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Magma degassing during the April 2007 collapse of Piton de la Fournaise: The record of semi-volatile trace elements (Li, B, Cu, In, Sn, Cd, Re, Tl, Bi)

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ABSTRACT

This study reports the concentrations of trace elements, including fluid mobile and semi-volatile species (e.g., Li, B, Cu, Re, In, Sn, Cd, Tl, Bi) in lavas erupted before and during the April 2007 collapse of the Piton de la Fournaise summit. Lavas erupted just prior to the collapse (April 5) display anomalous abundances in semi-volatile elements, with both depletion in Li, Cu and Tl (mostly on April 2) and enrichment in Cd, Bi, In and Sn (on April 3 and 4). These transient anomalies are thought to record unusual degassing conditions. Between March 30 and April 2, static decompression caused by magma withdrawal from the shallow magma reservoir might have triggered massive exsolution of a H_2O- and S-rich phase in which Li and Cu might have partitioned. Alternatively, the Li–Cu depletion could record the degassing of a magma body that intruded at shallow depth during the same period. The Bi–Cd–In–Sn enrichment observed in the April 3–4 magmas requires conditions that prevent magma outgassing. In the absence of evidence for the pressurisation of the reservoir or the onset of collapse before April 5, it is suggested that the occurrence of less degassed lavas on April 3 and 4 reflects a high rate of magma transfer from the shallow magma reservoir to the eruption site just prior to summit collapse. The kinetic (diffusive) fractionation of elements accounts for the observed anomalies. The short time-scales required to fractionate Li from Cd diffusively (minutes to hours) and Cd from Bi (few hours to two days) support the idea that the magmas underwent rapid pressure variations a few days before the summit collapse.

1. Introduction

Réunion Island (60×40×3 km) is located in the Indian Ocean at 21°10′S, 55°30′E (Fig. 1a). It is the emergent part of a basaltic cone of 240×200×7 km. The island is the present location of the hotspot that created the Deccan Traps, the Chagos–Maldive–Laccadive ridge, the Mascarene Plateau and Mauritius Island. The island is presently composed of two main volcanoes, the extinct Piton des Neiges in the NW and the active Piton de la Fournaise in the SE (Fig. 1b). Piton de la Fournaise has been regularly active since at least 530 ka (Gillot and Nativel, 1989) and is still presently in its shield building stage. Three major events, either collapses or landslides, marked the growth history of the volcano 250, 35 and 4.7 ka ago (Gillot et al., 1994). The result is three concentric calderas or depressions, the most recent of which (the Enclos Fouqué) is U-shaped (8×13 km) and open to the sea on its eastern side (Fig. 1c). A 400 m high cone with two coalescent summit craters (Bory and Dolomieu) rises inside the Enclos Fouqué.

Although collapse calderas are relatively common features of basaltic volcanoes, very few have been observed during their formation. The collapse of the Piton de la Fournaise summit in April 2007 is one of these formations. Due to the advanced monitoring network, the timing of the events and the temporal relationship between the magma withdrawal from the shallow reservoir and the collapse of the summit crater in particular are known in detail (Michon et al., 2007; Staudacher et al., 2009). Since 1977, the emitted lavas have been sampled regularly during the course of the eruption, providing a unique opportunity to track compositional changes that may be linked to caldera-forming processes. Previous geochemical studies of the April 2007 samples (Villemant et al., 2009; Vlastélic et al., 2009; Collins et al., 2012) have discussed general issues related to the magma source, magma differentiation and degassing trends, but none of them focused on the temporal-compositional evolution of the lavas erupted during, or just before, this major event, which is the object of this paper. This study focuses on trace elements, including fluid mobile and semi-volatile species (e.g., Li, B, Re, In, Cd, Tl, Bi). In particular, volatile trace metals are used to reconstruct the degassing history of this exceptional eruption, which is constrained from remote observations (Bhugwant et al., 2009; Gouhier and Coppola, 2011; Tulet and Villeneuve, 2011).

We first address the question of whether this exceptional, caldera-forming eruption was preceded by geochemical precursors. Thus, we investigate the previous eruptions of 2006 and 2007. Then, we consider the possibility that the temporal-compositional evolution of the April

