Earth and Planetary Science Letters 310 (2011) 509–517

Contents lists available at SciVerse ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

New age for the Skálamælifell excursion and identification of a global geomagnetic event in the late Brunhes chron

Brian R. Jicha [a,*], Leo Kristjánsson [b], Maxwell C. Brown [c], Brad S. Singer [a], Brian L. Beard [a], Clark M. Johnson [a]

[a] Department of Geoscience, University of Wisconsin, Madison, Wisconsin, USA
[b] Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík, Iceland
[c] Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum, Telegrafenberg, 14473 Potsdam, Germany

ARTICLE INFO

Article history:
Received 18 May 2011
Received in revised form 4 August 2011
Accepted 8 August 2011
Available online 1 October 2011

Editor: R.W. Carlson

Keywords:
Skálamælifell
excursion
Iceland
$^{40}Ar/^{39}Ar$ geochronology
paleomagnetism

ABSTRACT

Sixteen lava flows sampled from isolated hills, including Skálamælifell hill, on the Reykjanes Peninsula in southwest Iceland record excursional geomagnetic field directions that correspond to virtual geomagnetic poles (VGPs) grouped at 12°S, 250°E in the eastern Pacific Ocean. The VGPs are similar to those obtained in earlier studies of these lavas, for which the name Skálamælifell excursion was previously assigned. Based on unspiked K–Ar dating of nine samples from six hills, it has been accepted for more than two decades that the transitionally magnetized lavas reflect the 41 ka Laschamp excursion. However, nine new $^{40}Ar/^{39}Ar$ incremental heating experiments on four of the transitionally-magnetized lavas give an age of 91 ± 13 ka. Moreover, ^{238}U–^{230}Th isochrons determined for two of these lava flows yield a weighted mean age of 96 ± 10 ka (2σ). The weighted mean of the $^{40}Ar/^{39}Ar$ and ^{238}U–^{230}Th ages is 94.1 ± 7.8 ka (2σ), which is more than twice as old as the K–Ar data imply. We conclude that the Skálamælifell excursion is not synchronous with the Laschamp excursion. Rather, the Skálamælifell excursion likely corresponds to the post-Blake excursion at 94 ka, which coincides with a globally observed low in paleointensity. These findings highlight the potential shortcomings of K–Ar dating of young (<100 ka), low-K basalts, and reinforce the need for multiple independent chronometers when determining ages for geologic events throughout Earth's history.

1. Introduction

A geomagnetic excursion is generally defined as a brief, ca. 1–10 ka, period of reduced intensity of the Earth's magnetic field accompanied by a substantial shift in direction away from a geocentric axial dipole (GAD) configuration during an otherwise stable polarity chron (Laj and Channell, 2007). During an excursion, a polarity reversal is not established, and thus the field realigns to its original configuration. The exact number and timing of excursions that punctuate the Matuyama and Brunhes polarity chrons during the past 2.5 Ma have been debated and refined over the last three decades (Champion et al., 1988; Laj and Channell, 2007; Langereis et al., 1997; Singer et al., 2008). At least ten excursions are recorded in lava flows which erupted during the Brunhes normal chron and have been dated precisely using the $^{40}Ar/^{39}Ar$ method (Singer, 2007; Singer et al., 2008). Most of these Brunhes chron excursions, and at least two others, are also recorded in high deposition-rate marine sediments of the North Atlantic Ocean where they have been dated via astrochronology derived from the time series of O isotope variation (Channell, 2006; Laj and Channell, 2007). Defining the timing, frequency, and duration of geomagnetic excursions is essential for 1) placing constraints on the behavior of the geodynamo during these brief periods of time, and 2) using excursions as stratigraphic markers or tie-points in sedimentary and ice core chronologies (e.g., Singer et al., 2009).

Paleomagnetic research had been carried out in Iceland since the early 1950's (e.g., Hospers, 1951) because of the unique nature of its lava record, which is fairly continuous for the past 15 Myr (Kristjánsson, 2003). In SW Iceland, Kristjánsson and Gudmundsson (1980) reported that drill core samples from three hills, Siglubergsháls, Austara Hraunssels-Vatnsfell, and Skálamælifell, on the Reykjanes Peninsula give fairly consistent transitional directions with low negative inclinations (I = −16°) and westerly declinations (D = 260°) (Fig. 1). This mean direction corresponds to a virtual geomagnetic pole (VGP) at 12°S, 254°E in the eastern Pacific. No radiometric ages were available at that time to correlate this geomagnetic excursion with those in the Brunhes chron, so it was given the name Skálamælifell excursion.

