Earth and Planetary Science Letters 379 (2013) 146–157

Contents lists available at SciVerse ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Short length scale mantle heterogeneity beneath Iceland probed by glacial modulation of melting

Kenneth W.W. Sims [a,b,*], John Maclennan [c], Janne Blichert-Toft [d], Evelyn M. Mervine [b], Jurek Blusztajn [b], Karl Grönvold [e]

[a] Department of Geology and Geophysics, University of Wyoming, Laramie, WY 82071, USA
[b] Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA
[c] Department of Earth Sciences, University of Cambridge, Cambridge, CB2 3EQ, UK
[d] Laboratoire de Géologie de Lyon, CNRS UMR 5276, Ecole Normale Supériere de Lyon and Université Claude Bernard Lyon I, 46 Allée d'Italie, 69007 Lyon, France
[e] Institute of Earth Sciences, University of Iceland, Sturlagata 7, Askja, IS-101, Reykjavik, Iceland

ARTICLE INFO

Article history:
Received 1 December 2012
Received in revised form 9 July 2013
Accepted 16 July 2013
Available online 3 September 2013
Editor: G. Henderson

Keywords:
radiogenic isotopes
Icelandic volcanism
mantle heterogeneity
basaltic volcanism
mantle lithology

ABSTRACT

Glacial modulation of melting beneath Iceland provides a unique opportunity to better understand both the nature and length scale of mantle heterogeneity. At the end of the last glacial period, ~13 000 yr BP, eruption rates were ~20–100 times greater than in glacial or late postglacial times and geophysical modeling posits that rapid melting of the large ice sheet covering Iceland caused a transient increase in mantle decompression melting rates. Here we present the first time-series of Sr–Nd–Hf–Pb isotopic data for a full glacial cycle from a spatially confined region of basaltic volcanism in northern Iceland. Basalts and picrites erupted during the early postglacial burst of volcanic activity are systematically offset to more depleted isotopic compositions than those of lavas erupted during glacial or recent (< 7 kyr) times. These new isotopic data, coupled with major and trace element data, show that the mantle underneath northern Iceland is heterogeneous on small (< 100 km) length scales. The temporal response of the isotopic compositions of the basalts to glacial unloading indicates that the isotopic composition of mantle heterogeneities can be linked to their melting behavior. The present geochemical data can be accounted for by a melting model in which a lithologically heterogeneous mantle source contains an enriched component more fusible than its companion depleted component.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Icelandic geology records a dramatic relationship between deglaciation and increased volcanic activity. At the end of the last glacial period, ~13 000 yr BP, a large ice sheet covering Iceland and its surrounding shelf rapidly melted in ~2000 years (Norðdahl et al., 2008). A short-lived (< 2000 years) burst of volcanic activity followed this deglaciation, during which eruption rates were ~20–100 times greater than in glacial or late postglacial times.

This early postglacial volcanic pulse has been observed throughout Iceland's neovolcanic zones: at the Reykjanes Peninsula (Jakobsson et al., 1978), the Western Volcanic Zone (Sinton et al., 2005), the Veiðivötn fissure swarm in southern Iceland (Vilmundardóttir and Larsen, 1986), and the central and northern parts of the Northern Volcanic Zone (Sigvaldason et al., 1992; Slater et al., 1998; Maclennan et al., 2002). A recent compilation of ~2400 postglacial eruptions (Thordarson and Höskuldsson, 2008) shows that ~70% of postglacial volcanism in Iceland occurred in the early postglacial between ~5 and 11 kyr BP and that roughly one third of early postglacial volcanism took place in a burst between ~10 and 11 kyr BP.

