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Paleointensity on volcanic glass of varying hydration states

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ABSTRACT

We have characterised the magnetic properties of variably hydrated volcanic glasses that were collected from rhyolitic deposits at Bláhnúkur, Torfajökull, Iceland. The glasses span the range from fresh obsidians to highly fractured perlites that contain >2 wt% water. Lava hydration plays a key role in the formation of perlite and, hence, these rocks are ideal to study hydration effects on remanence carriers and reliability of the paleomagnetic record. The total volatile content of the different samples was determined as a proxy for the degree of perlitisation/hydration. It was found that coercivity of remanence, saturation magnetisation and saturation of remanence decrease with increasing hydration, i.e. that magnetic remanence carriers get lost and that magnetic stability is reduced. Additionally, thermal demagnetisation of a three component isothermal remanence revealed that mainly the high coercive material is destroyed within the more strongly hydrated samples while lower coercive material seems to be less affected. Grain sizes of all but one samples are in the pseudo-single domain range (the one exception shows multi-domain characteristics). It was impossible to unambiguously identify the remanence carriers, but titanomagnetites are most likely responsible for the lower coercivity component while hemoilmenites possibly represent the higher one. A modified Thellier method was used to determine paleointensity values. As most of the samples are hydrated it is not astonishing that the overall paleointensity data is not of very high quality. However, it is important to note that there are hydrated samples with well-defined Arai-diagrams. Although seemingly of high quality, these paleointensity values are incorrect as there is a trend towards lower paleointensity values observed with increasing perlitisation. We attempted to test for magnetic anisotropy and cooling rate dependency, but this was hampered by alteration during the experiments. However, we argue that both anisotropy and cooling rate dependency are unlikely to be responsible for the observed trend in paleointensity. Thus, even well-defined paleointensity values can be erroneous when obtained from hydrated glass. This emphasises the need for unaltered samples and additional attention during paleointensity determinations.

1. Introduction

Much of the ongoing research in paleomagnetism is dedicated to the improvement of paleointensity determination. This goal is mainly pursued in two ways: the development of new paleointensity methods (Dekkers and Böhnel, 2006; Fabian and Leonhardt, 2010a; Muxworthy and Heslop, 2011) and the search for ideal recording materials (Pick and Tauxe, 1993; Bowles, 2005; Leonhardt et al., 2006a; Cottrell and Tarduno, 1999; Tarduno et al., 2007). Both ways try to reduce problems that are often encountered during Thellier–Thellier paleointensity experiments (Thellier and Thellier, 1959) such as alteration (in geological time or in the laboratory experiment) (Valet et al., 1996), anisotropy of thermoremanence (Veitch et al., 1984), magnetic domain state bias (Leonhardt et al., 2004a) and different cooling histories in laboratory and nature (Leonhardt et al., 2006a).

Volcanic glass is one of the materials that has been proposed to carry ideal magnetic remanence carriers, i.e. remanence carriers in the single-domain (SD) range that are stable during repeated heatings in the experiment and for which corrections of anisotropy of thermoremanence and cooling rate dependency via relaxation geospeedometry (Wilding et al., 1995, 2004; Gottsmann and Dingwell, 2001a; Potuzak et al., 2008; Ferk et al., 2011b) are possible. However, in an earlier study on 750 ka year old rock from Tenerife we have found that devitrification of volcanic glass in nature is challenging when determining paleointensity (Ferk et al., 2011b): changes in rock magnetic parameters (loss of remanence carriers and magnetic stability) leading to a decrease in recording accuracy

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of paleointensity with increasing devitrification suggested the presence of a chemical remanence (CRM) that had at least partially overprinted the original thermoremanence (TRM).

To investigate problems connected to hydration/alteration of volcanic glass in more detail we have sampled two sites at Bláhnúkur, Iceland, that exhibited varying degrees of perlitisation. Perlite is volcanic glass that hosts abundant gently curved cracks (perlitic fractures) that surround cores of intact glass (McPhie et al., 1993) (Fig. 1). Lava hydration plays a key role in the formation of perlite. Denton et al. (2012) suggested that major fractures in the glass are formed due to cooling contraction. Water travels along these fractures and diffuses into the glass through the fracture-glass interface leading to the formation of arcuate perlitic fractures. The most significant perlitisation is likely to occur at temperatures just below the glass transition. Additional perlitisation may occur at ambient temperatures if time-scales are long enough. The two outcrops studied here consist of hyaloclastites, perlitised and non-perlitised obsidians and microcrystalline rhyolite lavas all of which clearly show varying degrees of hydration. Hence, they are well-suited to analyse the influence of hydration/alteration on magnetic stability and magnetic remanence.

2. Geology and sampling

Torfajökull volcanic complex is the largest rhyolitic centre in Iceland (e.g. Tuffen et al., 2001) with more than 80% of lavas being silicic (Gunnarsson, 1998). It is located at the intersection between the Eastern Rift Zone and the South Eastern Zone, an older crustal segment. Activity goes back to mid-Quaternary time forming a plateau of approximately 18×12 km^2. There are mainly subglacial and subaerial rhyolites, but basaltic hyaloclastites are also present (Tuffen et al., 2001). Bláhnúkur was formed during a small-volume effusive subglacial eruption in the last glacial period (115–11 ka ago) (Fig. 2) (Tuffen et al., 2001). Outcrops consist of (sometimes perlitised) obsidian and microcrystalline rhyolite lava lobes in a pale grey perlitised hyaloclastite breccia (Tuffen et al., 2001; Denton et al., 2009).

