



Renewed melting at the abandoned Húnaflói Rift, northern Iceland, caused by plume pulsing



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ABSTRACT

The abandoned Húnaflói Rift (HR), near Skagi in northern Iceland, provides an opportunity to investigate how relocation of an oceanic spreading ridge influences melt generation. Melting recommenced beneath HR several million years after spreading ceased at 7–4 Ma. Both the older (pre-HR abandonment) and younger (post-abandonment) lavas are tholeiitic basalts with high Fe–Ti and enriched incompatible trace element compositions. The HR lavas are compositionally similar to modern lavas from central Iceland (above the Iceland Plume conduit) and the Eastern Volcanic Zone (a propagating rift). Although older and younger HR lavas are compositionally similar, geological and geophysical observations indicate different mantle melting conditions. For the older lavas, a plume migration reconstruction suggests that the combination of incompatible trace element enrichment and crustal thickness of ~25 km can be explained by plume-driven upwelling, a scenario similar to central Iceland at present. The smaller volume of the younger HR lavas (<1 km melt thickness) and their greater distance from the plume centre argues against plume-driven upwelling to explain their enrichment. Rare earth element inversion modelling indicates that the younger lavas come from reactivation of the deepest part of the melting region beneath HR. We suggest that the base of the HR melting region was reactivated when a pulse of unusually hot asthenosphere, known to be producing unusually thick crust ~700 km away from the plume centre today, passed laterally beneath the HR at ~3 Ma. A thermal and kinematic ridge–plume interaction model indicates that this scenario can explain both the volume and composition of the younger Skagi lavas, provided that a small amount of decompression occurs. The decompression may result either from extension or from buoyancy-driven upwelling of hot mantle beneath the relatively thin lithosphere of the abandoned HR. The hypothesis that a hot plume pulse caused the younger HR lavas is significant not only as an example of interaction between mid-ocean ridge melting and time-dependent mantle convection, but also because this same hot pulse may have subsequently helped promote intensification of the Northern Hemisphere Glaciation when it uplifted the oceanic gateways either side of Iceland.

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1. Introduction

Re-location of mid-ocean ridge segments, especially in cases of plume–ridge interaction, is a common phenomenon by which constructional plate boundaries continually adapt their geometry (Small, 1995; Mittelstaedt et al., 2008). Melting usually ceases once an oceanic rift segment is abandoned because mid-ocean ridge melting is driven predominantly by decompression in response to plate spreading. However, in some cases melting contin-

ues after spreading has ceased, for example at the Galapagos Rise (Batiza et al., 1982; Haase et al., 2011b), the Mathematician Ridge (Batiza and Vanko, 1985), Davidson Seamount (Clague et al., 2009; Castillo et al., 2010) and the Phoenix Ridge (Choe et al., 2007; Haase et al., 2011a). These cases are of interest because they suggest that other melting processes besides plate-driven decompression are locally important. Here, we examine the case of rejuvenation of melting at the abandoned Húnaflói Rift (HR), in the Skagi region of northern Iceland (Fig. 1). The HR stopped producing melt at 7–4 Ma when plate spreading transferred eastward to the presently active Northern Volcanic Zone (NVZ; Sæmundsson, 1979; Jancin et al., 1985; Kristjánsson and Jónsson, 1998; Jóhannesson, 1980), but melting beneath the Skagi region recommenced several million years later (Pjetursson, 1905; Everts et al., 1972). This paper aims to explain why melting recommenced beneath the abandoned HR to generate the younger Skagi lavas.

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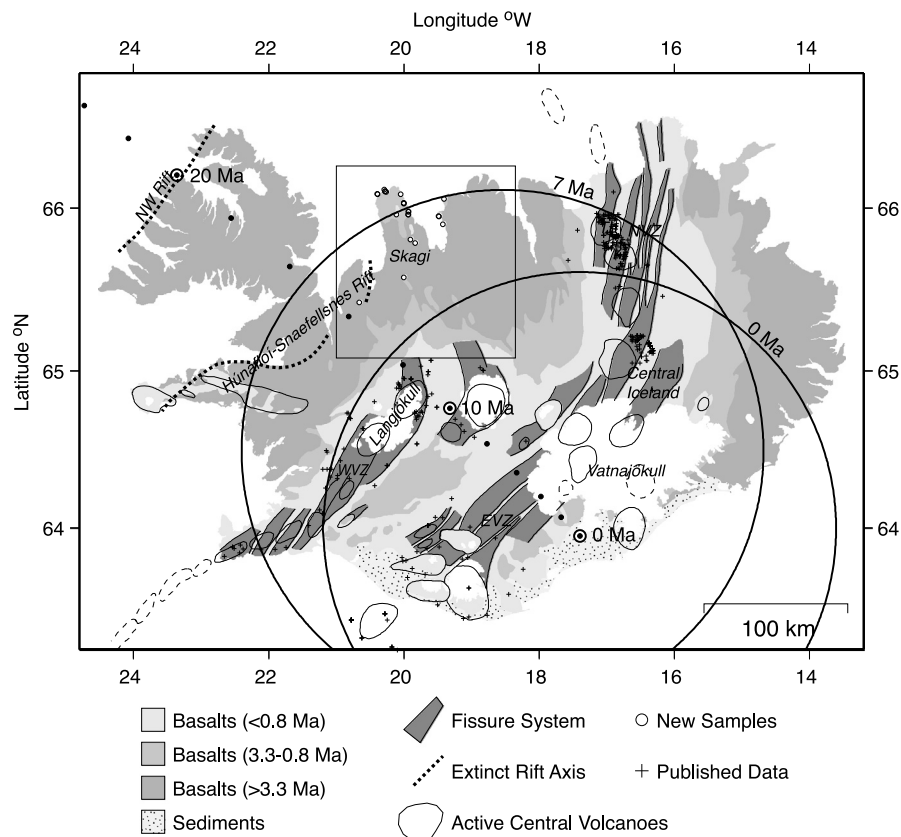