To account for this postglacial volcanic pulse it has been posited that rapid ice unloading causes a transient increase in the rate of mantle melting with an ensuing increase in volcanic production (Harðarson and Fitton, 1991; Jull and McKenzie, 1996; Slater et al., 1998; Maclennan et al., 2002; Sinton et al., 2005). The modeled increase in mantle melting rates is greatest in the shallow part of the melting region, where the melts being produced have very low incompatible element contents. Trace element data support this interpretation as primitive postglacial lavas have lower incompatible trace element concentrations than primitive glacial lavas (Maclennan et al., 2002). Similar temporal variations in trace element compositions have also been observed in southern Iceland in the Western Volcanic Zone (Sinton et al., 2005) and the Reykjanes Peninsula (Gee et al., 1998), with primitive early postglacial lavas having lower mean values of trace element ratios such as Nb/Zr than their subglacial or later postglacial counter-

* Corresponding author at: Department of Geology and Geophysics, University of Wyoming, Laramie, WY 82701, USA.
E-mail addresses: ksims7@uwyo.edu (K.W.W. Sims), jcm1004@cam.ac.uk (J. Maclennan), jblicher@ens-lyon.fr (J. Blichert-Toft), emervine@whoi.edu (E.M. Mervine), jblusztajn@whoi.edu (J. Blusztajn), karlgr@hi.is (K. Grönvold).

0012-821X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.epsl.2013.07.027

parts. The study of Gee et al. (1998) also noted a correlation between trace element abundances and Sr–Nd–Pb isotopic compositions of basalts from the Reykjanes Peninsula, as well as a shift in the MgO content of the erupted material, with early postglacial eruptions having higher mean MgO than the glacial and later postglacial samples. These authors focused their interpretation on the shift in trace element and isotopic diversity through time, arguing that early postglacial eruptions had a shorter residence in crustal chambers and therefore experienced less cooling, differentiation, mixing and assimilation. However, this model accounts for neither the large temporal shift in eruption rates nor the evolution in the mean trace element composition associated with ice unloading. The observation that the full range of variation of trace element ratios such as Nb/Zr is present in high-MgO (~ 12 wt%) samples from the Reykjanes Peninsula (Gee et al., 1998; Shorttle and Maclennan, 2011) indicates that the temporal variation in the mean trace element compositions of primitive basalts is better understood in terms of mantle heterogeneity and melting than in terms of crustal processing.

While isotopic variability in basaltic lavas (when considering the long-lived, lithophile, radiogenic isotope systems utilized in this study) indisputably documents long-lived mantle heterogeneity, the nature of the heterogeneity (lithologic variability or cryptic metasomatism) and its length scales remain uncertain. Although numerous isotopic studies provide evidence for long-lived mantle heterogeneity beneath Iceland and the adjoining spreading ridges (e.g. Hart et al., 1973; Hanan and Schilling, 1997; Chauvel and Hémond, 2000; Fitton et al., 2003; Thirlwall et al., 2004; Blichert-Toft et al., 2005; Kokfelt et al., 2006; Peate et al., 2010; Elkins et al., 2011; Koornneef et al., 2012), to date no studies have explicitly investigated how glacial modulation of melting is reflected in the isotopic compositions of Icelandic basalts. Comparison of radiogenic isotope ratios for early postglacial lavas, when melting rates are thought to have increased dramatically in the shallow part of the melting region, with both glacial and late postglacial lavas, allows investigation of how isotopic heterogeneity is linked to the fusibility of mantle material. While linked isotopic composition and fusibility may arise from either mineralogical variations or coupled increases in volatile element and incompatible element concentrations associated with cryptic metasomatism, a recent study of major and trace element systematics in Icelandic basalts found evidence that the isotopically enriched signature is carried by a relatively olivine-poor, low Mg/Fe source (Shorttle and Maclennan, 2011). We therefore use the effect of deglaciation on mantle melting to establish whether the proposed mineralogical variations associated with isotopically enriched heterogeneities are also coupled to variations in fusibility. The difference in the isotopic composition of Holocene eruptions from the flank and rift zones of Iceland has previously been linked to preferential melting of enriched fusible heterogeneities under the flank zones (Kokfelt et al., 2006). However, such spatial variations may reflect genuine long-wavelength variation in the mean isotopic composition of the mantle, rather than biased sampling of short-length scale heterogeneities. To circumvent this ambiguity, we instead examine temporal variation in a spatially restricted set of samples. Within a single glacial cycle the mantle is unlikely to have upwelled more than a few hundred metres. The mean composition of the mantle present in a ~ 100 km tall melting region under a single volcanic system therefore changes little within a glacial cycle, implying that any temporal variations in the isotopic composition of the mean melts generated must reflect variation in the way in which short-length scale heterogeneities are sampled by the melting process.

