How summit calderas collapse on basaltic volcanoes: new insights from the April 2007 caldera collapse of Piton de la Fournaise volcano

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1. INTRODUCTION

Basaltic volcanoes present summit calderas, whose formation is mostly related to lateral magma migration from the magma reservoir. Observations of basaltic calderas worldwide, and the few recorded collapse events, show common structural characteristics and collapse mechanisms whose origins are still debated. First, caldera collapses are contemporaneous with a periodic seismicity. Second, analyses of the surface deformation have long-revealed that collapses are coeval with the centripetal deflation of the edifice. Third, collapse calderas often show peripheral concentric extensional fractures hundreds of metres from the edge of the caldera rim.

In April 2007, Piton de la Fournaise volcano (PdF) experienced a caldera collapse during its largest historical eruption (Michon et al., 2007). This paper aims at determining the relationship between the concentric fractures and the collapse. It also attempts to better understand the mechanics of the collapse and its consequences in the eruption dynamics. Finally, it addresses the role of the pre-existing structures in the development of new calderas.

2. GEOLOGICAL SETTING

Piton de la Fournaise volcano is one of the world's most active volcanoes. Prior to April 2007, the summit of the active cone was cut by two collapse structures: Bory and Dolomieu, the location of the caldera collapse. On 30th March, a first eruptive fissure opened and remained active during 10 hours (Figure 1a). The magma emission started anew on 2nd April when an eruptive fissure opened at about 600 m asl, 7 km away from the summit. The discharge of magma increased during April 5th contemporaneously with a summit centripetal deflation. The caldera collapse occurred between April 5th and 7th. During this period, both the seismic signal and the summit displacements were organised in cycles characterised by an inward deflation coeval to the increase of the seismic signal, and ended with a sharp outward uplift of the caldera rim contemporaneous with the sudden decrease of the seismicity. The eruption continued at a low level until the 1st May 2007.

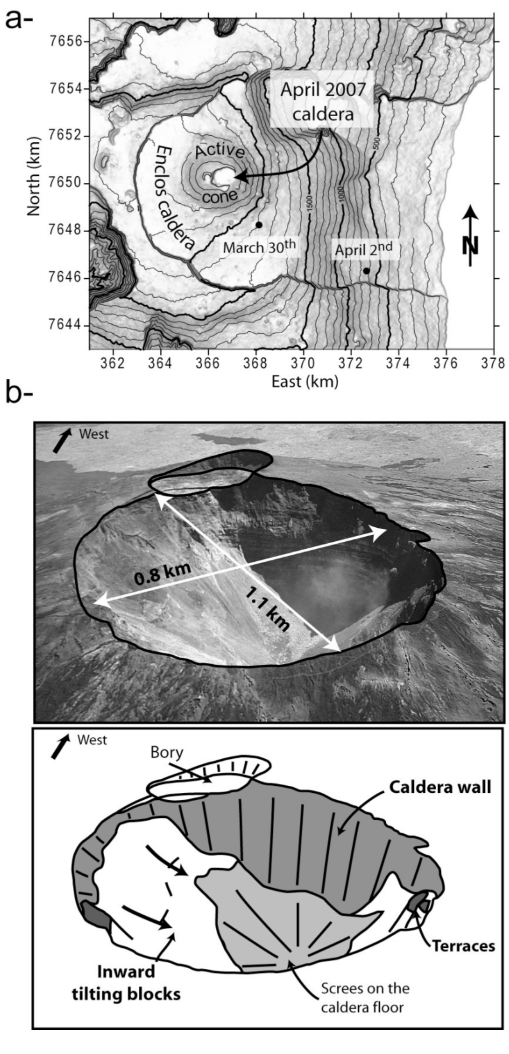

Figure 1: a- Location of the April 2007 caldera and of the eruptive fissures related to the April 2007 eruption. b- Geometry of the caldera.

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3. SUMMIT DEFORMATION RELATED TO THE APRIL 2007 ERUPTION

The summit deformation related to the caldera collapse was investigated by combining structural and precise GPS data. GPS campaigns in March and May 2007, *i.e.* prior and after the collapse, reveal a strong inward deflation of the caldera rim, with displacement values ranging between 10 cm to 253 cm. Displacement vectors suggest the occurrence of an E-W elongated deflation source located in the northern part of the caldera. The vertical geometry of the deflation source is further constrained by the ratio between horizontal and vertical displacements, which suggests a vertically elongated structure. Moreover, the sharp decrease of the displacement values from the caldera edge indicates that the first tens of meters of the caldera rim, experienced radial extension stresses. This zone of contrasted displacement is correlated with the development of a new network of concentric fractures.

The new caldera is characterised by a maximum depth of 320-340 m. Despite an intense vertical deformation, the caldera presents the same contour than that of the pre-existing Dolomieu. The first collapses occurred in the northern part of the structure, where the depression was bounded by sub-vertical scarps. This zone is superimposed to the deflation source inferred from GPS data. The caldera subsequently widen by the inward collapse of annular plateaus. This twofold evolution explains the two different geometries of the caldera walls, i.e. sub-vertical, 70-80°, or steep, 40-50° (Figure 1b). Note that remaining polished planes were observed on the sub-vertical walls, suggesting that they correspond to caldera ring faults.