Following the initial work of Kristjánsson and Gudmundsson (1980), several paleomagnetic, paleointensity, and geochronologic studies of these excursional lavas have been carried out. Marshall et al. (1988) determined that four excursional lavas had a mean absolute paleointensity value of 4.3 μT, which they noted was similar to the intensities observed in lavas from Chaîne des Puys, Massif Central, France, that record the 41 ka Laschamp excursion. A survey of 42 lava

* Corresponding author.
E-mail address: bjicha@geology.wisc.edu (B.R. Jicha).

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doi:10.1016/j.epsl.2011.08.007

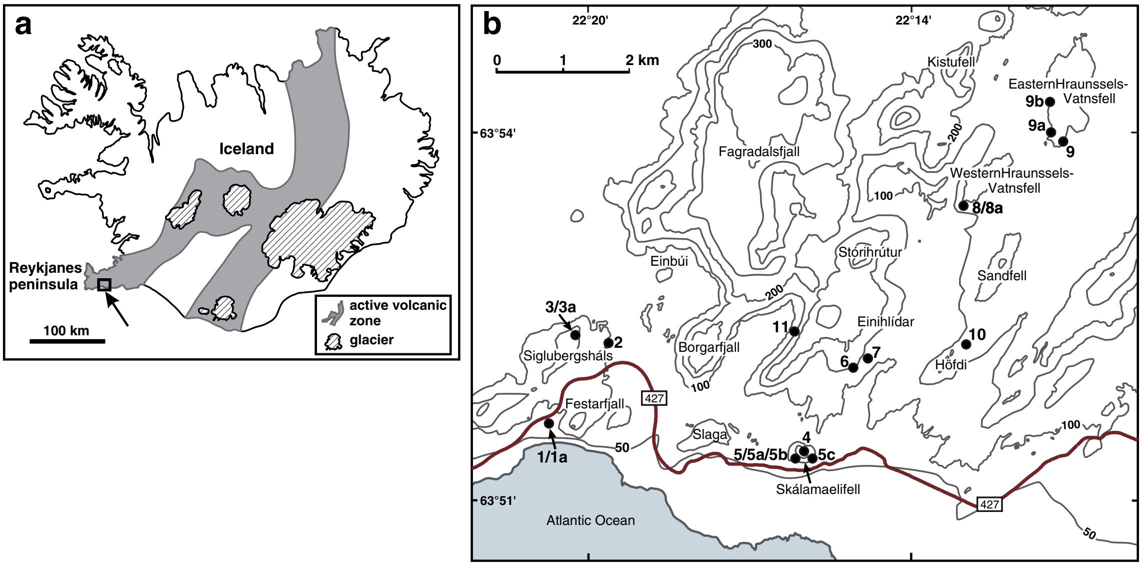

Fig. 1. (a). Iceland, showing the central active volcanic zones (gray) and glaciers. The box indicates the study area in the Reykjanes peninsula. (b) Map sketch of the area where outcrops belonging to the Skálamælifell excursion have been found. The map is simplified from the 1:25,000 scale series of the Iceland Geodetic Survey. Numbered dots indicate sampling localities of Table 1. Contour interval is 50 m.