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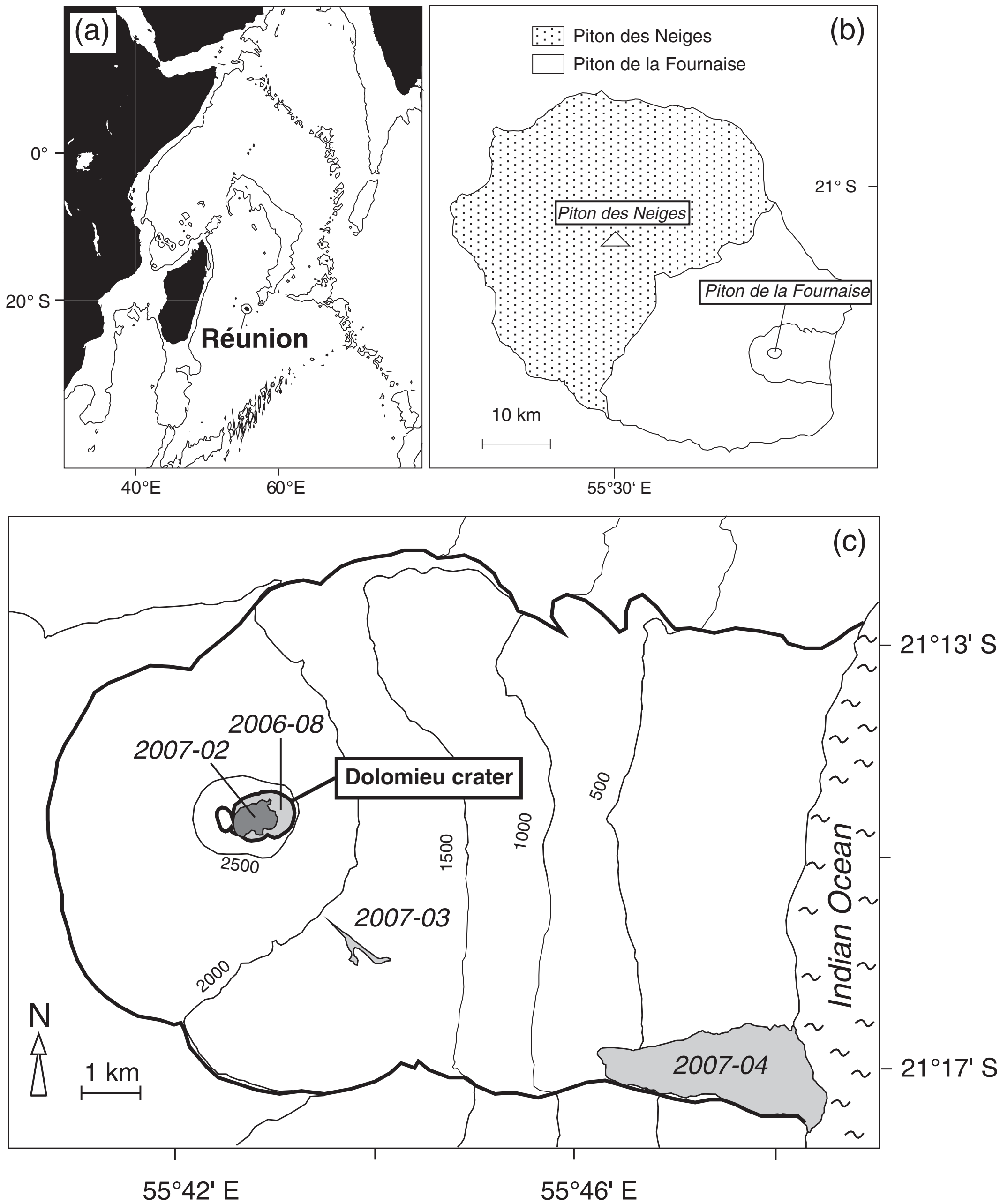

Fig. 1. Location maps. (a) Map of the Western Indian Ocean showing the location of Réunion Island. The 3000-m depth contour is indicated. (b) Map of Réunion Island showing the location of Piton des Neiges and Piton de la Fournaise. (c) Map of the Piton de la Fournaise volcano showing the lava flows produced during the eruptions of August–December 2006, February 2007, March 2007, and April 2007.

2007 lavas recorded the processes that affected the shallow magma reservoir shortly before, or even during, the eruption. These processes potentially include (1) pre-eruptive vapour transfer and accumulation at the top of the magma column, which could play a role in triggering major eruptions (Berlo et al., 2004; Kent et al., 2007; Rowe et al., 2008); (2) massive volatile exsolution in response to static decompression of the magma reservoir as magma drained to feed lateral eruptions (Johnson, 1992; Poland et al., 2009); (3) the rapid crystallisation of clinopyroxene and plagioclase microlites, depending on the thermal state of the shallowest magma reservoir and the dynamics of magma transfer to the eruption site (Welsch et al., 2009); and (4) magma contamination during storage. Interaction with or assimilation of oceanic crust or edifice material could occur as magma accumulates before high-flux eruptions (Vlastélic et al., 2005, 2007) or when volcanic activity resumes after a long period of quiescence, as in 1998 (Salaün et al., 2010). The scenarios of submarine collapse (Kent et al., 1999) and hydrothermal caldera (Merle et al., 2010) also raise the possibility of the entrainment of hydrothermally altered material that may compose the interior of the volcano (Lénat et al., 2000). These different possibilities are discussed in light of the trace element data presented.

2. Eruptive background

The Piton de la Fournaise volcano is very frequently active, but most eruptions are of small volume and short duration. Amongst the 105 eruptions estimated to have occurred between 1920 and 2007 (Stieltjes and Moutou, 1989; Peltier et al., 2009a), only four produced more than 50×10^6 m^3 of lava, and only two more than 100×10^6 m^3. These two most voluminous eruptions (July 1931 and April 2007) caused major summit collapses. Unlike in 1931, the eruptive history