Journal of Volcanology and Geothermal Research 241–242 (2012) 78–104

Contents lists available at SciVerse ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

A new comprehensive classification of the Piton de la Fournaise activity spanning the 1985–2010 period. Search and analysis of short-term precursors from a broad-band seismological station

Geneviève Roult [a,b,*], Aline Peltier [b,c], Benoît Taisne [a,b], Thomas Staudacher [b,c,d], Valérie Ferrazzini [b,c,d], Andrea Di Muro [b,c,d] and the OVPF team

[a] Equipe de Sismologie, Institut de Physique du Globe de Paris- Sorbonne Paris Cité, 1 rue Jussieu, 75238 Paris Cedex 05, France
[b] UMR CNRS 7154, Université Paris Diderot, France
[c] Equipe Géologie des Systèmes Volcaniques, Institut de Physique du Globe de Paris- Sorbonne Paris Cité, 1 rue Jussieu, 75238 Paris Cedex 05, France
[d] Observatoire Volcanologique du Piton de la Fournaise, 14RN3, 97418 La Plaine des Cafres, La Réunion, France

ARTICLE INFO

Article history:
Received 21 February 2012
Accepted 6 June 2012
Available online 21 June 2012

Keywords:
Piton de La Fournaise
Database
Eruption precursors
Failed eruptions
Broad-band seismic stations
Magma migration
Volcano monitoring

ABSTRACT

Piton de la Fournaise volcano (La Réunion Island) is one of the most active basaltic volcanoes, with an average of one eruption every 10 months. This study provides the first exhaustive compilation of all volcanic events (intrusions, eruptions, seismic crises) and related parameters at Piton de la Fournaise in the 1985–2010 period. This compilation has been correlated with the analysis of the records from the very broad-band seismological RER station (Geoscope network), located 8.5 km north of the summit. Our approach allowed us to identify short-term long period seismic precursors for most eruptions and intrusions. After a signal filtering process that consists in removing the instrumental response and the theoretical Earth tides effect, these precursors can be distributed into 4 classes that depend on their waveform and are globally considered as tilt related with magma transfer inside the sub-aerial part of the volcano edifice. The shapes and characteristics of these transient phenomena (time delay, duration or class) exhibit particular features that can be partly related to other simple eruption or intrusion parameters (location, altitude, volume). Statistical analyses of all events (intrusions and eruptions) are then derived. Estimates of acceleration rates of tilt signal at the RER station have been retrieved for eruptions and intrusions, with the challenge of providing a way to differentiate one from the other in real-time. Acceleration rates seem to correlate with eruptive lava flow volume and a threshold value can be determined allowing us to discriminate between intrusions and eruptions, illustrating the interest of analyzing them for real-time monitoring. The correlation with the initial seismic crisis marking the opening of magma ascent path was investigated, showing that the delay between the RER transient phenomenon and the start of the seismic crisis has been increasing since the major caldera formation event of 2007. This longer delay may be due to a combination of drastic changes in the internal structure of the edifice: a concomitant decrease in volume of magma batches and a deeper origin of magma setting off volcanic unrest. Our study highlights the additional role of external factors like loading and unloading related to the rainy season and stress field evolution due to Earth tides in influencing magma propagation and volcanic activity.

1. Introduction

The predictability of earthquakes or volcanic eruptions, allowing short-term hazard mitigation, remains a challenging problem. Forecast of volcano behavior (intrusion versus eruption) is still an extremely difficult task. We use the term “intrusion” when no eruption ensues. Both intrusions and eruptions are often preceded by a seismic crisis. Early discrimination between these phenomena, during the seismic crisis, may be attempted either with a multi-parameter approach (ground deformation, seismicity, degassing), or by searching for subtle eruptive precursors (see Dzurisin, 2003 for a complete review; Brenguier et al., 2008 and Peltier et al., 2009a for the case of Piton de La Fournaise). This research can best be conducted on a well-monitored volcano, displaying frequent eruptive activity. Piton de La Fournaise, with an average of one eruption every 10 months, appears to be a good target for such a study.

* Corresponding author at: Equipe de Sismologie, Institut de Physique du Globe de Paris, Sorbonne Paris Cité, 1 rue Jussieu, 75238 Paris Cedex 05, France.
E-mail address: groult@ipgp.fr (G. Roult).

0377-0273/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.jvolgeores.2012.06.012

