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'Tornillo'-type seismic signals at Galeras volcano, Colombia, 1992–1993

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Abstract

Unusual low-frequency seismic events, called 'tornillos' ('screws') at the Observatorio Vulcanológico y Sismológico de Pasto (OVSP), have been observed at Galeras volcano during 1992–1993. Of six eruptions that occurred between July 1992 and June 1993, five were preceded by episodes of tornillo signals. These signals are characterized by (1) a waveform having a homogeneous distribution of frequencies, (2) a long coda lasting up to several minutes, (3) a small amplitude compared to the duration, and (4) a slow decay of the coda. The tornillo signals have been grouped into thirteen principal forms. The 1992–1993 tornillos showed four main periods of occurrence, each of which was followed by an eruption. Episode I occurred from 11 to 16 July 1992 and consisted of nine events. Episode II lasted from 23 December 1992 to 14 January 1993, with twenty events. Episode III was observed from 13 February to 23 March 1993, with 74 events. Episode IV lasted from 10 April to 7 June 1993, with 109 events. The seismic activity at Galeras in April–May 1993 was characterized mainly by the occurrence of tornillo signals. The behavior of these signals was similar to that before previous episodes ending with eruptions; these observations permitted us to forecast the 7 June 1993 eruption several days to weeks beforehand. The occurrence of tornillos is the most important criterion for determining the probability of an eruption at Galeras in the current period of reactivation. The maximum daily number of tornillos and the longest duration of individual events occur near the end of each episode. Within an individual episode, the durations of single events increase progressively near to the point of eruption. A positive correlation is observed between the total number of pre-eruptive tornillo signals during an episode and the volume of material ejected by the eruption. These observations may suggest that the presence of tornillos is an indication of variations in the physical conditions between the fluid and the surrounding solid material within the volcano, and they constitute an important tool for forecasting future eruptions at Galeras.

Keywords: Galeras volcano; seismic signals; eruptions

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1. Introduction

The eruptions at Galeras volcano between July 1992 and June 1993 have been characterized by their sudden violence, their short duration (between several minutes and a few hours), and low explosivity (VEI = 1). Moreover, these eruptions have occurred at a time when other measures of activity of the volcano have reached low levels; for example, occurrence and energy of seismic events, rate of deformation, flux of SO_2, and fumarolic activity. This paper discusses a particular type of volcanic seismic signal, known as tornillos, whose importance has been their occurrence prior to the 1992–1993 eruptions. In addition, this type of seismicity has shown a characteristic behavior in parameters such as occurrence of the signals, period associated with the maximum amplitude and volume of the material ejected by the eruptions. A preliminary version of this manuscript, completed on 28 May 1993, helped us to develop an approach to forecast the 7 June 1993 eruption.

Analogue seismic records of tornillo signals registered by the seismic network on Galeras have allowed an investigation of maximum seismic amplitudes, signal durations, and number of events prior to individual eruptions. We seek to determine if there is a common pattern to the 1992–1993 eruptions on Galeras to help us forecast future eruptions.

2. Description

Using the classification adopted by the OVSP for its monitoring of Galeras, a tornillo applies to a long-period seismic event (Chouet, 1996) whose shape bears a resemblance to the profile of a screw thread (Fig. 1). The tornillo signals are characterized by (1) a long duration compared to the amplitude, (2) a long, quasi-linear, slowly decaying coda and (3) a low frequency and monochromatic or quasi-monochromatic waveform sometimes showing a weak high-frequency onset superimposed on the low frequency (Torres et al., 1996).

3. Classification

Among the diversity of tornillo signals that have been registered, it has been possible to classify them according to their shapes, and we have recognized thirteen principal groups of tornillos. A summary of frequencies and durations of each type of tornillo is shown in Table 1. This preliminary classification was made mainly using the signal forms recorded by the Cráter-2 seismic station, located 1.6 km south of the active crater (its total sensitivity is around 1500 $cm_{pp}/cm/s$) (Fig. 2); the station is equipped with telemetered vertical component seismometers. The seismometer is a Spregnether short-period, model L-4C with a natural period of 1.0 s, and a damping coefficient of approximately 0.72 critical.

(1) 'Gota' ('Drop'): this type of signal resembles a drop of liquid, of which the end is stretched out (Fig. 3a). Observed signal durations are 22–67 s, and frequencies associated with the maximum amplitude are 1.33–3.64 Hz. This signal form was registered on 11 July 1992 and 1, 21, 22, 23 March 1993 and 10 April 1993.

(2) 'Punzón' ('Punch'): This type of signal is characterized by smaller amplitudes, with the maxi-

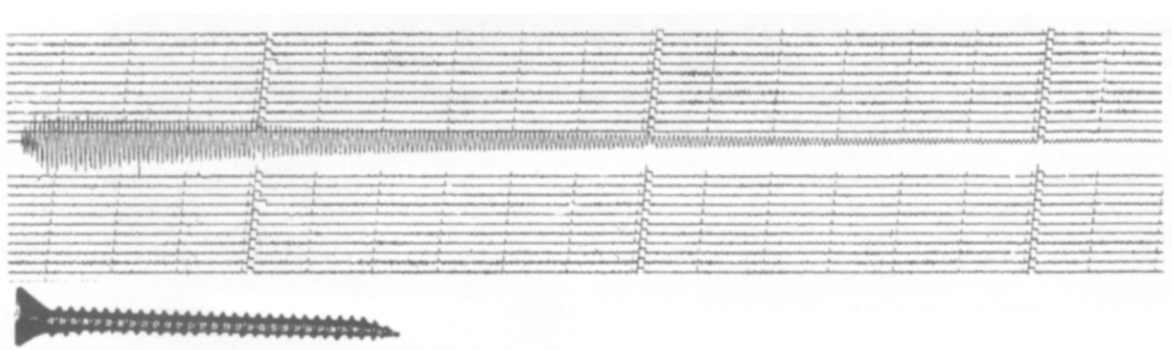

Fig. 1. Example of a tornillo event registered on Galeras volcano at Cráter-2 station on 4 June 1993. A screw is shown below to demonstrate the similar shape. The large ticks represent 60 s, while the small ticks represent 10 s.

