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New palaeointensity data from Holocene Icelandic lavas

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ABSTRACT

We present rock magnetic and palaeointensity data from Holocene Icelandic lava flows, including historical and pre-historical lavas. Susceptibility versus temperature measurements indicate that the magnetic mineralogy is dominated by primary titanomagnetite that have experienced variable degrees of high-temperature oxidisation. The analyses also demonstrate that virtually all studied samples are thermally stable up to their Curie temperatures. Thellier palaeointensity experiments were carried out on 89 samples from fourteen different lava flows (spanning the age of 167 to 9450 cal. years BP). Microwave Thellier experiments were used for one third of the samples, while conventional thermal Thellier was used for the remainder; the two methods produced similar palaeointensities. Altogether, reliable absolute palaeointensity estimates were obtained from all of the lava flows, with values ranging from $38.2 \pm 5.0\,\mu T$ to $117.9 \pm 8.3\,\mu T$. The new results indicate that the Holocene geomagnetic field intensity was more dynamic than suggested by the current field models, possibly including brief intervals of anomalously high field strength.

1. Introduction

The Earth's magnetic dipole moment (DM) has decreased rapidly since 1840, when direct measurement of the strength of the Earth's magnetic field began. The detailed evolution of the DM further back in time remains poorly constrained even for the most recent prehistoric past (Gubbins et al., 2006). Recent reconstructions based on global compilations of palaeointensity data (Korte and Constable, 2005; Knudsen et al., 2008) represent a smoothed version of the actual variation, but these reconstructions still suggest that the prehistoric DM was dynamic. Analyses of high-resolution Holocene palaeointensity data from specific regions appear to indicate an even more dynamic DM than was previously believed (Gallet et al., 2003), possibly including brief periods of very high field strength (Ben-Yosef et al., 2009).

Iceland is situated on the boundary between the North American and Eurasian plates, where it is superimposed on the Icelandic mantle plume or anomalously hot mantle, a unique geological setting associated with enhanced volcanic activity (Wolfe et al., 1997). Considerable efforts have been made to constrain ages of postglacial lavas and tephras, the primary motivations being: the investigation of Holocene eruption history and tephra stratigraphy in Iceland (Thordarson and Larsen, 2007; Larsen and Eiríksson, 2008a,b; Thordarson and Höskuldsson, 2008); research into tephrochronology for dating and correlation of terrestrial and marine sediment; as well as glacier palaeoclimatic archives used for assessment of climate variability in the North Atlantic region (e.g. Haflidason et al., 2000; Eiríksson et al., 2000; Andrews et al., 2002; Geirsdóttir et al., 2009; Vinther et al., 2006).

Iceland produces one eruption every three to five years on average, and ~20% of those are effusive (lava-producing) events. The region records a number of young lava flows with well-constrained ages (e.g. Thordarson and Höskuldsson, 2008), making Iceland an ideal sampling area to further extend our knowledge of dipole moment variation with high temporal resolution in the most recent pre-historic past.

Considering the abundance of Holocene lava flows on Iceland, palaeomagnetic data from this region are surprisingly scarce. Altogether, three palaeomagnetic studies have been carried out on Holocene lavas from Iceland (Brynjólfsson, 1957; Doell, 1972; Schweitzer and Soffel, 1980), but only the study of Schweitzer and Soffel (1980) includes palaeointensity measurements. In this study, we present new palaeointensity data based on samples collected in 2004 from fourteen well-dated Holocene Icelandic lava flows that span the period from 167 to 9450 cal.

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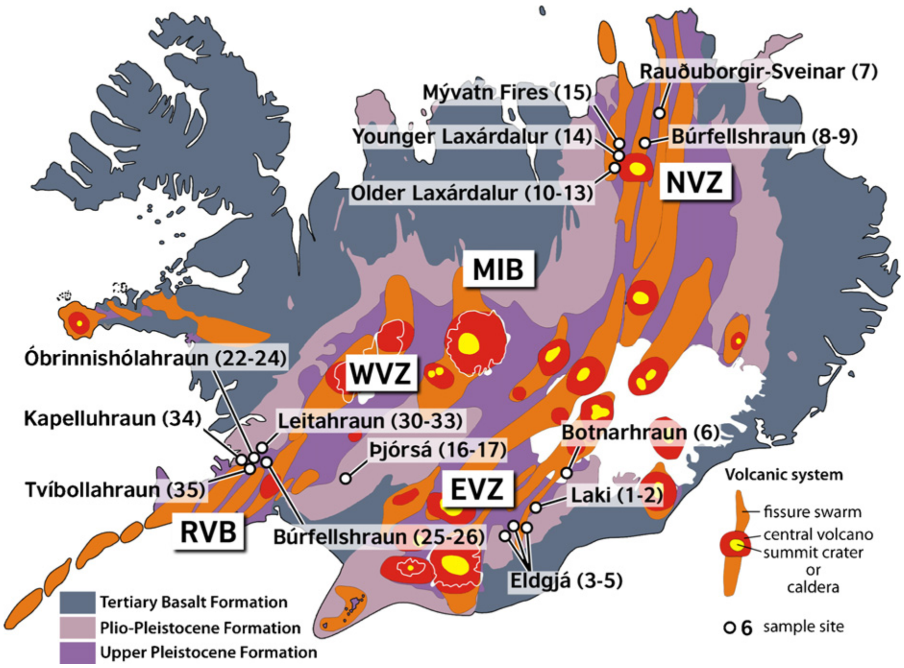