Samples were taken on a field trip to Iceland in August 2008. We sampled two sites where pristine obsidian and obsidian with different degrees of perlitisation (perlite) were found. Site C1B (Fig. 3) is a large outcrop (20 m long, 8 m high and 10 m deep) on the northern slope of Bláhnúkur (817 m elevation, N63°58′36.9″, W019°04′43.2″). The presence of columnar joints in the upper parts of the outcrop suggests the lava was constrained by an ice wall or now-eroded hyaloclastites. Perlitised obsidian at the base indicates that the lava interacted with meltwater during cooling. The geometry of the outcrop is difficult to ascertain as it does not have a typical lobelike morphology. A largely microcrystalline interior is surrounded by an obsidian carapace as is the case in most lobes at Bláhnúkur. The samples represent a sequence away from a well-defined contact between the perlitised margin and the surrounding hyaloclastite. The samples analysed were named C1B a (flow banded transitional lava), bi (obsidian), bii (perlite), biii (perlite), biv (perlite) and bv (hyaloclastite). The lava lobe is vesicle and phenocryst-poor (less than 10%). The second site W2u (Fig. 4) is the upslope side of a small lobe on the apex of a southwest to south trending ridge at Bláhnúkur (N63°31′29″, W019°04′37.7″, 860 m elevation) that is moderately to highly vesicular (up to 50%). It contains a hyaloclastite (W2u z) which grades into a large zone of brecciated perlitised obsidian (samples W2u x and W2u y), that gradually changes into a columnar-jointed perlitised obsidian (samples W2u w, W2u v-w). The perlitisation gradually decreases in intensity until an unperlitised obsidian (W2u v) and a flow banded transition lava (W2u v fb) is reached.

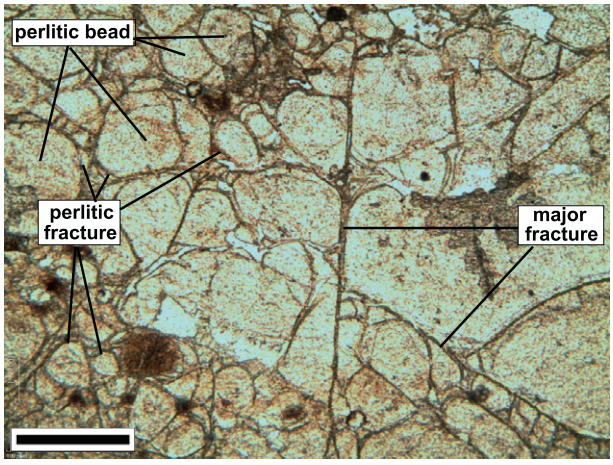

Fig. 1. Thin section photograph of perlitised obsidian in plane polarised light. Major and perlitic fractures and perlitic beads are labelled. The scale bar is 0.5 mm long.

3. Degree of perlitisation, volatile content and glass transition temperature

Degree of perlitisation, fracture populations, volatile contents and thermal characteristics of the samples were analysed in the course of a study by Denton et al. (2012) on the formation of perlite. We only recapitulate those measurement procedures and those results that are of direct importance for the research presented here.

Field observation of perlitisation was an estimate by eye of the proportion of grey hydrated material to black unhydrated material. The actual number i.e. 10% perlitised refers to 10% grey (hydrated) material and 90% black (unhydrated) material (Fig. 5). Visible perlitisation in the field was quite variable and as a result the uncertainties are relatively large. Volatile contents and thermal characteristics of samples were analysed by differential scanning calorimetry–thermogravimetric analysis–mass spectrometry (DSC–TGA–MS) using a TA Instruments SDT Q600 simultaneous DSC–TGA instrument coupled to an HPR-20 QIC gas analysis system mass spectrometer at Lancaster University. The DSC–TGA technique measures the weight loss and thermal characteristics of a sample while it is subject to a controlled heating programme. DSC–TGA measurements were done in oxygen-free nitrogen. The addition of a mass spectrometer allows the identification of the exsolved gases. Samples were crushed and sieved. The 125–500 μm size fraction was washed with acetone and then oven-dried at 50 °C for about 1 h (Newman et al., 1986). After drying, the sample was transferred to a desiccator to minimize atmospheric water adsorption before analysis. Approximately 50 mg of the sample were placed in a tared platinum cup on the DSC-TGA sample beam and heated at 5 °C/min from ambient temperature to 1250 °C. Total volatile loss (i.e. total volatile content; TVC) was calculated by subtracting the end weight from the start weight.

Additional simultaneous thermogravimetric (TGA) and calorimetric (DSC) measurements were carried out using a Netzsch STA 449 C at the University of Munich to determine the glass transition temperature. Here specimens of samples C1B bii, biii and biv and W2u v of approximately 37 mg were heated in a platinum crucible (with lid) with a heating rate of 25 °C/min to 1000 °C in Argon.

Lancaster TVC-data together with field estimates of degrees of perlitisation are shown in Table 1 and in Fig. 6. Error bounds of TVC data in Fig. 6 are analytical errors, which are ±10%. Denton et al. (2009) showed that duplicate analyses of perlitised obsidian often give different results due to heterogeneities of water