mum amplitude occurring in the first few seconds. Afterwards, the signal decays slowly, eventually dissolving into the background noise (Fig. 3b). Signal durations are 32–214 s, the longer signals providing the maximum duration observed for all tornillos. The maximum-amplitude frequency is between 1.25 and 8.00 Hz. This type of signal was the most common, representing 43% of all tornillo signals and occurring principally in May and June 1993 and sporadically in April 1993.

(3) 'Tornado' ('Tornado'): this signal shows a rapid increase in amplitude in the first few seconds, followed by an exponential decline of the coda (Fig. 3c). Several signals show a high-frequency tail superimposed on the dominant lower frequency. Durations are 41–125 s, and maximum-amplitude frequencies are 1.33–2.86 Hz. These events were observed mainly in July and December 1992 and at the beginning of January 1993.

(4) 'Serpentina' ('Serpentine'): This signal is characterized by a bundled form due to amplitude modulations which can be highly regular (Fig. 3d). The period of these modulations ranges from 2.9 to 4.0 s. Durations are 25–210 s, and maximum-ampli-

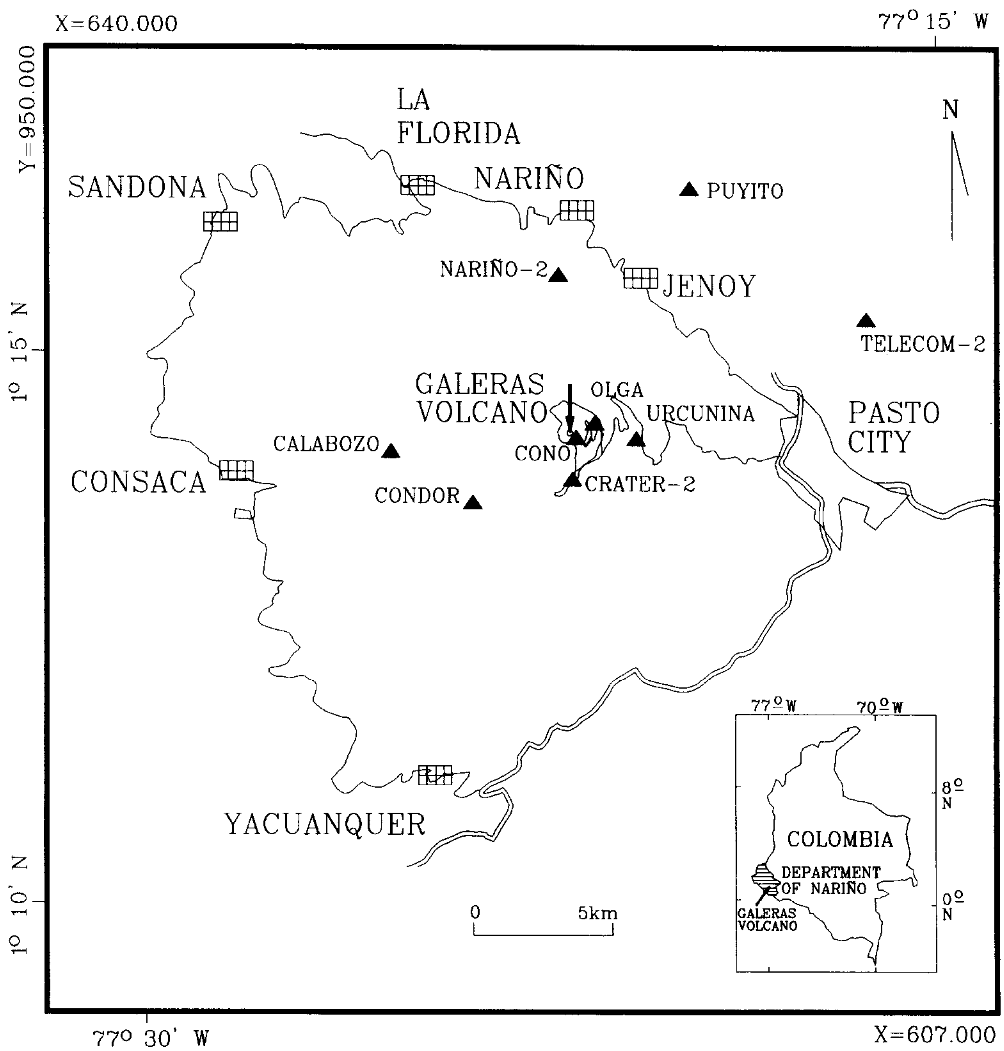

Fig. 2. Location of Galeras volcano and its telemetered seismic network. The stations are represented by triangles and the crater by an arrow.