Fig. 1. Geological and tectonic map of Iceland, adapted from Jóhannesson and Sæmundsson (1998a). Skagi peninsula is outlined on the north coast of Iceland (Fig. 3). The extinct Húnaflói Rift axis is shown to the west of the Skagi (Jóhannesson, 1980; Harðarson et al., 1997). The active volcanic zones, composed of series of en-echelon fissure systems, are labelled: Eastern Volcanic Zone, EVZ; Northern Volcanic Zone, NVZ; Western Volcanic Zone, WVZ. Locations of published data represent analyses of samples from the active volcanic zones used in the geochemical investigation. The plume track in the reference frame of the Skagi region over the past 20 Myr is shown as black dots every 2 Myr with larger circles at 0, 10 and 20 Ma. The track was calculated using the poles of Jones (2003) for Greenland relative to the hotspot reference frame of Muller et al. (1993) and the plume centre of Shorttle et al. (2010). The estimated maximum radii of plume-driven upwelling, based on MacLennan et al. (2001a), at 0 Ma and 7 Ma are shown as large solid black circles.

Fluctuations in melt production throughout Cenozoic time are observed across the North Atlantic region surrounding Iceland, and many cases are known to be related to temperature fluctuations in the head of the Iceland mantle plume. For example, the V-Shaped Ridges (VSRs) are nested ridges of thick crust developed along the Mid-Atlantic Ridge (MAR) to the north and south of Iceland. They form by melting patches of relatively hot mantle that propagate episodically outward from Iceland within the head of the Iceland Plume (Vogt, 1971; Ito, 2001; Jones et al., 2002; Poore et al., 2009, 2011; Jones et al., submitted for publication). Other fluctuations in melt production were associated with the start-up phase of the Iceland Plume during Paleocene–Eocene time (Barton and White, 1997; Holbrook et al., 2001). The timing of changes in plume productivity proxies in relation to volcanic activity on Iceland is shown in Fig. 2. Based on observations from the VSRs by Jones et al. (submitted for publication), the most recent pulse of hot mantle left the plume conduit at ~ 3.8 Ma and would have passed beneath the abandoned HR at ~ 3 Ma, coincident with timing estimates for the renewed volcanic activity. This timing also correlates with a sharp decrease in Northern Component Water strength in the southern ocean shortly after 3 Ma, in response to elevation of the oceanic gateways either side of Iceland (Poore et al., 2006).

A review of the field relationships, radiometric ages and chemical characteristics of the Skagi lavas shows that the younger lavas represent reactivation of melting several million years after abandonment of spreading (Section 2). We present a new set of geochemical analyses of the older (Tertiary, pre-abandonment) and younger (Quaternary, post-abandonment) Skagi lavas (Section 3).

Comparison with the compositions of modern lavas generated at the active rift zones suggest that both sets of Skagi lavas have been strongly influenced by deep melting, within the garnet stability field, and Rare Earth Element (REE) inversion modelling supports this inference (Section 4). Despite chemical similarity between the older and younger Skagi lavas, the different associated melt thicknesses and locations relative to the plume centre require different models for melt generation. The older Skagi lavas can be explained using a model that has already been successfully applied to the modern central Iceland region (MacLennan et al., 2001a). In this model, the deep melting signature comes from plume-driven upwelling of mantle source through the base of the melting region, while upwelling at higher levels is predominantly plate-driven. We develop a new hypothesis for the origin of the younger Skagi basalts in which a patch of relatively hot mantle was carried laterally beneath the abandoned HR within the head of the Iceland Plume (Section 5). We test this idea by modelling the temperature structure and melting beneath the HR, accounting for cooling from above after rift abandonment and heating from below caused by plume pulsing, and calculating the associated chemical compositions (Section 5).

2. The Húnaflói Rift and the Skagi lavas

Rift relocations have affected the onshore part of the MAR at Iceland since at least the Middle Miocene, the age of the oldest onshore rocks (Sæmundsson, 1979; Jóhannesson, 1980; Harðarson et al., 1997; Kristjánsson and Jónsson, 1998). During one of these

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