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Magma flow directions inferred from field evidence and magnetic fabric studies of the Streitishvarf composite dike in east Iceland

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ABSTRACT

Anisotropy of magnetic susceptibility (AMS) and rock magnetic studies have been made on three outcrops separated by 12 km along strike (NNE–SSW) on the Streitishvarf composite dike in east Iceland. Samples for this study have been collected from the inner quartz-porphyry part of the dike, which show clear field evidence of a lateral flow component from north to south at one of the sites. This flow component is consistent with margin AMS results from all three sites. The quartz-porphyry has a substantial bulk magnetic susceptibility (10^{-2} SI) mainly carried by magnetically soft titanium-poor titanomagnetite (MDF ~15 mT). The ferrimagnetic grains yield a characteristic remanent magnetization in all three sites which gives a virtual geomagnetic pole at latitude 52.6° *S* and longitude 319.6° *E*. The degree of anisotropy is low ($P_J = 1.033$) and the magnetic fabrics shifts from oblate to prolate shapes depending on dike margin and outcrop. The magnetic fabric has been interpreted according to the imbrication model, using the minor susceptibility axis as shear plane indicator. The absolute directions given by the minor susceptibility are then quantified using vector algebra. The magma flow is indicated as an upward directed flow, flowing from north to south with an inclination between 30° and 64°, with a 95% confidence ellipse of 3°–9°. A model for the intrusion of the Streitishvarf dike has been constructed where a magma pocket with felsic magma is punctured by a mafic dike, enabling the felsic magma to rise and extend to the south within the pathway created. The results of this study confirm the applicability of AMS in studies of magma flow directions in igneous dikes of felsic composition.

1. Introduction

The understanding of magma propagation in igneous dikes is important for our understanding of volcanism and crustal dilatation (e.g. Brooks and Nielsen, 1978; Buck et al., 2006; Paquet et al., 2007). The dikes represent feeder channels for magma from its source to alternate crustal levels. Magma movement can potentially be inferred by anisotropy of magnetic susceptibility (AMS), where the susceptibility relates the induced magnetization a rock acquires due to a weak external field. Due to preferred spatial distributions of minerals, grain shapes and crystallographic properties the susceptibility will in most cases be directionally anisotropic, and is thus a proxy of the petrofabric (Tarling and Hrouda, 1993). Igneous rocks may have fabrics related to magma flow (Nicolas, 1992) and studies on mafic dikes have been carried out in several geological provinces in order to define magma movement directions (e.g. Herrero-Bervera et al., 2001; Callot and Geoffroy, 2004; Raposo et al., 2007; Aubourg et al., 2008; Soriano et al., 2008). Similar studies have been conducted on felsic dikes (e.g. Walderhaug, 1993; Aubourg et al., 2002; Poland et al., 2004; Chadima et al., 2009). Few studies of anisotropy of magnetic susceptibility (AMS) have been published on Icelandic dikes (Ellwood, 1978; Ellwood, 1979; Craddock et al., 2008; Kissel et al., 2010). Here we present AMS data from a single composite dike in east Iceland sampled in three outcrops separated by ~12 km along strike. We use imbrication of magnetic foliation planes to infer the flow at each of these three outcrops. The availability of recurrent sampling locations on the same dike with exposed margins is very rare in Iceland, but here we are able to test the reproducibility of AMS on the same dike as well as make estimations of absolute flow directions along the strike of the dike. The AMS results and available field evidence are used to construct a geological model for the emplacement of the felsic part of the dike.

2. General geology

The bedrock of east Iceland is of Neogene age and consists of a gently dipping pile of flood basalts (Fig. 1a; Walker, 1958; Gibson et al., 1966; Saemundsson, 1979; Hardarson and Fitton, 1997). The age of the oldest lavas visible above sea level is sparsely constrained, but should not exceed 13.5 Ma for the easternmost promontory (Watkins and Walker, 1977; Mussett et al., 1980; Kristjansson et al., 1995). The lava pile is

