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REAL TIME MONITORING OF VERTICAL GROUND DEFORMATIONS DURING ERUPTIONS
AT PITON DE LA FOURNAISE

Jean-Paul Toutain
Institut de Physique du Globe de Paris, Observatoire Volcanologique
de Piton de la Fournaise

Patrick Bachelery
Département des Sciences de la Terre, Université de La Réunion

Pierre-Antoine Blum, Jean-Louis Cheminée, Hugues Delorme
Institut de Physique du Globe de Paris, Observatoire Volcanologique

Laurent Fontaine, Philippe Kowalski and Philippe Taochy
Institut de Physique du Globe de Paris, Observatoire Volcanologique
du Piton de la Fournaise

Abstract. Tilt changes related to a summit dike emplacement at Piton de la Fournaise volcano have been recorded by a 4 continuously recording electronic tiltmeters network during the April 18, 1990 eruption. The real-time processing of these data at the Observatory allows to calculate during the emplacement the relative position of the inflation center from the tilt vectors supplied by the nearby stations. Two main steps have been identified: an initial subvertical intrusion step, followed by a lateral dike migration from the summit cone. This monitoring allows to calculate a high average intrusion velocity of about 0.2 m.sec⁻¹ which can be related to the highly fractured pattern of the summit area.

Introduction

Forecasting eruptions at active volcanoes requires continuous monitoring of numerous geophysical parameters, mainly using instrumental surveillance networks. Among these, seismic networks are generally considered to provide the most suitable data for eruption prediction, because of the systematic stress release accompanying magma movements. Nevertheless, continuous observations of deformation patterns on active volcanoes, and especially on basaltic shield volcanoes, demonstrate that rapid inflation of the volcanic pile and upheaval of the summit area also occur just before central eruptions as the result of dike injections (Okamura et al., 1985; Lénat et al., 1989 a and b; Delorme et al., 1989). Real time monitoring of vertical ground deformation is therefore expected to provide good short-term precursor evidence for imminent eruptions on such volcanoes, as well as constraining the dike location during an intrusive crisis (Okamura et al., 1988; Trygvason, 1986; Toutain et al., 1991).

In this paper, we will show that an electronic tilt network allows real-time sampling and processing of vertical ground deformations to be undertaken during eruptions at Piton de la Fournaise. With this objective, we will 1) relate the ground deformation patterns linked to the April 18, 1990 eruption of Piton de la Fournaise volcano and 2) establish that electronic tilt monitoring enables in real time, both the detection of magmatic emplacement prior to eruptions, and the tracing of

the small displacements caused by dike injection, and therefore 3) demonstrate that such measurements provide a powerful tool for the location of effusive sites prior to the eruption.

Activity and surveillance of Piton de la Fournaise

Piton de la Fournaise volcano (Reunion, Indian Ocean) is one of the most active volcanoes in the world, with about 25 eruptions occurring within the last 10 years (Lénat and Bachelery, 1988; Dubois and Cheminée, 1991). On this volcano, monitoring of activity is performed by means of a 5 station clinometric network (Delorme et al., 1989; Delorme et al., in prep), 16 station seismic network (Hirn et al., 1991) and an 8 station differential magnetism network (Zlotnicki and Le Mouél, 1990). These networks supply radio-transmitted data to a volcanological observatory (OVPF) installed in 1980 (Bachelery et al., 1982). Figure 1 is a map showing the distribution of the OVPF permanent monitoring networks. Due to both the high density of geophysical sensors and the frequent eruptions of the volcano, Piton de la Fournaise therefore provides great opportunities to test the validity of monitoring strategies, such as the use of electronic tilt surveillance methods.

