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# New behaviour of the Piton de La Fournaise volcano feeding system (La Réunion Island) deduced from GPS data: Influence of the 2007 Dolomieu caldera collapse

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ABSTRACT

After 15 months of summit deflation, the unrest of Piton de La Fournaise renewed in August 2008 with several seismic crises and the re-pressurization of the plumbing system. The successive seismic crises, sometime accompanied by ground displacements detected by GPS, were associated with inter-eruptive dyke intrusions. It was the first time since the implementation of the observatory that such successive inter-eruptive magma migrations, not reaching the surface, were observed at Piton de La Fournaise. The change in the volcano activity, with an increase in the frequency of pure dyke intrusions, have followed the Dolomieu caldera collapse of April 2007 and reveals its strong influence on the new eruptive regime. Stress changes in the volcanic edifice have, temporarily at least, favoured the arrest of dykes in depth. During these successive dyke intrusions, magma stopped at shallow depth to form transitory magma storages before to erupt during three successive small summit eruptions (September 21st–October 2nd, 2008; November 27th; and December 14th, 2008–February 4th, 2009). The same kind of change in the pre-eruptive and eruptive behaviour can be expected on other volcanoes having experienced a summit caldera collapse.



## 1. Introduction

The probability of a volcanic eruption is linked to the capability of a magma to propagate from shallow reservoirs to the surface. Understanding the mechanisms leading to the rupture of the magma reservoir and to the propagation of a dyke toward the surface are crucial to forecast eruptions and their dynamisms. Dyke propagation, location and arrest strongly depend on the local stresses in the individual rock layers that constitute the volcano. On basaltic volcanoes, dyke propagate easier through a multi-layers lithology and requires less energy to reach the surface than on stratovolcanoes (Gudmundsson, 2009). Local stresses are determined by the mechanical properties of the rock layers but also by the depth, the shape and the loading conditions of the magma reservoir and they can be disturbed by consequences of the eruptive activity as the dyke injections and the crater or caldera collapses (Gudmundsson, 2006; Marti and Gudmundsson, 2000).

Piton de la Fournaise, has one of the highest eruption frequencies in the world, and is thus considered as an excellent study case where dyke propagation and dyke arrest mechanisms can be assessed. In April 2007, Piton de La Fournaise experienced one of its major eruptions of the last century. In 1 month, more than $140 \times 10^6$ $m^3$ of lava flows (ten times larger than during its typical eruption) had been emitted from a distal eruptive fissure located on the southeastern flank. After only 4 days of eruptive activity the Dolomieu summit crater collapsed on April 5th and 6th to form a new caldera (Michon et al., 2007a; Peltier et al., 2009a; Staudacher et al., 2009). The large withdrawal of the magma reservoir at the beginning of the eruption led to the Dolomieu crater collapse (340 m deep; Michon et al., 2007a; Urai et al., 2007; Peltier et al., 2009a; Staudacher et al., 2009). During the collapse, new structures appeared with the formation of concentric fractures on the caldera rims (Michon et al., 2009) and the weakness of the rock column located between the magma reservoir (~$2200 \pm 500$ m depth) and the surface (Peltier et al., 2009a). Following the April 2007 eruption, the volcano remained dormant during 16 months. This was the longest repose time period recorded at Piton de La Fournaise since 1998. Eruptive activity restarted inside the new Dolomieu crater from September 21st to October 2nd 2008 and continued with two other eruptions, located also in the Dolomieu crater, on November 27th 2008 and between December 14th 2008 and February 4th 2009. In this paper, we study the different phases of the 2008 volcanic unrest by analyzing the ground deformation recorded by the continuous GPS network of the Piton de la Fournaise volcano observatory. GPS is a well known tool in volcano-

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geodesy to investigate the dynamics of the magma feeding system on active volcanoes (e.g. Nunnari and Puglisi, 1995; Dvorak and Dzurisin, 1997). In our study, analysis of GPS data provided useful information to discuss the magma supply processes leading to the 2008 intrusions and eruptions and to evaluate the influence of the new collapse structure formed in April 2007 on the following eruptive activity.

## 2. Volcanic activity at Piton de La Fournaise

### 2.1. General view

Piton de La Fournaise is an oceanic basaltic shield volcano located on La Réunion Island (Fig. 1a,b). With a mean of 1–2 eruptions per year since the first observations during the 18th century, it is one of the most active basaltic volcanoes in the world (Peltier et al., 2009b). Piton de la Fournaise recent activity has been fully described in several papers published in the Journal of Volcanology and Geothermal Research special issue (vol. 184, issue 1–2, 2009). Eruptions occurred mainly either at the summit, inside the Dolomieu crater, or along the N25-30 and N120 rift zones defined by Michon et al. (2007b) (Fig. 1c). From 1970 to 2000, eruptions were fed by the progressive drainage of an occasionally recharged shallow magma reservoir with no long-term (weeks/months) ground deformation precursors, whereas from 2000 to 2007, eruptions were fed by a continuous filling in magma of the plumbing system which generated long-term (weeks/months) ground deformation precursors (Peltier et al., 2009b). From 2000 to 2007, eruptive activity took place in cycles of successive eruptions (Peltier et al., 2009b). Each eruptive cycle was characterized by a sequence (3 to 10 months in duration) of summit and near-summit, proximal, eruptions, and ended with a distal, low-elevation, eruption on the eastern flank of the volcano. Each eruptive cycle was preceded by 100–130 days of slight summit inflation (0.4–0.7 mm day$^{-1}$) and typically followed by 30–90 days of summit deflation (0.3–1.3 mm day$^{-1}$). During a same cycle, the summit inflation is continuous and is only interrupted by large short-term displacements (~0.2–1 m) recorded during dyke propagations toward the surface. Modelling of the long-term summit pre-eruptive inflation using a 3D-Mixed Boundary Element Method combined with a Monte-Carlo exploration algorithm (Cayol and Cornet, 1997; Fukushima et al., 2005) evidenced the involvement of a single over-pressurized magma reservoir for each pre-eruptive period, located at around 2200 ± 500 m depth (Peltier et al., 2007, 2008, 2009a,b).

