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Calderas, landslides and paleo-canyons on Piton de la Fournaise volcano (La Réunion Island, Indian Ocean)

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ABSTRACT

Based upon a re-interpretation of previous data and a new field campaign, a structural evolution is proposed for the early history of Piton de la Fournaise volcano from 500,000 to 50,000 years. Conceptually, it is shown that the formation of a caldera in which lava flows are contained inside the caldera depression, gives time for erosion to excavate deep canyons on the external slopes of the volcano, for example, the Rivière des Remparts, the Rivière Langevin and the Rivière de l'Est canyons on Piton de la Fournaise volcano. These canyons are infilled when lavas, filling the caldera and overflowing its rim, are able again to flow on the external slopes of the volcano. In the past, this excavating/infilling process has occurred twice following the formation of the Rivière des Remparts and Morne Langevin calderas. The formation of the third caldera, the Plaine des Sables caldera, was followed by the excavation of the current canyons. In addition to this process, two large landslides have been documented in the field. The first, which happened about 300,000 years ago, is apparently the first episode of the break up of Piton de la Fournaise volcano, predating the formation of the four large calderas. The second landslide, which occurred 150,000 years ago and is considered to be less extensive, has carried away the entire southern flank of the Rivière des Remparts caldera.

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1. Introduction

La Réunion Island is located in the Mascareignes Archipelago, off Madagascar in the Indian Ocean. Nowadays, the island is constituted of two juxtaposed volcanoes: Piton des Neiges in the west, which has been dormant for 12 ka (Deniel et al., 1992), and Piton de la Fournaise in the east (Fig. 1). The latter, active for about the last 500 ka, is partly built on an older edifice, the Alizés volcano, identified by gravimetric data (Rousset et al., 1989; Malengreau et al., 1999; Gailler et al., 2009) and through drill hole data (Rançon et al., 1989), which reveal the presence of an ancient system of magma chambers beneath the Grand Brûlé area.

As with most large shield volcanoes, Piton de la Fournaise exhibits a complex volcano-tectonic evolution, difficult to unravel due to inaccessible, nearly vertical cliffs (e.g. 1000 m high in the Rivière des Remparts and the Rivière Langevin canyons) and exuberant tropical vegetation which covers the volcanic series. Even when they are visible or accessible, these volcanic series are difficult to unravel, as dates are rare and not always reliable. (MacDougall, 1971; Gillot et al., 1990).

Despite these difficulties, a geological history has emerged in the 80s and 90s, making it possible to show that the long-term evolution of Piton de la Fournaise has been characterised by the formation of large calderas, several kilometres in width, with activity shifting to the east. The most recent is the 9 km-wide Enclos Fouqué caldera, in the centre of which the active cone has been built. Predating the formation of the Enclos Fouqué caldera, three large calderas are documented, namely, from oldest to youngest: the Rivière des Remparts caldera, the Morne Langevin caldera and the Plaine des Sables caldera (Fig. 2) (Bachèlery, 1981; Chevallier and Bachèlery, 1981; Lénat, 1987; Bachèlery and Mairine, 1990; Mairine and Bachèlery, 1997).

Note that these calderas have been interpreted differently by some authors who regard them as being scars of large successive landslides to the east and/or to the south-east (Duffield et al., 1982; Gillot et al., 1994; Oehler et al., 2004, 2008), with the notable exception of the Morne Langevin caldera, which is not taken into account in this interpretation. This hypothesis of eastward or south-eastward landslides, generating as it would each time a slope in this same direction, cannot be reconciled with the observation of huge lava flows through time, which overflowed the caldera rims westward and north-westward, leaving beyond very thick horizontal lava piles, up to 1000 m thick, like the *Morne Langevin* unit.

In this article, we propose a new structural evolution of the time period from 550 ka to 40 ka, which, while confirming in general the previous scheme (Bachèlery and Mairine, 1990; Mairine and Bachèlery, 1997), is now refined, with new interpretation of data which had remained unclear up to now. This represents a new step forward in the