Experimental procedures

The Piton de la Fournaise clinometric network is composed of 5 radio-transmitted 2-component stations, located within the Enclos Fouqué caldera (BOR, DOL, CHA, FLE and SFR stations - Figure 1). Each station is composed of 2 perpendicular electronic tiltmeters oriented radially and tangentially with respect to the summit crater. Sensors are horizontal silica pendulums designed at IPGP by one of us (P.A.B) and sealed to the rock by means of a silica cone. Such an apparatus allows both good mechanical amplification and thermal inertia. Tiltmeters operate by measurement of the motion of a light spot on a cell, with detection limits of about 0.1 microradian and very low electronic drift. These tiltmeters have been found to be insensitive to nearby explosions and the lack of long period parasitic oscillations within seismic frequencies has been evidenced. More precise descriptions of this apparatus can be found in Saleh (1986), Briole (1990) and Briole et al. (1990). Data are sampled at each station every minute by a microcomputer, and consist of the values of the two sensors, of the atmospheric and rock (5 cm depth) temperatures, and of electronic parameters allowing the real-time check of the

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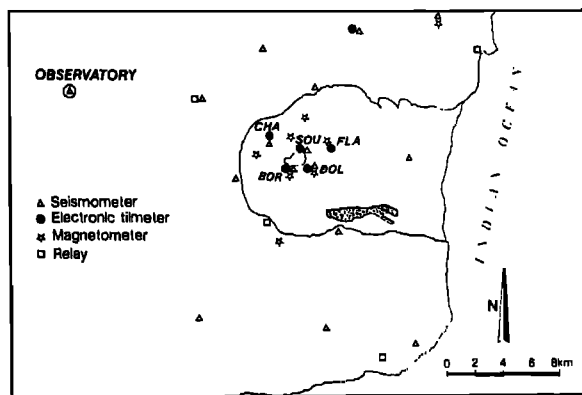


Fig. 1. Distribution of the monitoring networks of OVPF and location of the april, 1990 lava flow.

good working of the station. Blocks of 5 successive data are telemetered every 5 minutes via a relay station, and are therefore available in real time at the Observatory.

Global deformation patterns and reliability of the method

To check the reliability of this ground tilt measurement method (i.e. to establish that these local measurements are representative of the general deformation of the summit), we will also consider two kinds of deformation data obtained by means of improved geodetic measurements. Long-term horizontal and vertical displacements of 13 benchmarks around and into Dolomieu crater have been determined by EDM measurements and trilateration surveys. Long-term tilts have also been calculated using precise levelling methods (known as "dry tilt" method, see Fiske and Shepherd, 1990) for four stations distributed on the summit zone.

Figure 2 displays horizontal and vertical displacements (computed assuming that the Enclos Fouqué caldera rim remains stable) of reference points in the summit area for the period March-July, 1990. Horizontal deformation indicate significant and coherent movements of the marks in the eastern part and very limited and coherent movements of the marks in the western part.

Figure 3 displays in contour-lines the general deformation of the summit zone, that has been constructed from both vertical displacement of the 13 summit benchmarks and observed tilt variations measured at the four "dry-tilt" stations in the summit area. This reconstruction seems reasonable, based upon the good agreement between the two sets of data.

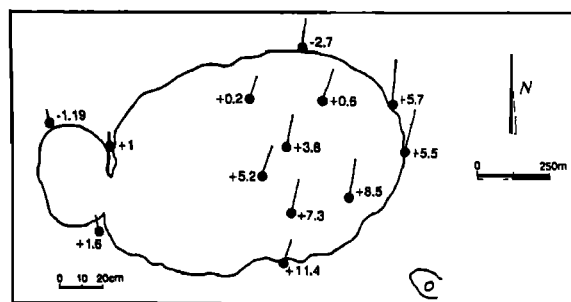


Fig. 2. Direction and value of horizontal (plain line, see scale on the figure) and vertical (bold numbers, in cm) displacements of benchmarks (period Feb-July, 1990). Precision is of about 1 cm.