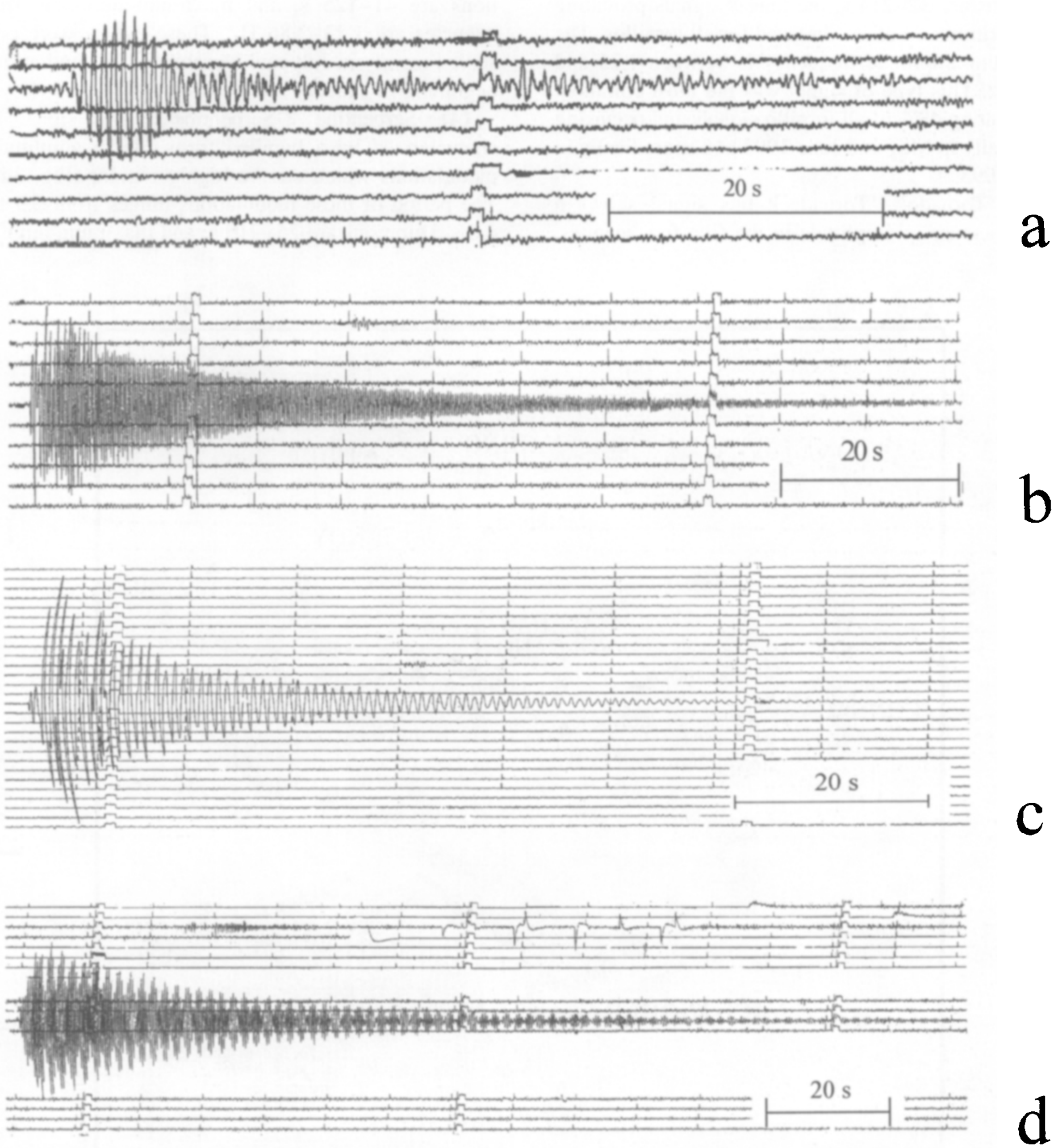

Fig. 3. Examples of tornillo-type signals at Galeras which were registered at the Cráter-2 seismic station during 1992–1993 resembling: (a) A Drop ('Gota'), recorded at 12.39 h on 11 July 1992. Filters out/30 Hz, sensitivity 1358 $cm_{pp}/cm/s$. (b) A Punch ('Punzón'), recorded at 06.40 h on 22 April 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$. (c) A Tornado ('Tornado'), recorded at 06.28 h on 1 January 1993. Filters out/30 Hz, sensitivity 1092 $cm_{pp}/cm/s$. (d) A Serpentine ('Serpentina'), recorded at 13.24 h on 12 March 1993. Filters out/30 Hz, sensitivity 1092 $cm_{pp}/cm/s$.

tude frequencies are 2.35–3.64 Hz. These signals were recorded principally between 7 and 19 March 1993. After Punzón-type signals, Serpentina were the most frequently observed, comprising 11% of all signals.