Piton de La Fournaise volcano (La Réunion hot spot, Fig. 1a, b) is one of the most active basaltic shield volcanoes in the world, with the occurrence of 54 eruptions and at least 11 intrusions since December 1985. Eruptive vents and lava flows found during each of those eruptions are reported in Fig. 1c. Typically, each intrusion or eruption is preceded by weeks/months of inflation of the summit cone and an increasing number of shallow (above sea level) volcano-tectonic events and rock-falls (particularly since the 2007 collapse). Several networks have been maintained by the Volcano Observatory of Piton de la Fournaise (OVPF) since 1979 to monitor the volcano activity: short-period seismic stations, broad-band seismic stations since 2009, tiltmeters, extensometers, GPS stations, DOAS and MultiGas stations. In addition to the seismic stations installed by the OVPF on the volcano, one of the first broad-band stations of the global seismological GEOSCOPE network, was installed close to the Volcano Observatory in 1982, 15.3 km from the crater (Fig. 1a), the PCR seismic station (Plaine des Cafres, la Réunion). This station was equipped with three high-quality Streckeisen seismometers (STS-1, Wielandt and Streckeisen, 1982). In the beginning for the GEOSCOPE network, the only recording channels corresponded to the ground acceleration and the transfer function of the acquisition chain in 12 bits was flat in the 0.01 s–3600 s period range (Romanowicz et al., 1991). Due to bad environmental conditions, the noise power spectral density was high. At the time the challenge of the GEOSCOPE network, affiliated to FDSN (Federation of Digital Seismographic Networks), became the availability of very-broad band data in real-time. We decided to progressively upgrade all the GEOSCOPE stations and to move the acquisition chain from a broad-band configuration to a very-broad band configuration in 24 bits (Roult et al., 2010). The STS-1 seismometers of the PCR station were moved to a new site in February 1986, at RER (Rivière de l'Est, La Réunion; Fig. 1a), 8.5 km north of the summit crater. This station is located at 21.171 S, 55.741E, at an elevation of 834 m, in a vault corresponding to a 4.7 km long tunnel that highly reduces the noise due to temperature variations. It has been operational for 25 years (apart from the February 11th 2003 to September 5th 2004 breakdown period). The sensors, installed on a glass plate, are covered with a permalloy shielding (vertical only), an aluminum shielding and a glass bell. A styrofoam box, sheeted with aluminum is put over each sensor as a protection against fast changes in temperature and air flow. A second important upgrade occurred in 1990. The new equipment consisted of the three same STS-1 connected to a Q330HR digitizer; the available seismic channels record either the ground velocity (BH*, LH*, VH*) or the ground acceleration (boom position, LM*). Before 1990, the large number of glitches on the recordings and the low sensitivity of the acquisition chain made the observation of eruption precursory signals very difficult. The high sensitivity of the acquisition chain since 1990, allowed a better identification of transient signals due to the Piton de la Fournaise activity. In September 2010 the sensitivity increased even more with a new upgrade of the station by a 26 bit acquisition chain. Short-term precursors have thus been identified in the form of long period signals that occur mostly on the RER horizontal components during the minutes or hours that accompany magma migration. Battaglia et al. (2000) first reported such transients for 5 eruptive events from July 1991- March 1998 at RER station. Houlié and Montagner (2007) also distinguished two kinds of transients from the 1998–2005 RER records. Up to now no exhaustive and complete study from the RER station analysis exists in the literature.

In this study, we first compiled information on all volcanic events (eruptions, intrusions, seismic crises, pit craters and caldera collapses) at Piton de La Fournaise that have occurred since December 1985 (i.e. a few months before the RER station installation) and established a comprehensive database. Then, we systematically retrieved and analyzed the RER recordings corresponding to all these events. Statistical analyses of the characteristics of all eruptions and intrusions allow us to discuss the volcanic processes associated to the RER transient precursors. This work, with the presentation of a new comprehensive compilation of eruption/intrusion characteristics since December 1985, also aims to provide a working database for future studies on Piton de La Fournaise.

2. A comprehensive Piton De La Fournaise database

We have extracted as much information as possible on all eruptive events spanning the 1985–2010 period to allow further studies on Piton de la Fournaise behavior and transient modeling. The database is presented on Appendix A. It is subdivided in four distinct sections whose parameters are successively described in Appendixes B, C, D and E, as follows:

(1) volcanic event characteristics
(2) parameters of the transient observed at the RER seismological broad-band station
(3) parameters of the theoretical Earth acceleration tide
(4) dyke parameters from previous studies.

In this paper we will present these four sub-sections one by one.

In order to fill and complete our catalog of events, we used the monthly OVPF bulletins, the individual recordings, the spectral diurnal analyses for each station belonging to the network, the existing literature and academic works (Bachèlery, 1999; Peltier, 2007), as well as internal OVPF reports (Staudacher, 1992–2008; ***http://www.volcano.si.edu/***) and international publications (i.e. Delorme et al., 1989; Lénat et al., 1989; Stieljes and Moutou, 1989; Peltier et al., 2009a). For eruptions spanning the 1985–1987 period we analyzed the "Sefram" paper recordings from 8 seismic stations to gather new information and check previous descriptions.

Our review results in the identification of 83 volcanic events including 54 eruptions, 26 seismic crises not followed by an eruption, 2 summit pit crater formations and 1 caldera collapse. We do not discuss all the listed variables in this paper, but they should serve as an extensive and validated database for further studies. Our large database compilation, covering 25 years of eruptive activity at Piton de La Fournaise, allows us to complete and improve previous observations on the dynamics of the volcano. In the two following sections we will present the eruptive event characteristics and parameters of the associated signals recorded by the distant RER broad-band station.

3. Volcanic event characteristics

The main features of all identified volcanic events are summarized in Appendix A. We considered that two eruptions were distinct (and associated with a specific family type) when each of them was preceded by a distinct seismic crisis. As a consequence of this choice, two 'apparent' eruptive events, separated by several hours or days, may be attributed to a single eruption in Appendix A (example March 30th 2007 and April 2nd 2007 eruptive events preceded by a single seismic crisis). The definitions of the volcanic event characteristics under study reported in Appendix A (type, eruption timing, site, fissures, elevation, lava flow, seismic crisis, seismic swarm…) are given in Appendix B.