Fig. 1. Map of Iceland showing the sites sampled and the locations of relevant volcanic systems: North Volcanic Zone (NVZ); West Volcanic Zone (WVZ); East Volcanic Zone (EVZ); Reykjanes Volcanic Belt (RVB); and the Mid-Iceland Belt (MIB) (modified from Thordarson and Höskuldsson, 2008). Refer to Thordarson and Larsen (2007) and Thordarson and Höskuldsson (2008) for a detailed description of the volcanic zones.

years BP, with particular attention paid to the rock magnetic properties of the Icelandic lavas. (Note: 0 cal. years BP ≡ AD 1950.)

2. Experimental procedures and results

2.1. Sampling

Fourteen lava (*hraun*) flow fields in Iceland (Fig. 1) were selected for this study. Where feasible, each lava flow field was sampled at several different sites to account for possible in-flow variations caused by (for example) differing degrees of oxidation and weathering, or post-magnetisation modification by lava inflation. The lava flow fields in the south-west are Óbrinnishólahraun (2141 ± 191 cal. years BP), Kapelluhraun (799 cal. years BP), Tvíbollahraun (1050 ± 124 cal. years BP), Búrfellshraun in Heiðmörk (8089 ± 261 cal. years BP) and Leitahraun (5254 ± 206 cal. years BP), which contains the Rauðhólar rootless cone group. All of these lavas originated from fissures within the Reykjanes Volcanic Belt (RVB) (Jónsson, 1978). The 167 Laki, 1016 Eldgjá, 6500 ± 500 Botnar and 8596 ± 170 cal. years BP Thjorsa (Þjórsá) lava flow fields were produced by fissures within the East Volcanic Zone (EVZ; e.g. Thordarson et al., 2003). The remaining flow fields, Mývatn Fires (226 cal. years BP), Búrfellshraun in Mývatnsöræfi (~3150 cal. years BP), Younger (2221 ± 140 cal. years BP) and Older (3905 ± 48 cal. years BP) Laxárdalur, and Rauðuborgir-Rauðhólar-Sveinar (~9450 cal. years BP), all originated as fissure vent systems within the North Volcanic Zone (NVZ). Further details, including flow field ages and geographic coordinates of sampling sites, are listed in Tables 1 and 2.

Oriented palaeomagnetic drill cores were collected from 28 different sites representing 14 individual lava flow fields (altogether more than 400 oriented palaeomagnetic drill cores – see Table 1) using a 25 mm-diameter petrol-powered drill. The cores were oriented with a magnetic compass, and when possible a sun compass. Each cored sample was cut into three 20 mm-long pieces in the laboratory at Lund University (Sweden) and labelled A, B and C (top – nearest the surface of the lava flow, middle, and bottom respectively). Whenever possible, the lowermost samples were used, in order to measure the least weathered sample. For the microwave analyses, a 5 mm-diameter sample was drilled from a 25 mm section.

2.2. Magnetic hysteresis

Hysteresis measurements on 61 samples were carried out on a Princeton Measurements Corporation alternating gradient magnetometer (AGM-M2900-2). The magnetic domain state (magnetic grain-size) of each sample can be established by plotting ratios of saturation remanence to saturation magnetisation ($M_{rs}/M_{s)}$), and coercivity of the remanence to coercivity (H_{cr}/H_{c}) (Day et al., 1977). The results of the hysteresis measurements can be seen for every site in Fig. 2a. Fig. 2b shows the average magnetic domain state for each lava flow. Most samples lie within the pseudo-single domain (PSD) range which indicates a mixture of single domain (SD) and multi domain (MD) grains, or PSD grains (Dunlop, 2002a,b).

2.3. Susceptibility versus temperature

The temperature dependence of magnetic susceptibility was assessed by measuring 28 samples – representing all lava formations – on a Geofyzica Brno KLY-2 Kappa bridge with a CS-2 facility. The resulting heating and cooling curves tend to arrange samples into three groups referred to here as Types I–III (Fig. 3). Type I sample curves have low Curie temperatures (~150 °C), indicating non-oxidised primary Ti-magnetites. The Type II sample curves have Curie temperatures around 300 °C, and – in most cases – a higher temperature phase with Curie temperatures around 580 °C. Most Type II curves are reversible up to 300–400 °C, and some are reversible up to 500 °C. The majority of the measured samples from all sites exhibit Type II curve behaviour and we interpret them to indicate that the titanomagnetite grains were affected by minor deuteric oxidation upon cooling. The Type III curves are reversible,