(5) 'Martinete' ('Drop Hammer'): this type of

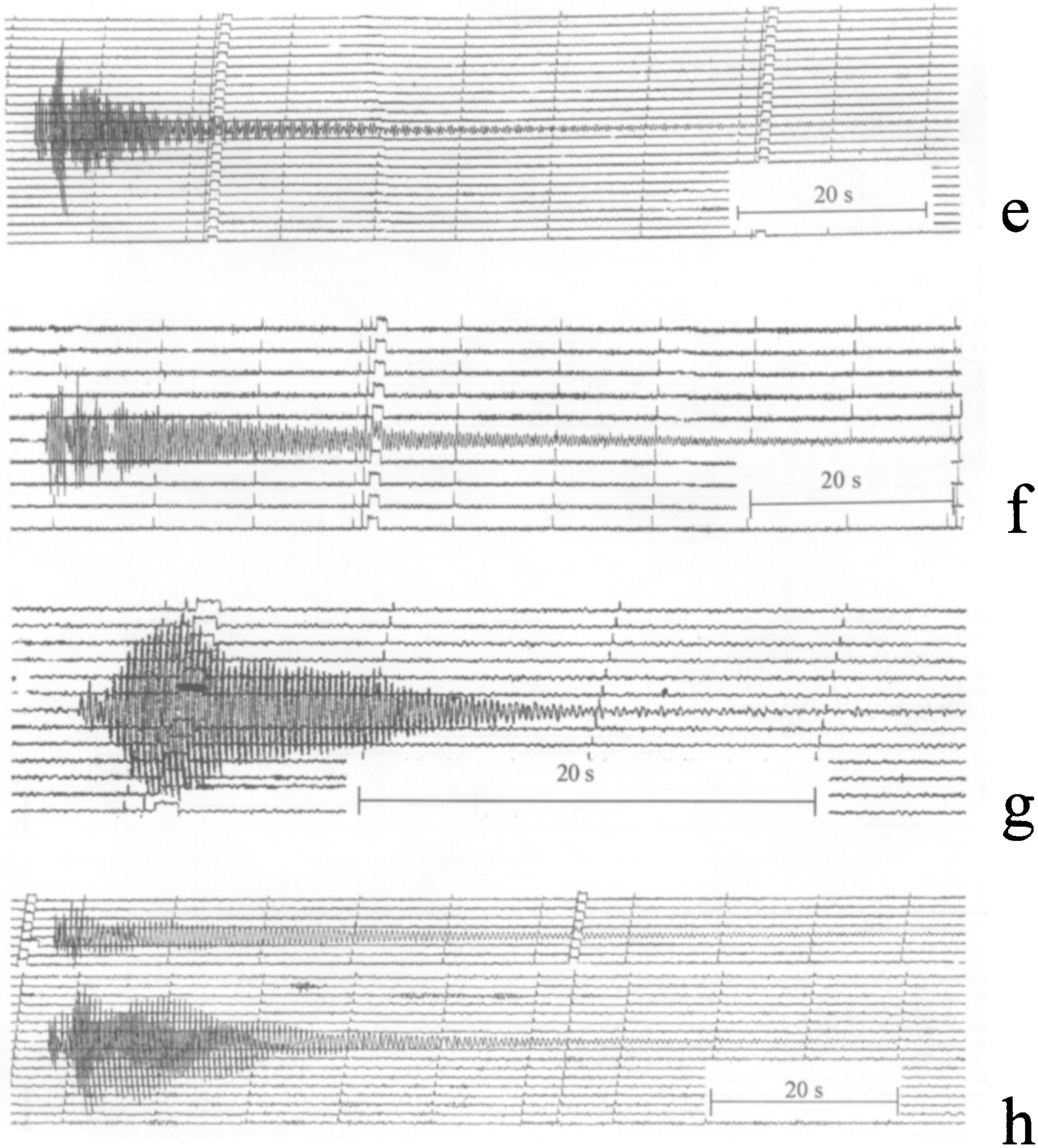

Fig. 3(continued). (e) A Drop Hammer ('Martinete'), recorded at 14.03 h on 4 March 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$. (f) A Comet ('Cometa'), recorded at 05.01 h on 17 February 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$. (g) A Top ('Trompo'), recorded at 11.34 h on 28 February 1993. Filters out/out, sensitivity 13.28 $cm_{pp}/cm/s$. (h) A rod of Aesculapius ('Esculapio'), recorded at 04.55 h on 13 May 1993. Filters out/30 Hz, sensitivity 2627 $cm_{pp}/cm/s$.

signal is characterized by its sudden arrival. The development of the maximum amplitude occurs rapidly after the first few seconds (Fig. 3e). Signal durations are 40–150 s, and maximum-amplitude frequencies are 2.86–3.33 Hz. These signals occurred occasionally in January, March and May 1993.

