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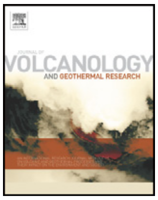

Origin and evolution of silicic magmas at ocean islands: Perspectives from a zoned fall deposit on Ascension Island, South Atlantic

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ABSTRACT

Ascension Island, in the south Atlantic is a composite ocean island volcano with a wide variety of eruptive styles and magmatic compositions evident in its ~1 million year subaerial history. In this paper, new observations of a unique zoned fall deposit on the island are presented; the deposit gradationally changes from trachytic pumice at the base, through to trachy-basaltic andesite scoria at the top of the deposit. The key features of the eruptive deposits are described and are coupled with whole rock XRF data, major and trace element analyses of phenocrysts, groundmass glass and melt inclusions from samples of the compositionally-zoned fall deposit to analyse the processes leading up to and driving the explosive eruption. Closed system crystal fractionation is the dominant control on compositional zonation, with the fractionating assemblage dominated by plagioclase feldspar and olivine. This fractionation from the trachy-basaltic andesite magma occurred at pressures of ~250 MPa. There is no evidence for multiple stages of evolution involving changing magmatic conditions or the addition of new magmatic pulses preserved within the crystal cargo. Volatile concentrations range from 0.5 to 4.0 wt.% H_2O and progressively increase in the more-evolved units, suggesting crystal fractionation concentrated volatiles into the melt phase, eventually causing internal overpressure of the system and eruption of the single compositionally-zoned magma body. Melt inclusion data combined with Fe–Ti oxide modelling suggests that the oxygen fugacity of Ascension Island magmas is not affected by degree of evolution, which concentrates H_2O into the liquid phase, and thus the two systems are decoupled on Ascension, similar to that observed in Iceland. This detailed study of the zoned fall deposit on Ascension Island highlights the relatively closed-system evolution of felsic magmas at Ascension Island, in contrast to many other ocean islands, such as Tenerife and Iceland.

1. Introduction

Ascension Island, in the south Atlantic, is a 12 km diameter ocean island volcano located 90 km west of the mid Atlantic Ridge (MAR). It is similar to Iceland and many other ocean island volcanoes in having a significant proportion of silicic volcanic products preserved at the surface (~14% of the surface exposure, Nielson and Sibbett, 1996, compared with ~10% surface area in Iceland, Walker, 1966, Carley et al., 2011). Understanding the processes responsible for the production of silicic magmas at ocean islands is important not only for our present understanding of magmatic processes and magmatic evolution, but also provides critical insights into the mechanisms behind the generation of the first continental crust in the Archean (e.g. Gazel et al., 2014; Mancini et al., 2015). Two main methods have been proposed for the generation of evolved melts in thin oceanic crust: (i) low-degree partial melting of hydrothermally-altered crust to produce primary silicic melt (e.g. Sverrisdottir, 2007; Carley et al., 2011; Kuritani et al., 2011) or (ii) fractionation (in potentially multiple stages) from a basaltic parental magma (e.g. Watanabe et al., 2006; Snyder et al., 2007; Mortensen et al., 2009; Mancini et al., 2015), or some combination of these processes.

Zoned volcanic deposits preserve the moment in magmatic evolution when distinct magmas are erupted together, and might only be observable through disequilibria in phenocryst assemblages in otherwise homogeneous deposits. They can provide a direct record of processes responsible for magmatic evolution (and timescales over which they occur), such as fractionation, mixing and assimilation (e.g. Watanabe et al., 2006; Snyder et al., 2007; Sverrisdottir, 2007; Mortensen et al., 2009; Carley et al., 2011; Kuritani et al., 2011; Mancini et al., 2015).

