olivine macrocrysts show substantial overlap with those from the NVZ and WVZ, indicative of a predominantly peridotite mantle source. These conclusions are supported by Shorttle and MacLennan [2011], who found that the whole rock compositions of lavas in Iceland broadly can be attributed to a compositionally heterogeneous but primarily peridotite mantle.

4.2 Al-in-Olivine thermometry

An independent constraint on the mantle temperature beneath Snæfellsnes benefits melting models and refines hypotheses regarding mechanisms for the renewed Quaternary magmatism (e.g. is the off-axis mantle appreciably cooler than the rift?). The Al-in-olivine thermometer (T_{Al} ; Wan et al. 2008; Coogan et al. 2014) provides the most robust estimate of crystallization temperatures for primitive basaltic magmas because it does not require independent knowledge of melt compositions and relies just on the temperature dependence of Al partitioning between olivine and spinel. Furthermore, diffusion of Al in olivine is very slow, which means that it is robust to secondary processes. An earlier study by van der Meer et al. [2021] presented T_{Al} data for five Snæfellsnes basalts: two from the Snæfellsjökull system (T_{Al} 1169–1309 °C) and three from the western Ljósufjöll system (T_{Al} 1174–1317 °C). Our

study provides T_{Al} results on a larger number of samples, that also include samples from the eastern part of the Ljósufjöll system, closest to the active rift of the WVZ. The range of T_{Al} values for western Ljósufjöll and Snæfellsjökull systems (T_{Al} 1182–1310 °C) is similar to that found by van der Meer et al. [2021] (Figure 5). In the eastern part of the Ljósufjöll system, two closely spaced flows (Staðarhraun and Helgastadir) contained olivine-spinel pairs that included the highest T_{Al} crystallization temperatures found so far in Snæfellsnes basalts (T_{Al} 1341–1351 °C; Figure 5).

Most of the observed variation in olivine crystallization temperatures can be explained by the cooling during progressive fractional crystallization, as is shown in Figure 5, where olivine forsterite content serves as a proxy for magmatic evolution. The curves show the expected decrease in temperature during olivine-only crystallization from melts derived from depleted and enriched peridotite mantle. Additional scatter can also result from diffusive re-equilibration, which affects the forsterite value but not T_{Al} , and mixing between heterogeneous primary melts [e.g. Matthews et al. 2016; Matthews et al. 2021]. These effects can be minimized by selecting the maximum T_{Al} values found in the most primitive olivines. It is generally assumed that olivine crystals with Fo ~91 are in equilibrium with mantle olivine and represent the first crystals formed from primary mantle melts [e.g. Matthews et al. 2016]. For western Ljósufjöll, the highest T_{Al} values (1300–1310 °C) are found in Fo ~90.7 olivines from Berserkjahraun (Kothraunskúla). The highest T_{Al} values (1341–1351 °C) from eastern Ljósufjöll come from the Staðarhraun and Helgastadir flows in Fo ~90.3 olivines. In both cases, the high forsterite contents (Fo > 90) largely eliminate the need to make any corrections for the effects of fractional crystallization, diffusion, and/or melt mixing.

Quantitative translation of maximum crystallization temperatures (T_{Al}) in Fo 91 olivines (= primary crystallization temperature; Matthews et al. 2016) to mantle potential temperature is a complex procedure with numerous assumptions [see Matthews et al. 2016; Matthews et al. 2021]. However, it is possible to make valid qualitative assessments, because Matthews et al. [2016] showed that there is a good correlation on a global scale between primary crystallization temperature estimates and calculated mantle potential temperature. Matthews et al. [2016] estimated primary crystallization temperatures of 1280 ± 20 °C for MORB and 1383 ± 22 °C for the Iceland rift zones. The primary crystallization temperature estimates for western and eastern Ljósufjöll lie between these two endmembers, and indicate that the mantle beneath Snæfellsnes is cooler than the active rift zones, but higher than mid-ocean ridge mantle (Figure 5). In detail, the higher temperatures found in eastern Ljósufjöll might relate to their location on the flank of the active melt generation zone related to plate separation in the WVZ [e.g. Siebach 2020; Jordan et al. 2022].

5 SUMMARY

Olivine minor element compositions from transitional-alkaline Snæfellsnes basalts show no evidence for involvement of olivine-free pyroxenite lithologies and overlap completely

with olivine compositions from the tholeiitic rift lavas in the Northern and Western Volcanic Zones. This implies that the mantle source for Snæfellsnes basalts is predominantly a variably fertile, enriched peridotite source. The maximum crystallization temperatures (T_{Al}) derived from Al-in-olivine analyses in primitive (Fo 90–91) olivines for Snæfellsnes basalts are lower than found in the main rift zone, but higher than those found at mid-ocean ridges. These elevated temperatures indicate that melt generation models for off-axis volcanism in Snæfellsnes should not assume ‘normal’ mantle temperatures.

AUTHOR CONTRIBUTIONS

This work is part of Jacob Siebach’s doctoral dissertation. David Peate was Jacob’s Ph.D. advisor. L. Kenneth Horkley provided his expertise refining procedures and methods for high precision trace element analysis on the Electron Probe Microanalyzer.

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DATA AVAILABILITY

The data presented in this paper are available and included as a supplementary file.

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