Here we present the first time-series of Sr–Nd–Hf–Pb isotopic data for a full glacial cycle (glacial–early postglacial–late postglacial/modern) from a spatially confined region of basaltic volcanism in northern Iceland. We focus on the Krafla and Theistareykir volcanic systems because they both were subjected to a large pulse of early postglacial volcanism (Maclennan et al., 2002), and the glacial, early postglacial, and late postglacial lavas from these volcanic systems have all been well characterized in terms of petrography and major and trace elements (Sæmundsson, 1991; Nicholson et al., 1991; Nicholson and Latin, 1992; Jónasson, 1994; Slater et al., 1998, 2001; Maclennan et al., 2002, 2003a, 2003b; Stracke et al., 2003b).

2. Geologic setting

The Krafla and Theistareykir volcanic systems are situated at the northern end of the Northern Volcanic Zone (Fig. 1). Three distinct periods of volcanism have been identified at Krafla and Theistareykir: glacial (~ 100– ~ 12 kyr BP), early postglacial (~ 12–7 kyr BP), and late postglacial/recent (< 7 kyr BP).

2.1. Glacial–postglacial volcanism in the Northern Volcanic Zone

Eruptions from the last glacial period are easily identified by their distinctive morphology. Subglacial eruptions contain pillow lavas and hyaloclastites (from ice–lava interaction) and often form characteristic table mountains and hyaloclastite ridges (e.g. Nicholson et al., 1991; Slater, 1996; Maclennan et al., 2002). The largest of the table mountains is Gæsafjöll, with an approximate volume of 7 km^3.

2.2. The early postglacial pulse

Early postglacial eruptions generally form large, shallow-sloping lava shields with subaerial morphologies such as pahoehoe, a'a, tumuli, and hornitos (e.g. Slater, 1996; Maclennan et al., 2002). The early postglacial lava shields at Krafla and Theistareykir were produced by long-lived (years to decades) eruptions of olivine tholeiite or picritic magmas interpreted to be dominantly derived from overspill of sustained lava lakes residing in a summit crater (Rossi, 1996; Thordarson and Höskuldsson, 2008). Stóravítishraun is the largest of the postglacial lava shields with an approximate volume of 30 km^3 (Slater, 1996; Slater et al., 1998).

2.3. Late postglacial lavas

Late postglacial eruptions, which occurred more recently than 7 kyr BP, also produced edifices with subaerial morphologies, but generally do not form lava shields, probably because the eruptions are relatively short-lived and produce small volumes relative to the early postglacial volcanic pulse. Rather, late postglacial eruptions (such as the historical eruptions at Krafla) tend to form small lava flows emanating from fissures. While there have been several glacial–postglacial cycles in Iceland, it is straightforward to distinguish glacial and postglacial lavas produced during the most recent cycle. This is because lavas produced during previous glacial cycles have had their original surface features eroded as a result of the most recent glaciation. Additionally, ages of select lava flows have been constrained through tephrochronology (Sæmundsson et al., 2012), which allows the relative ages of other lava flows to be constrained through stratigraphy. Thus, in the Northern Volcanic Zone it is possible to sample glacial, early postglacial, and late postglacial lavas associated with the most recent deglaciation.

3. Sample description

The present sample suite includes glacial, postglacial, and historic samples from Krafla and Theistareykir. Existing glacial isotopic data for Krafla and Theistareykir are extremely sparse. For this

Download English Version:

https://daneshyari.com/en/article/6430076

Download Persian Version:

https://daneshyari.com/article/6430076

Daneshyari.com