Zoned volcanic deposits may also yield insights into the processes responsible for eruptive triggering (e.g. Sverrisdottir, 2007; Kuritani et al., 2011). Recharge of volcanic systems (potentially preserved as two magmatic types in zoned volcanic deposits) has often been cited as a trigger for eruptions (e.g. Sparks and Sigurdsson, 1977; Pallister et al., 1992; Sverrisdottir, 2007; Saunders et al., 2012; Sliwinski et al., 2015) whether due to a direct increase in volume, causing failure of the

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magma chamber wall rocks (e.g. Jellinek and DePaolo, 2003), the buoyancy-driven effects of accumulating magma (e.g. Caricchi et al., 2014; Malfait et al., 2014), or by indirectly causing changes in volume of saturated gases and crystal cargo (e.g. Snyder, 2000). However, other eruptive triggers are well-documented, including tectonic triggers from earthquake activity (e.g. Allan et al., 2012), changing crustal stress-states (e.g. Bonali et al., 2013) and internal overpressure from crystal fractionation driving increased volatile concentrations in the remaining magma (e.g. Stock et al., 2016).

Here we present field observations, whole rock major and trace element data, mineral compositions and melt inclusion analyses from a unique zoned fall deposit on Ascension Island, to understand the processes responsible for felsic melt generation, evolution and eruption in young (<7 Ma) oceanic crust on Ascension Island. The zoned fall deposit is unique on Ascension Island in that it changes gradationally from trachytic pumice at the base of the unit, to a trachy-basaltic andesite scoria at the top of the unit, with no textural evidence for mingling between pumice and scoria. We use this deposit to probe the origins of felsic melt at Ascension Island, to understand how the zonation is produced, and by inference what may have triggered the eruption. In particular, we use this deposit to test whether the zonation is the result of two distinct magma batches partially homogenizing (open system), if it is generated via in situ fractionation (closed system), or if it is the result of a combination of multiple processes.

2. Geological setting

Ascension Island (7° 56′ S; 14° 22′ W) is located in the southern Atlantic Ocean, 90 km west of the Mid-Atlantic Ridge and 50 km south of the Ascension Fracture Zone (AFZ; Fig. 1). Volcanism has been present at Ascension for ~6–7 Myr and the subaerial portion of the island (only 1% of the total ~ 3800 km^3 edifice, Harris, 1983) was formed in the last ~1 Myr (Weaver et al., 1996; Jicha et al., 2013). Volcanic deposits on Ascension are widely variable, with lava flows, lava domes and pyroclastic fall units, pyroclastic flow units (Daly, 1925; Harris, 1983; Weaver et al., 1996; Hobson, 2001).

Subaerial volcanism has been the product of a transitional to mildly alkali magmatic series of olivine basalt – hawaiite – mugearite – benmoreite – trachyte – rhyolite. Previous investigations into Ascension Island volcanism have focussed on the geochemical distinctions between magmas; mafic volcanic products have been split into three main categories, based on their Zr/Nb ratios, which has been inferred to represent varying source characteristics underlying Ascension. Mafic volcanic products occur across all of Ascension, but felsic volcanic products are more localised and outcrop in two main areas of the island: a 'Central Felsic Complex', which contains Green Mountain, the highest point on the island at 859 m asl, (see Fig. 1; Kar et al., 1998) and the younger 'Eastern Felsic Complex' (Fig. 1; Kar et al., 1998; Hobson, 2001; Jicha et al., 2013). Previous studies have suggested that the felsic magmas are a product of fractional crystallisation from the high Zr/Nb basalt (Weaver et al., 1996; Kar et al., 1998), with limited evidence for interaction between magma batches (Kar et al., 1998).

3. The compositionally zoned fall

The compositionally-zoned fall unit (Fig. 2) is found in multiple locations across the island (Fig. 3) although it is dominantly found in the Eastern Complex (Fig. 1). Along the North East coast the compositionally-zoned fall outcrops below a (geochemically un-related) voluminous trachyte flow at NE Bay, which has a ^{40}Ar/^{39}Ar date of 169 ka (±43 ka [2σ], Jicha et al., 2013). Thus the eruption responsible for the deposition of the compositionally-zoned fall is also likely comparatively young.