### 2.2. The 2008–2009 eruptive activity

After the major distal eruption of April 2007 during which the Dolomieu crater collapsed to form a new caldera (Michon et al., 2007a; Staudacher et al., 2009), an unusual summit deflation was recorded during 15 months as a consequence of the edifice destabilization and the large withdrawal of the magma reservoir. The first signs of a new volcanic unrest were recorded in August 2008 with an increase of the seismicity below the Dolomieu crater (up to 50 volcano–tectonic earthquakes per day; M<3). Seismic activity associated with the volcano unrest has been described in detail by Staudacher (in press). Between August and September 2008, six major seismic crises, not followed by an eruption, occurred (August 4th, 15th, 31st and September 7th–8th, 8th–9th, 15th with more than 100 volcano–tectonic earthquakes recorded in a few hours). On September 12th, a tremor was recorded between 06:00 and 07:20 (UTC) and between 11:50 and 16:00, revealing the presence of magma at shallow depth below the summit. But except $SO_2$ degassing, no eruptive activity was observed in surface (Garofalo et al., 2009). On September 21st, after a short seismic crisis of about 10 volcano–tectonic events, eruptive tremor appeared at 11:35. The eruptive vent was located in the western wall of the Dolomieu crater. The eruption continued until October 2nd and emitted 0.8–1 × $10^6$ $m^3$ of lava. Following this eruption, seismic crises were recorded on October 20th and 31st (with 191 and 226 events respectively) and on November 6th and 21st (114 and 239 events respectively). On November 27th the seismic crisis was followed by the resumption of the eruptive activity at 07:49 from the same vent as

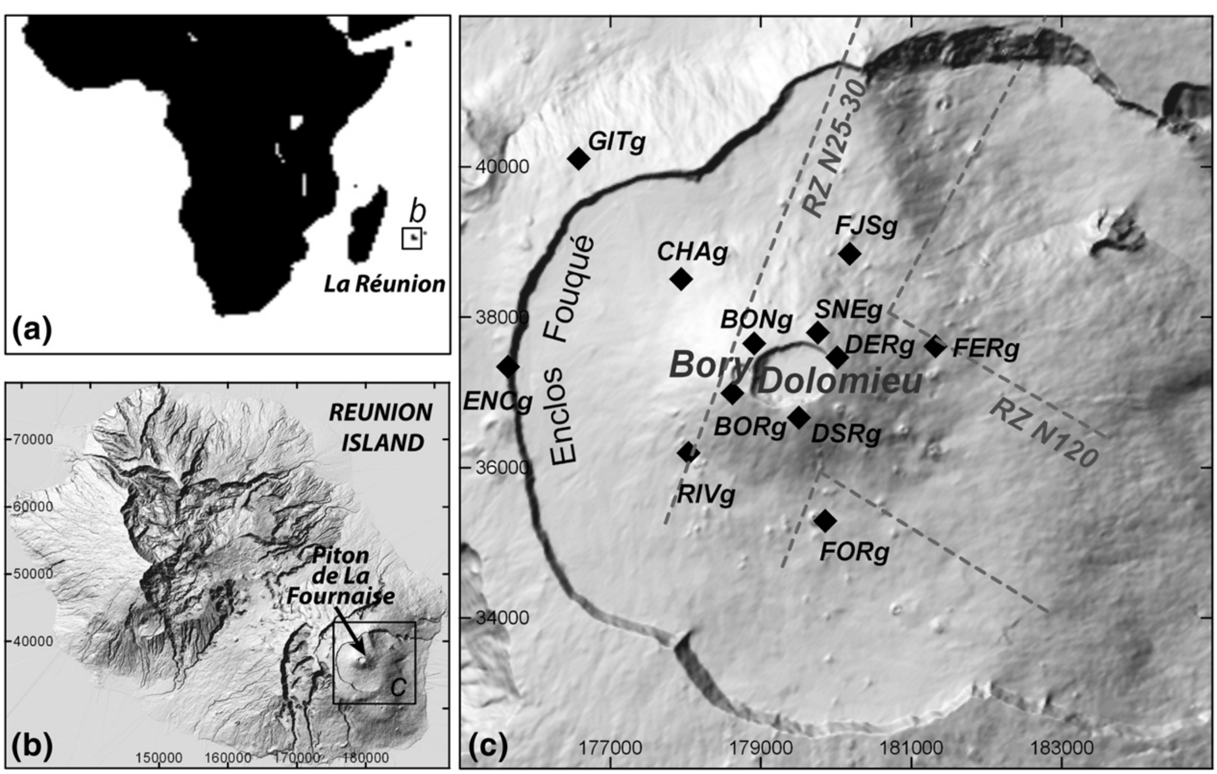


**Fig. 1.** Location of (a) La Réunion Island, and (b) Piton de La Fournaise volcano. (c) Location of the rift zones (grey dotted lines; after Michon et al., 2007a) and permanent GPS stations (diamonds) (Gauss Laborde Réunion coordinates, in meters).