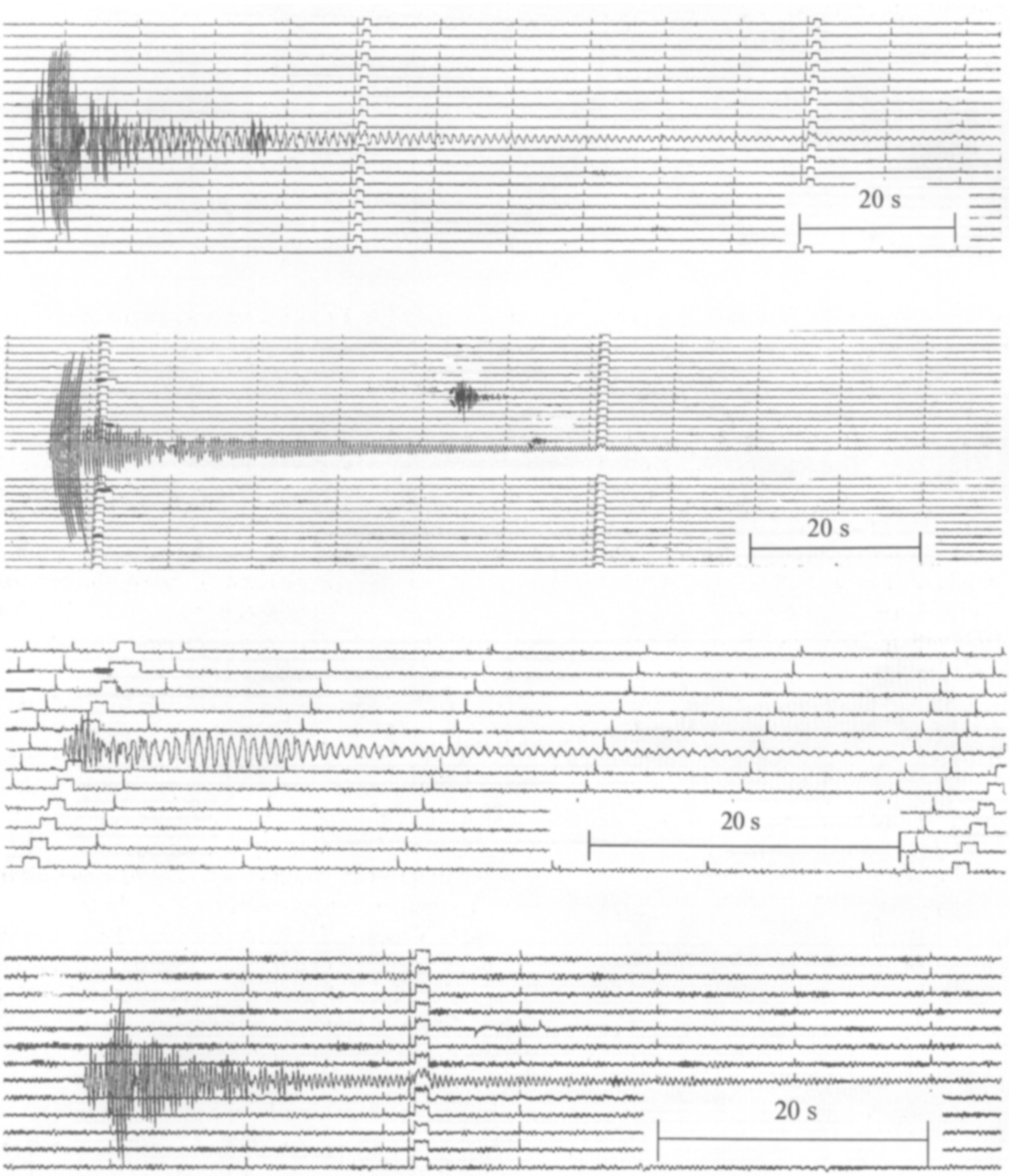

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Fig. 3(continued). (i) A Cane ('Bastón'), recorded at 01.40 h on 11 January 1993. Filters out/30 Hz, sensitivity 1287 $cm_{pp}/cm/s$. (j) A Thumbtack ('Tachuela'), recorded at 07.44 h on 17 March 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$. (k) A Rattlesnake ('Cascabel'), recorded at 06.19 h on 10 April 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$. (l) A Key ('Llave'), recorded at 10.02 h on 4 March 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$.

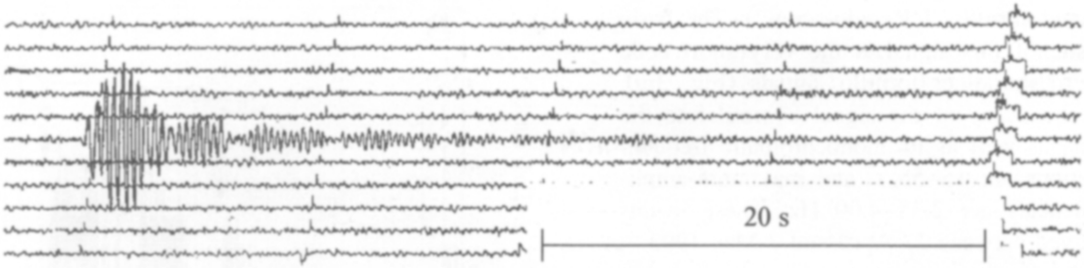

Fig. 3(continued). (m) A Pseudo-screw ('Seudotornillo'), registered at 10.34 h on 28 April 1993. Filters out/out, sensitivity 1328 $cm_{pp}/cm/s$.

(6) 'Cometa' ('Comet'): This signal generally exhibits three initial pulses, within which is found the maximum amplitude. Afterward, the decay of the coda is approximately linear (Fig. 3f). Durations are 42–120 s, with maximum-amplitude frequencies of 2.67–3.64 Hz. These signals were observed in February 1993.

(7) 'Trompo' ('Spinning top'): This signal shows an emergent form which develops to the point of maximum amplitude, followed by decay of the signal (Fig. 3g). This signal was observed only on 28 February 1993, with a duration of 35 s and a maximum-amplitude frequency of 3.33 Hz.

(8) 'Esculapio' ('Rod of Aesculapius', which is the symbol of medicine): This type of signal was observed at the Urcunina seismic station, which is located 2.1 km east of the crater (Fig. 2). The Esculapio signal is unusual because of the intermingling of frequencies (Fig. 3h). Durations are 32–150 s and maximum-amplitude frequencies 1.67–3.08 Hz; these data are consistent with those from the Cráter-2 station. These signals occurred between 12 and 16 May 1993.