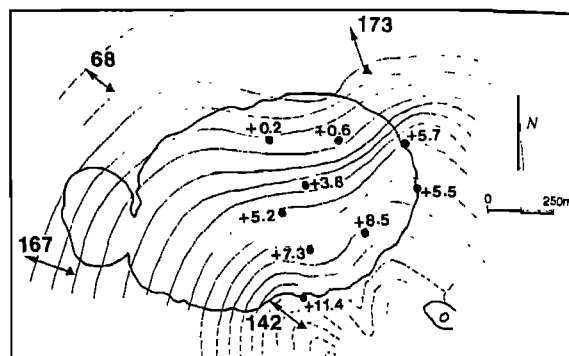


Fig. 3. Contour-lines showing the general deformation of the summit area. Contour-lines have been extrapolated from geodetic (values in cm) and dry-tilt data (plain lines, bold numbers, values in microradians).

These results suggest a general upheaval of the southeastern part of the summit zone, with a general N.W. tilt of the Dolomieu crater area. The slight curvature of the contour-line in the center of the "deformation map" (fig. 3) is not well defined but suggests a dike-induced deformation pattern.

Table 1 lists values of the direction and intensity of slope changes in the summit area, as determined by electronic tilt and precise levelling methods. Table 1 shows that very good agreement between "dry tilt" and electronic tilt data is obtained, especially concerning tilting directions, with differences lower than 3%. Significant differences can however be observed for intensity values between the methods (from 22 to 40%). These latter probably are the result of the slightly different periods of investigation considered, and/or of soil heterogeneity effects that might cause different intensities of tilt from one lava block to another.

General patterns of the April, 18 eruption

The April 18, 1990 eruption at Piton de la Fournaise was preceded by about 15 days of increasing seismicity. Events of the eruption have been recorded by OVPF as follows (in minutes): 1) 125 to 174 : swarm of 4 low energy earthquakes 2) 186 to 206 : swarm of about 40 shocks 3) 206 to about 240 : seismic crisis, with almost continuous shallow shocks 4) about 243 to 530 : lower frequency seismicity and 5) minute 530 : opening of eruptive vents indicated by generalized harmonic tremor (SEAN, 1990). Lava outpoured in the southeastern area of Enclos Caldera (Figure 1), accompanied by both vigorous fountaining and lava flows, with an estimated emission rate of about 20 to 30 cubic

Table 1. Comparison of azimuth (D, degrees) and intensity (I, microradians) of summit tilt supplied by electronic tilt and precise levelling methods.

	Dry tilt		Electronic tilt	
	D	I	D	I
BOR	292	167	288	130
DOL	311	142	314	190
SOU	343	173	332	290

In conclusion, assuming a total migration duration of 317 minutes (minute 213 to 530) for an horizontal distance of about 4000 m, we can suggest an average velocity for the intrusion of 0.21 m. sec⁻¹.

This value is in good agreement with estimations of Briole (1990) for the average extrusion rate of dikes at Piton de la Fournaise (0.21 m. sec⁻¹). It must be noted that the migration of the dike has also been accompanied by a significant change of both the general pattern and the spectral character of seismicity with respect to the previous inflation phase. Indeed, this latter phase showed normal shallow high frequency earthquakes swarms whereas the migration phase was characterized by wavetrains with a considerably lower frequency (roughly 1 Hz).

Conclusion

Electronic tilt measurements of the april 18, 1990 eruption of Piton de la Fournaise volcano allows the monitoring of vertical deformation patterns caused by the subvertical intrusion, and successive lateral migration of a dike in the summit cone. Such a monitoring system, including real time data acquisition and processing (with real-time mapping of inflation centers) is now operating at Piton de la Fournaise Volcanological Observatory, and allows the location of the eruptive site to be predicted. This is, in the context of Piton de la Fournaise, a significant new tool for mitigating the effects of effusive eruptions.

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- P. Bachelery, Département des Sciences de La Terre, Université de la Réunion, 15 avenue René Cassin, 97489 St Denis cedex, France.
- P.A. Blum, J.L. Cheminée and H. Delorme, IPGP, Observatoires volcanologiques, 4 Place Jussieu, 75252 Paris cedex 05, France.
- L. Fontaine, Ph. Kowalski, Ph. Taochy and J.P. Toutain, Observatoire Volcanologique du Piton de la Fournaise, 14RN3, Km 27. 97418 La Plaine des Cafres. France.

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