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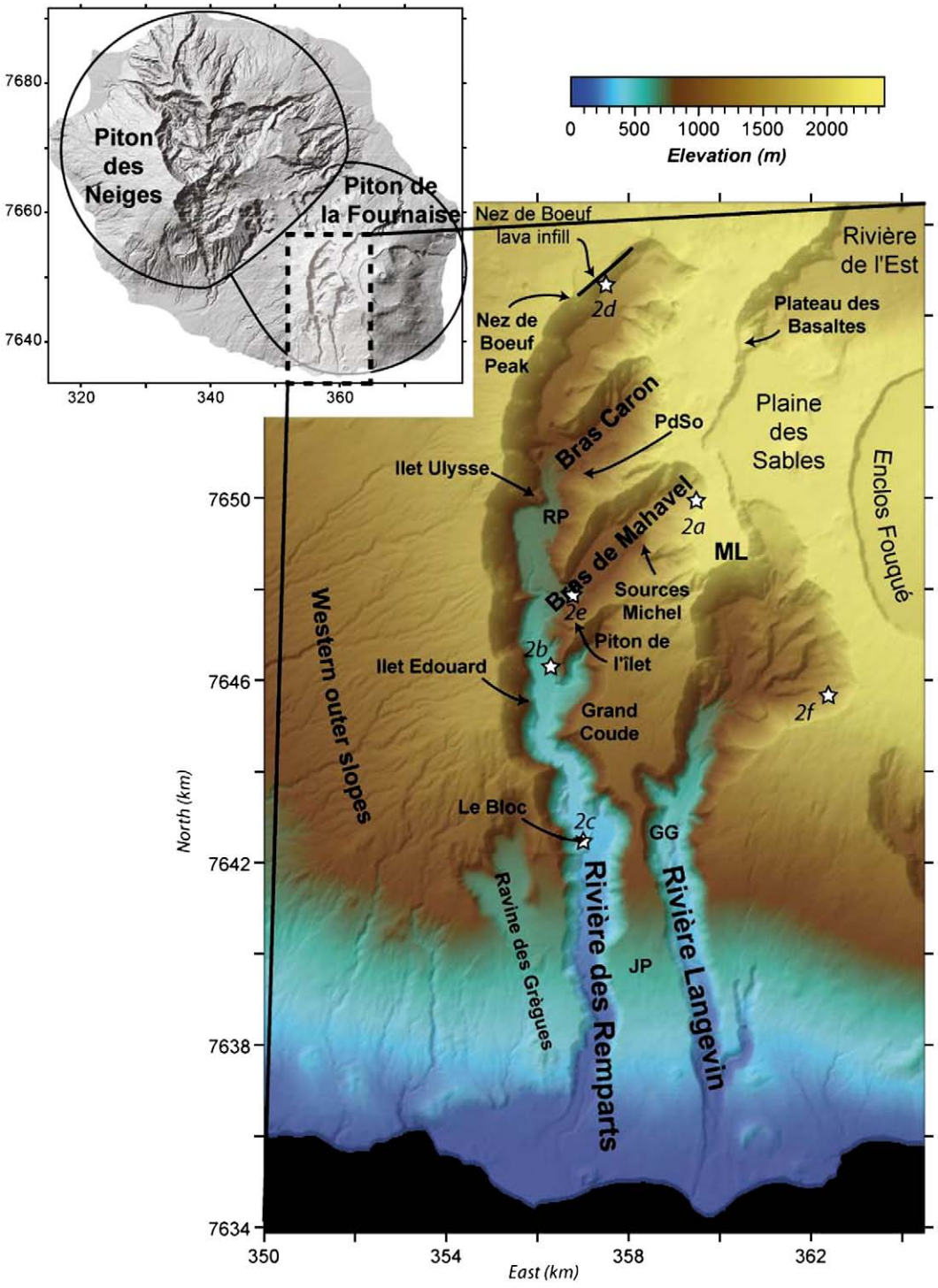

Fig. 1. Digital Elevation Model of the study area and location of the cross-sections of Fig. 6. Insert: La Réunion Island with Piton des Neiges Volcano to the west and Piton de la Fournaise volcano to the east. GG: Grand Galet, JP: Jean Petit, ML: Morne Langevin peak, RP: Roche Plate hamlet, and PdSo: Plateau des Sources.

understanding of the volcano-tectonic history of Piton de la Fournaise volcano, and the relationship between calderas, erosion and landslides, the three main structural processes that have shaped the morphology of the edifice and have led to its present-day structure.

This early geological history of Piton de la Fournaise is best exposed in the Rivière des Remparts, Rivière Langevin and Rivière de l'Est canyons, the latter being unfortunately almost inaccessible. Elsewhere, in the Plaine des Sables and Enclos Fouqué calderas, recent lavas entirely cover ancient deposits, preventing any direct studies on them.

2. Caldera and erosion

Following field studies conducted in the 90s (Bachèlery and Mairine, 1990; Mairine and Bachèlery, 1997), the major discovery is that an important erosional phase led to the formation of a paleo Rivière des Remparts having a course pretty close to the present-day Rivière des Remparts. The model proposed at that time, which is confirmed by this study, defined the structural role played by the caldera. The caldera rim is viewed as a barrier preventing lavas from flowing outside the

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