Table 1
Summary of some characteristics of tornillo signals

No.	Type	Maximum-amplitude frequencies (Hz)	Duration (s)
1	Gota	1.33–3.64	22–67
2	Punzón	1.25–8.00	32–214
3	Tornado	1.33–2.86	41–125
4	Serpentina	2.35–3.64	25–210
5	Martinete	2.86–3.33	40–150
6	Cometa	2.67–3.64	42–120
7	Trompo	3.33	35
8	Esculapio	1.67–3.08	32–150
9	Bastón	2.53–4.00	43–200
10	Tachuela	2.22–2.86	22–120
11	Cascabel	1.25–3.33	57–103
12	Llave	3.33–3.64	80
13	Seudotornillo	2.35–4.00	15–55

(9) 'Bastón' ('Cane'): These signals are characterized by an emergent beginning having higher frequencies, compared to the end of the signal (Fig. 3i). Durations are 43–200 s and maximum-amplitude frequencies 2.53–4.00 Hz. These signals were observed sporadically during January, March and April 1993.

(10) 'Tachuela' ('Tack'): This signal is characterized by the rapid development of the maximum amplitude, which is comparatively large (Fig. 3j). This type of signal was registered only on 17 and 23 March 1993, with durations of 22–120 s and maximum-amplitude frequencies of 2.22–2.86 Hz.

(11) 'Cascabel' ('Rattlesnake'): These signals show an initial part with higher frequencies than the rest of the signal (Fig. 3k). Durations are 57–103 s, and maximum-amplitude frequencies are 1.25–3.33 Hz. These signals occurred on 20 February, 5 March, 10 April and 3 May 1993.

(12) 'Llave' ('Key'): This signal exhibits an emergent arrival which shows discrete pulses (Fig. 3l). Durations are 80 s and maximum amplitude frequencies 3.33–3.64 Hz. These signals were recorded on 1 and 4 March 1993.

(13) 'Seudotornillo' ('Pseudo-screw'): The basic characteristic of this signal is the very short coda compared to the other tornillo signals (Fig. 3m). However, the decay of the signal is similar to the other types, as well as its monochromatic frequencies. Durations are 15–55 s, and maximum-amplitude frequencies are 2.35–4.00 Hz. These events were observed between 27 April and 7 May 1993.

4. Occurrence

Tornillo signals have acquired great importance due to their occurrence days to months before most of the 1992–1993 eruptions (Fig. 4a). These eruptions were characterized by vulcanian explosions laden with pyroclastic materials (ash and blocks) (Cortés and Calvache, 1993). The tornillos usually have disappeared several hours to a day before the eruptions.

The seismic station at Cráter-2 recorded 212 individual tornillo signals between 11 July 1992 and 7 June 1993. The maximum daily number of tornillos was 6, which occurred on 28 May 1993. The intervals of occurrence allow us to define four discrete episodes of tornillos which have ended with the eruptions of 16 July 1992, 14 January 1993, 23 March 1993 and 7 June 1993 [2]. The occurrence of tornillos before the eruption of 13 April 1993 was very short, and we believe that this eruption together with the 4 April eruption may be phases of the 23 March or 7 June eruptions. For this reason, we include the signals before the 13 April eruption within the last episode prior to the 7 June eruption (Fig. 4a,b).

Episode I was relatively short, lasting from 11 to 16 July 1992 and totaling 9 tornillo signals (Fig. 5a). The main type of tornillo observed was the Tornado, with subsidiary Gota, Serpentina, and Punzón forms. The maximum daily number of tornillos was 5 on 16 July, with the last tornillo occurring at 15.39 h local time (LT = GMT − 5) about one hour before the eruption, which occurred at 16.40 h.

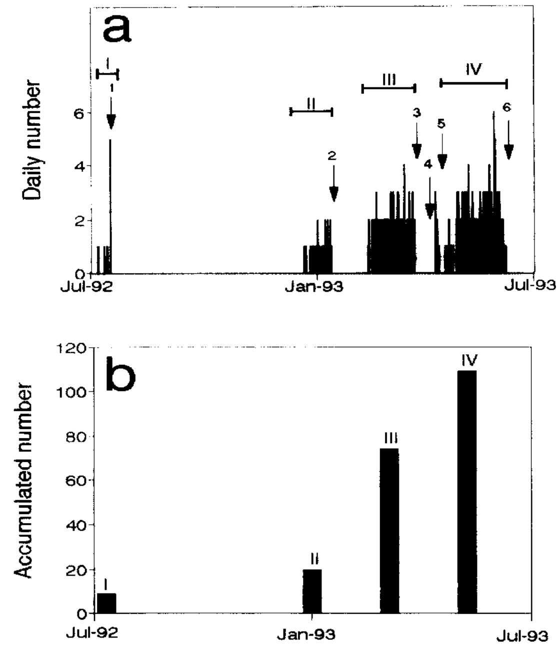

Fig. 4. (a) Daily occurrence of tornillo signals from July 1992 to June 1993. The Roman numerals above the bars represent episodes of tornillos. Arrows indicate the date of eruption: (*1*) 16 July 1992, (*2*) 14 January 1993, (*3*) 23 March 1993, (*4*) 4 April 1993, (*5*) 13 April 1993, (*6*) 7 June 1993. The tornillos disappeared after each eruption. (b) Accumulated number of tornillo signals for each corresponding episode. Each episode of tornillos is represented by a Roman numeral.

Episode II began on 23 December 1992 and ended on 14 January 1993, with twenty tornillos recorded during this time (Fig. 5b). Serpentina, Martinete, Bastón, Tornado and Punzón forms were observed. During this episode, the maximum daily number of tornillos was 3, which occurred on 3 January. The last tornillo occurred on 14 January at 09.47 h, approximately four hours before the eruption at 13.41 h.