outcrops in the area in the 1980's (Levi et al., 1990) located transitionally magnetized directions along the Einihlídar–Bratthálskrókur slopes as well as in the hills Höfdi and Vestara Hraunssels-Vatnsfell (Fig. 1b). The samples have a mean characteristic remanence direction within two degrees of that reported by Kristjánsson and Gudmundsson (1980). A subset of the Levi et al. (1990) samples has a mean paleointensity of 4.2 μT, in agreement with the results of Marshall et al. (1988). Unspiked K–Ar dating of nine samples from six hills by two laboratories yielded a mean age of 43 ± 8 ka (2σ) (Levi et al., 1990), statistically indistinguishable from the Laschamp excursion (Bonhommet and Babkine, 1967; Hall and York, 1978). Further reconnaissance in the area (Kristjánsson, 2003) located additional outcrops of flows with the characteristic excursion direction, as well as 33 lava sites in Fagradalsfjall (Fig. 1b) that give a mean VGP in West Africa. Recently, Ferk and Leonhardt (2009) reported a paleodirectional, paleointensity, and rock-magnetic study on samples from the area, and found lavas that record transitional and normal polarity directions. The low paleointensities found by previous workers (4–5 μT) were confirmed, as were the paleodirections similar to those of the Skálamælifell excursion (their sites BL 1, 2, and 3 in the Siglubergsháls hill). They also confirmed the occurrence of West African VGPs in six sites on the southwestern edge of Fagradalsfjall. These yield paleointensities of 19.9 ± 2.4 μT, which Ferk and Leonhardt (2009) attribute to the waning stages of the excursion.

We report new paleomagnetic as well as $^{40}Ar/^{39}Ar$ and $^{230}Th-^{238}U$ data from low-K, basaltic lava flows that record the Skálamælifell excursion. Our findings, which are based on two independent chronometers, imply that the intermediate directions and low absolute paleointensities of these Icelandic lavas are associated with the post-Blake excursion at ~94 ka. These results also place new constraints on the interpretations of the geology, tectonics and geomorphologic processes of the Reykjanes peninsula.

2. Sample sites

The study area is located on the Reykjanes Peninsula in southwest Iceland, east-northeast of the town of Grindavik (Fig. 1). Numerous volcanic structures found in the Reykjanes Peninsula are sculpted into long ridges trending ~35° east of north, presumably due to recent glaciation, but there are also many isolated hills of volcanic origin. They typically rise 100–200 m above their surroundings and are mostly composed of lava flows and hyaloclastites, indicating subglacial or subaqueous emplacement. The largest single hill is Fagradalsfjall (Fig. 1b), which reaches up to 300 m above a lava field to the west. In much of the peninsula, the lowlands are covered by either late glacial and Holocene lava flows or by small plains of detrital material.

Oriented 25 mm diameter core samples were collected at 11 sites in lava flows known to record excursional field directions (Table 1) using a portable gasoline-powered drill. Cores were taken across 10–40 m laterally at each site. The sun or distant geographic objects were used for reference azimuths. Measured remanence directions from several samples, especially from sites 5, 5c and 7, were unsatisfactory as a result of weak or unstable remanence, suspected outcrop movements, or lightning effects. In many locations on the excursion hillslopes, two or more flow units may be seen, usually separated by scoria or hyaloclastite, but these units are often thin and discontinuous. At some of these sites (1, 3, 5, 8, 9) we sampled the lava units above or below our original 11 sites (e.g., sites 5, 5a, 5b or 3, 3a, etc.) in order to check on changes in the ambient geomagnetic direction during buildup of the hills. The adjacent flows record transitional directions similar to those of the original sites (Table 1).

It is important to note that the names of the hills are often labeled differently on various geodetic maps and thus have been interchanged in previous studies. In an attempt to avoid further geographic confusion, we offer a comparison of our sample sites to those of the previous studies (Ferk and Leonhardt, 2009; Kristjánsson and Gudmundsson, 1980; Levi et al., 1990; Marshall et al., 1988), in addition to providing GPS coordinates and short site descriptions (Table 1). Our site 3 at Siglubergsháls is a few hundred meters north of sites BL2 and BL3 of Ferk and Leonhardt (2009) and site 14C-3 of Marshall et al. (1988), all of which record similar excursional directions. Excursional sample M7 of Marshall et al. (1988) is from the west side of Skálamælifell, which is likely very close to our site 5 (Fig. 1b). The hill names used by Levi et al. (1990) are identical to those in this study. The samples of Levi et al. (1990) were collected in separate campaigns by groups at Oregon State University and Gif-sur-Yvette, France. Eight excursional lavas were identified in a gully south of the road between Fiskidalsfjall and Festarfjall. These lavas also underwent paleointensity analysis. Our site 1 corresponds to the uppermost excursional lava in this gully. On the southern slope of eastern Hraunssels-Vatnsfell, sample #14 of the Gif-sur Yvette group that gave a mean K–Ar age of 50 ± 21 ka (Levi et al., 1990) is likely identical to our site 9 (Fig. 1b).