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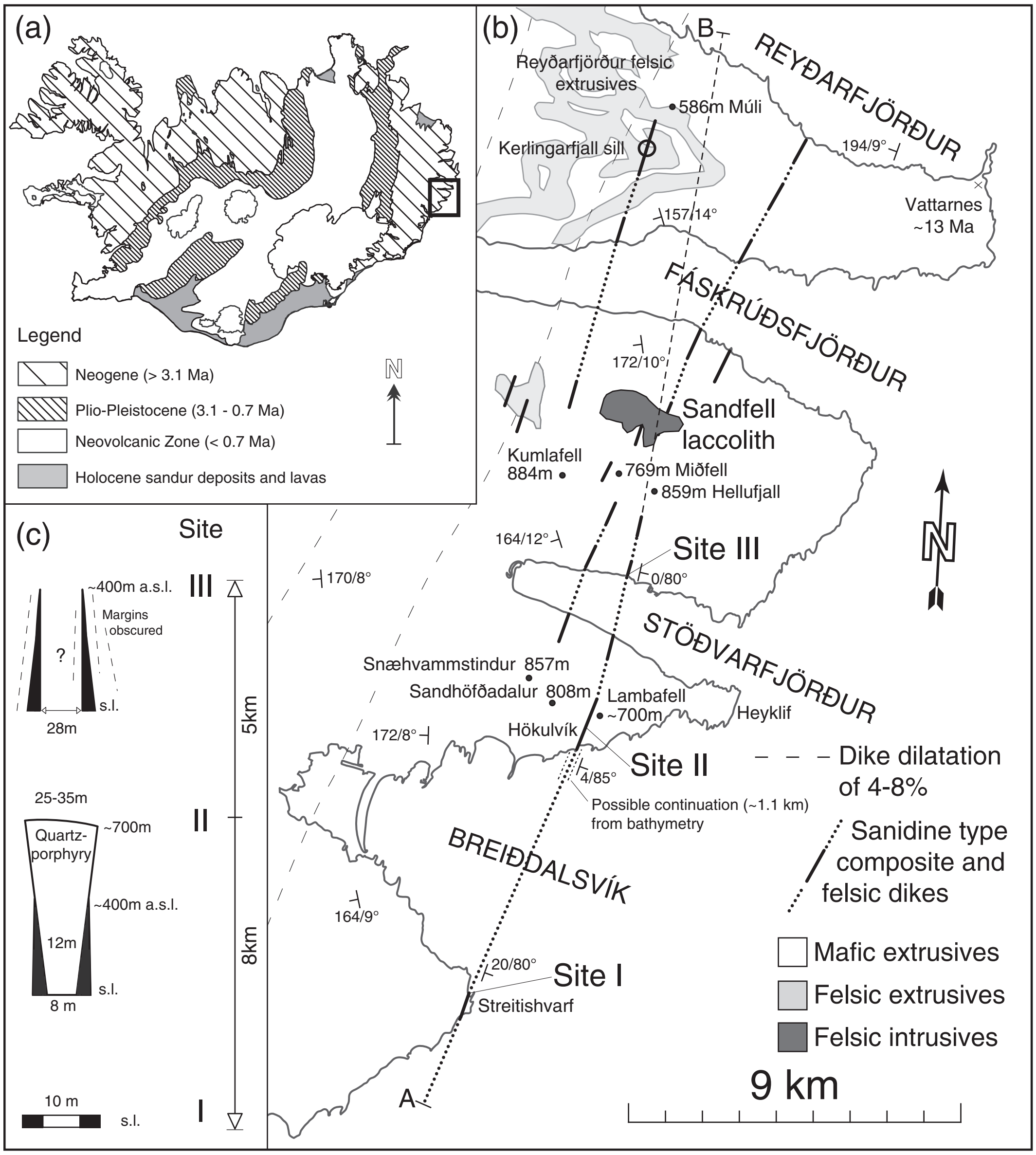

Fig. 1. (a) Geological map of Iceland showing the age succession of the bedrock. The enclosed area is shown in (b). Miocene (~16 — 3.1 Ma) rocks are found along the northwest and east coast. These are overlaid by volcanics of Plio-Pleistocene age (3.1 — 0.7 Ma), and of volcanics in the neovolcanic zone (<0.7 Ma). Holocene sandur deposits occur prominently along the south coast. Map simplified from Jóhannesson and Sæmundsson (1998). (b) Schematic geological map over the study area, showing felsic and composite dikes as mapped by Gibson and Walker (1963) and us, larger felsic intrusives and extrusives. Visible outcrops are denoted by black lines, and their assumed continuation is denoted with dotted lines. The thin dashed lines indicate the zone of maximum dilatation within the dike swarm belonging to the Reyarfjörur volcanic system. The dike dilatation maxima of the Álftafjörur volcanic system lie further down to the south-west outside the figure frame. The cross section marked A–B is shown in Fig. 12. The dots represent selected mountain peaks, with height above sea level included. The strike/dip directions for the composite dike and the regional lavas are marked by ⊥ and given for selected areas. The easternmost part of the lava pile should not exceed ~13 Ma (Gerpir porphyritic group, which outcrop at Vattarnes) while the westernmost should not exceed ~11 Ma (McDougall et al., 1976; Watkins and Walker, 1977; Duncan and Helgason, 1998). (c) Schematic vertical sections of sites I, II and III. The section at site III is poorly constrained since the outcrops are partly obscured by debris, but field evidence supports the loss of the dolerite margins at ~400 m a.s.l.. Figure (c) constructed from own field evidence and observations by Guppy and Hawkes (1925) and Gudmundsson (1985).

interrupted by now exhumed volcanic centers with accompanying regional dike swarms (e.g. Walker, 1963; Carmichael, 1964; Walker, 1966; Carmichael, 1967; Walker, 1974; Paquet et al., 2007). These exhumed central volcanoes occur in the field as ensembles of major felsic intrusions, felsic extrusives, volcaniclastics and occasionally gabbroic bodies (Walker, 1966). The vast majority of the dikes are mafic, but felsic and composite dikes do occur, especially in the vicinity of volcanic centers (Gibson and Walker, 1963). The composite dikes are characterized by outer mafic margins and an inner felsic core; several are found in between Reyarfjörur and Breidalsvík (Fig. 1b; Gibson and Walker, 1963; Gibson et al., 1966; Walker, 1966). Both the lavas and the exhumed volcanic centers have been buried and tilted 5°–10° westwards subsequent to emplacement due to the spreading accommodated across the rift axis (Fig. 1b, Bodvarsson and Walker, 1964; Saemundsson, 1979; Pálmason, 1986). Subsequent glacial erosion and isostatic rebound have uncovered and uplifted the remains. The crust has suffered ~1500 m of erosion from the paleo-surface (Walker, 1960; Gibson et al., 1966; Neuhoff et al., 1999).

2.1. General field relations of the composite dike

Gibson et al. (1966) mapped six composite dikes, including the Streitishvarf dike, forming a NNE–SSW trending swarm centered around Sandfell, a rhyolitic oligoclase porphyry laccolith (Hawkes and Hawkes, 1933). The outcrops appear from the south shore of Breiðdalsvík to the north shore of Reyðarfjörður (Fig. 1b). The