The vent for the compositionally-zoned fall deposit was identified by the coarsening characteristics of the multiple exposures (see Fig. 3 for maximum lithic clast and thickness variations at every outcrop observed), and by the presence of a fissure through an underlying mafic lava flow, overlain by the coarsest and thickest deposits of the compositionally-zoned fall on the island. At this locality the bombs of pumice are up to 30 cm in diameter, and lithic clasts (of trachyte lava and dense mafic lava and scoria) are up to 15 cm in diameter. The limited outcrops indicate dispersal towards the north east, which is consistent with the dominant south-westerly wind direction at Ascension (see Fig. 3).

For the purposes of systematic sampling, three distinct subunits were delineated (Figs. 2, 3). The lowermost subunit (A) consists of felsic cream to light brown coloured pumice which is variably oxidised to orange and purple colours in the centre of clasts, and ~15% lithic clasts. Juvenile pumice is crystal poor, with <5% crystals which include feldspar and olivine. Crystals are always <1 mm in diameter. Lithic clasts present include green trachyte lava and mafic lava (oxidised to red and unoxidised black). Subunit B marks the first appearance of the transitional brown pumice-scoria with a coarser vesicularity than that of the light brown pumice (Fig. 4). The change from cream pumice to brown pumice-scoria is gradational, with transitional light brown pumice-scoria clasts identified, implying that the change in colour is both textural and compositional in origin. Lithic clasts comprise ~15% of this unit, and are dense mafic lavas (red and black) and minor green trachyte

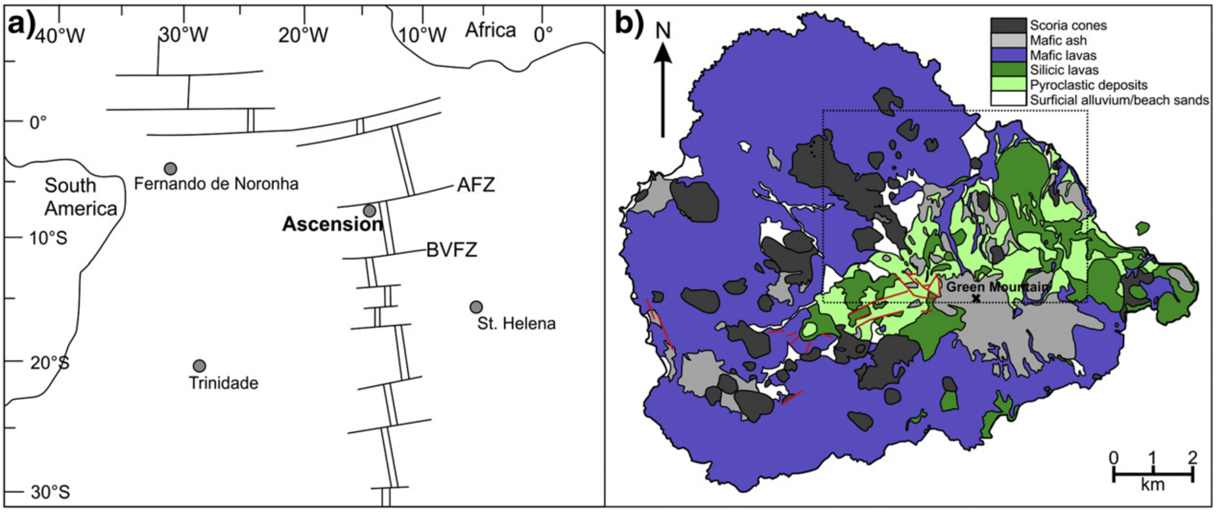

Fig. 1. Ascension Island location map (a) shown in relation to the Mid Atlantic Ridge, the Ascension Fracture Zone (AFZ) and the Bode Verde Fracture Zone (BVFZ). Geological map of Ascension Island (b) showing the areas where lavas, scoria cones and pyroclastic deposits are exposed at the surface. Faults are shown as red lines.