Episode III began on 13 February and ended on 23 March 1993, with 74 tornillos being recorded (Fig. 5c). The principal type of tornillo was Serpentina, but all forms were noted except for the Esculapio. The maximum daily number of four tornillos occurred on 15 March, and the last tornillo occurred on 23 March at 08.27 h, approximately 14 h before the eruption at 22.39 h.

Prior to episode IV, a small eruption occurred on 4 April 1993 at 16.03 h. Episode IV began on 10

[2] On 23 September 1994 and 11 January 1995, two more small eruptions occurred. Both were preceded by the presence of tornillo signals.

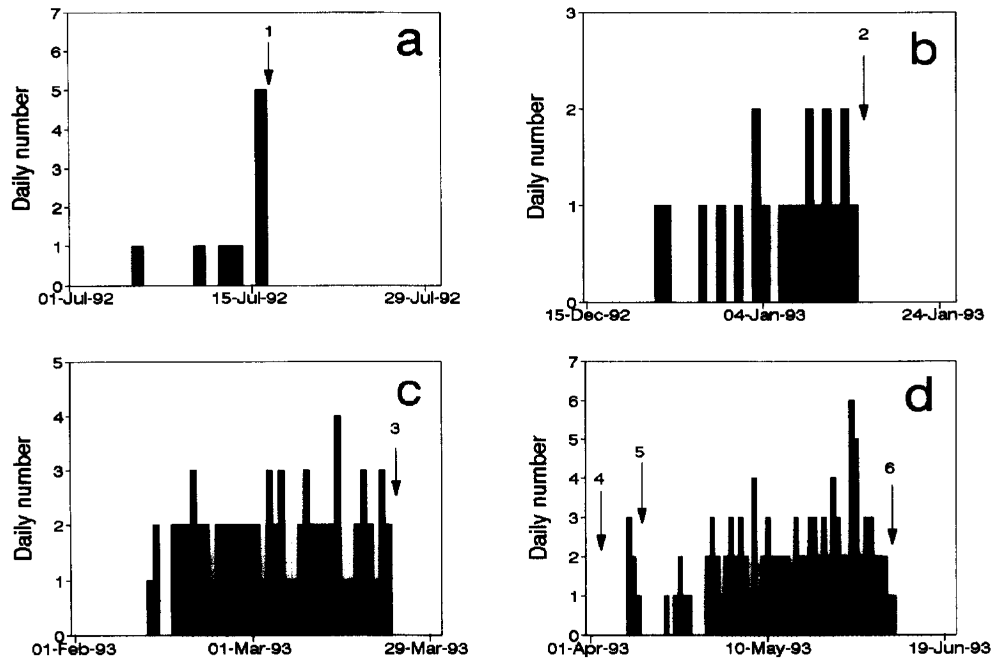

Fig. 5. Daily occurrence of tornillo signals during: (a) episode I, July 1992, (b) episode II, December 1992 to January 1993, (c) episode III, February to March 1993 and (d) episode IV, April to June 1993. Arrows indicate eruptions.

April and ended on 7 June 1993, with a total of 109 tornillos being recorded (Fig. 5d). Tornillo types were mainly Punzón, with subsidiary Esculapio, Seudotornillo and Gota forms. During this period, three eruptive events occurred: the first on 13 April at 03.21 h, and two more on 7 June at 03.42 and 21.37 h. The last tornillo occurred on 12 April at 02.01 h, about 25 h before the 13 April eruption. The maximum daily number of 3 tornillos occurred on 10 April. From the 13 April eruption to the 7 June eruption, a total of 103 tornillos were registered. This was the largest registered number of tornillos prior to an eruption at Galeras during 1992–1993. The maximum daily number of 6 tornillos was regis-

Table 2
Relationship between eruptions and tornillo signals at Galeras (modified from Cortés and Calvache, 1993)

Eruption				Tornillo events		
Date	Local time	Volume ($\times 10^6$ m^3)	Column height (km)	Accumulated number	Days of record	Episode
16 July 1992	16.40	0.282	6	9	5	I
14 January 1993	13.41	?	?	20	16	II
23 March 1993	22.39	0.835	8	74	37	III
4 April 1993	16.03	0.180	5	0	0	
13 April 1993	03.31	0.220	6	6	3	IV
7 June 1993	03.42	1.250	9	103	46	IV

Note: For the 14 January 1993 eruption it was not possible to estimate characteristics due to the fatalities that occurred during the eruption.

tered on 28 May, and the last recorded tornillo occurred on 7 June at 00.34 h, approximately three hours before the first eruptive phase which began at 03.42 h.

The most notable aspect of these four tornillo episodes is the occurrence of eruptions at the end of each episode (Fig. 5). The only eruption that did not have precursor tornillos was that of 4 April 1993. Interestingly, the volume of material ejected by this eruption was substantially less than that emitted by the eruptions of 23 March 1993 and 7 June 1993, which were preceded by greater numbers of tornillos and the largest signal durations.

The eruptions of 23 March 1993 and 7 June 1993 were the largest during the current activity cycle (1988–1995) in terms of erupted volumes, column heights, eruption rates, number of precursor tornillos, number of days of tornillos, as well as for changes in the morphology of the active cone (Cortés and Calvache, 1993; Ordóñez and Cepeda, 1997). Table 2 shows some of the parameters mentioned above. These data indicate the positive correlation between the total number of pre-eruptive tornillos during an individual episode and the volume of material ejected by the eruption. The histograms of daily tornillo occurrence also indicate that the maximum number occurs near the end of each episode (Fig. 5). However, because there is a variable interval of time between the date of maximum tornillos and the eruption point, it is difficult to accurately forecast the eruptions using solely this criterion. Nevertheless, the occurrence of tornillo signals can be one of the most important criteria for determining the probability of an eruption at Galeras.