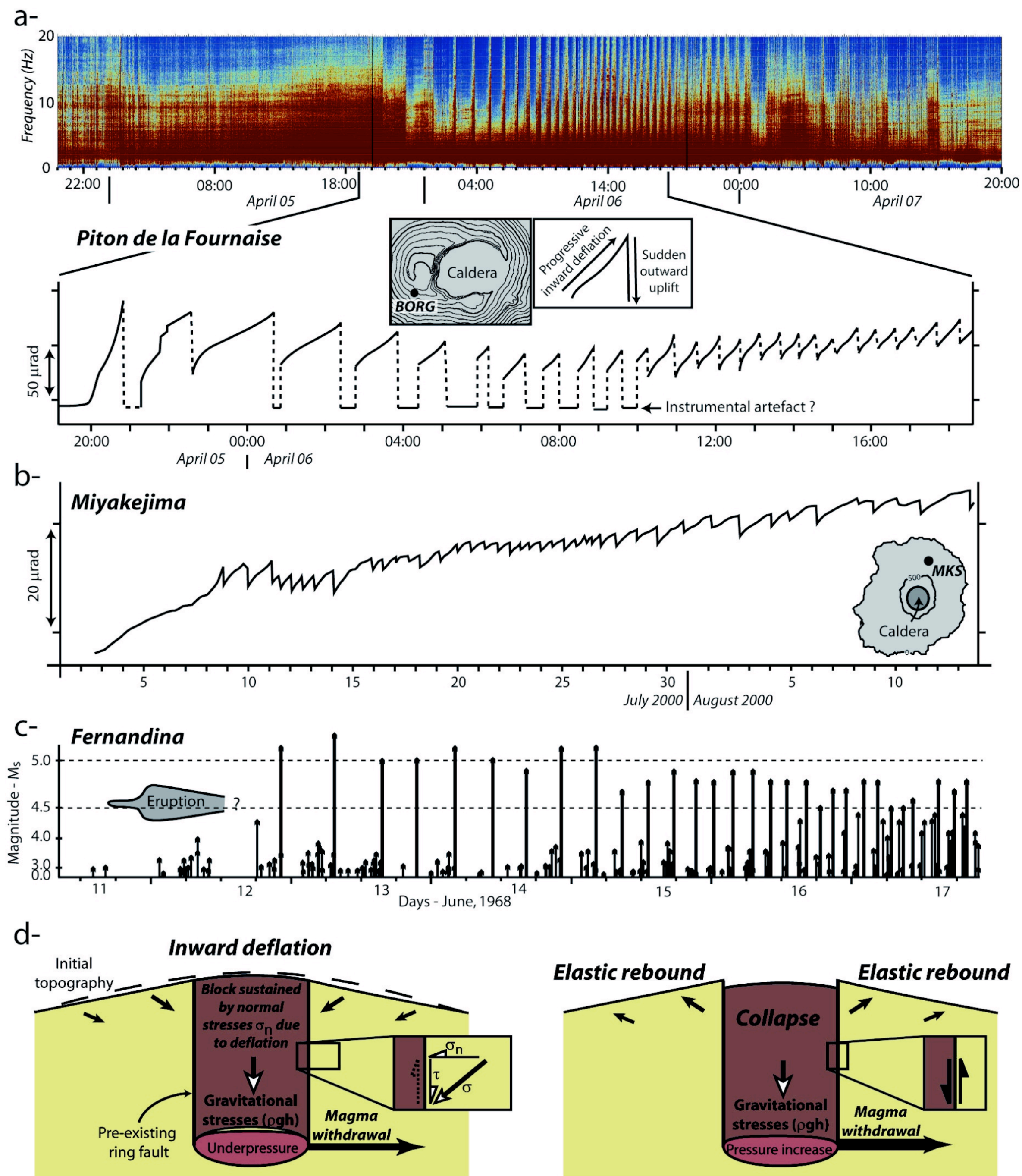

Figure 2: a-Seismic signal and radial deformation measured by tiltmeter (after Staudacher et al., submitted) at Piton de la Fournaise during the April 2007 caldera collapse. BORG: location of both stations. b- Deformation data (radial tiltmeter) recorded during the collapse at Miakejima (after Ukawa et al., 2000). MKS: location of the station. c- Seismicity related with the caldera collapse at Fernandina (after Filson et al., 1973). d- Conceptual models explaining the pulsating dynamics of caldera collapse.

4. DYNAMICS OF CALDERA COLLAPSE

Comparison of the caldera collapses at PdF, 2007, Miyakejima, 2000, and Fernandina, 1968, reveals striking similarities. Deformation and seismic data show that the caldera collapses have been characterized by a cyclic dynamics (Figures 2a, 2b and 2c). Each cycle corresponds to a progressive inward deflation coeval with an increasing seismicity, ended by a sudden radial outward motion when the collapse occurs. Hence, the similar evolution at Fernandina, Miyakejima and PdF strongly suggests that each caldera collapse occurred in a similar way. Combining the different characteristics of these caldera collapses, we propose a unifying mechanism of caldera formation in basaltic setting.

First of all, the deformation of the summit of basaltic volcanoes starts when large lateral eruptions or magma intrusions occur. The pressure decrease into the magma chamber caused by the magma withdrawal entails, above all, the centripetal subsidence of the edifice and subsequently a stress increase within the edifice (Figure 2d). The centripetal deflation prevents the downward motion of the rock column due to gravitational stress by increasing the normal stress along the pre-existing ring faults. The collapse of the rock column occurs when the gravitational stress exceeds the shear strength of the ring faults. The immediate, short outward deformation of the caldera rim after the collapse corresponds to the elastic response of the edifice, when the downward stress is sporadically released during the motion of the rock column. The collapse stops when the pressure increase into the magma chamber sustains the rock column anew. The ongoing subsidence, which directly results from the magma withdrawal, promotes a new stress increase and prevents the collapse of the rock column. The collapse occurs anew when the shear strength is overcome by the gravitational stress exerted on the rock column. The pulsating dynamics of caldera collapse consequently results from a competition between deflation, which prevents the collapse, and gravity exerted on the block, which makes it possible despite deflation.

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