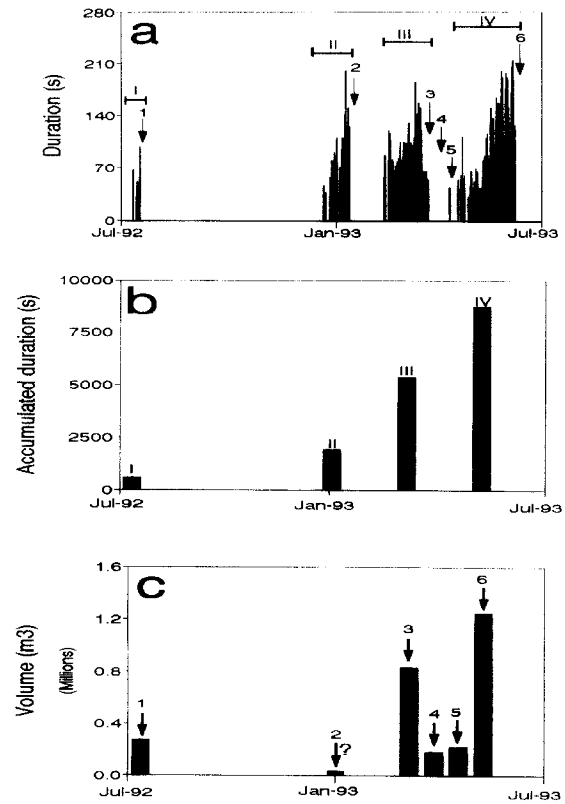

Fig. 6. (a) Durations in seconds of tornillo-type events from July 1992 to June 1993. For each episode, a progressive increase was observed in the durations of tornillo events, followed by a decrease a few days before the eruptions. (b) Accumulated duration of tornillo signals for each period. (c) Volume of solid material ejected in cubic meters during the different eruptions of 1992–1993. The volume of material from the 14 January eruption (episode II) is not well estimated due to the tragic nature of this eruption. The Roman numerals represent episodes of tornillos. Arrows indicate the dates of 1992–1993 eruptions.

5. Duration

Chouet (1992) assumes that the source of long-period events can be explained by the resonance of a three-dimensional, fluid-driven crack induced by a pressure transient applied over a small area of the crack wall. Chouet (1992) has shown that an increase in the duration of the seismic signal correlates with a decrease in the relation b/μ, or an increase in the impedance contrast Z:

$$Z = \frac{\rho_s \alpha}{\rho_f a} \quad (1)$$

where b is the bulk modulus of the fluid, μ is the rigidity of the solid which encloses the fluid, ρ_s is the density of the solid, ρ_f is the density of the fluid, α is the velocity of the compressive wave in the solid and a is the velocity of the acoustic wave in the fluid (Aki et al., 1977).

For each episode, there is a progressive increase in the durations of tornillo signals (Fig. 6a), which shows a positive correlation with the volumes of material ejected during the eruptions of 16 July 1992, 23 March 1993 and 7 June 1993 (Fig. 6). These repetitive increases in the durations may be the result of changes in physical conditions of the material which generate these types of seismic signals, such as continued crystallization of the magma (Stix et al., 1993) or an increase of gas in the fluid (Torres et al., 1996).

The maximum durations appear to occur in the last third of each episode of tornillo occurrence. In detail, episodes II and IV show similar behavior, with durations increasing progressively to a maximum value, followed by a small decrease immediately before the eruption. Since episode I is relatively short, no changes in the durations can be observed. In contrast, episode III shows a greater degree of regularity, with an increase and subsequent decrease in durations.

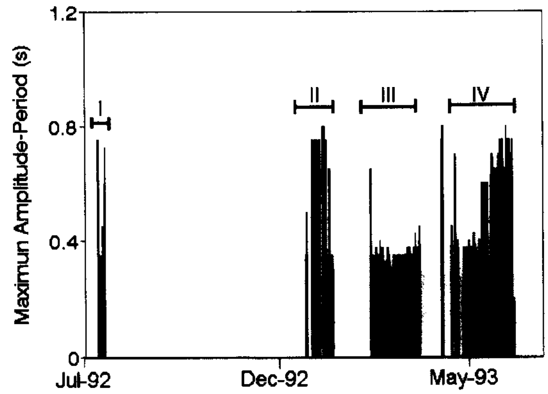

Fig. 8. Period associated with the maximum amplitude. Episodes III and IV show an increase in the period of the signals. The Roman numerals indicate tornillo episodes.

6. Seismic amplitude

The maximum values for vertical ground velocity obtained in the Cráter-2 station for an individual event occurred during episode II (Fig. 7a). For this episode, a gradual increase to a maximum value is observed, followed by a decline to the point of eruption. For episode III, maximum values are observed close to the middle of the episode. Maximum accumulated values for episodes of ground velocities occur in episode III (Fig. 7b). For episode IV, it is difficult to see a clear trend; nevertheless, we note that this episode was characterized by the smallest amplitudes compared to the other episodes. Using these data, it is not easy to identify a pattern useful to forecast eruptions at Galeras volcano.

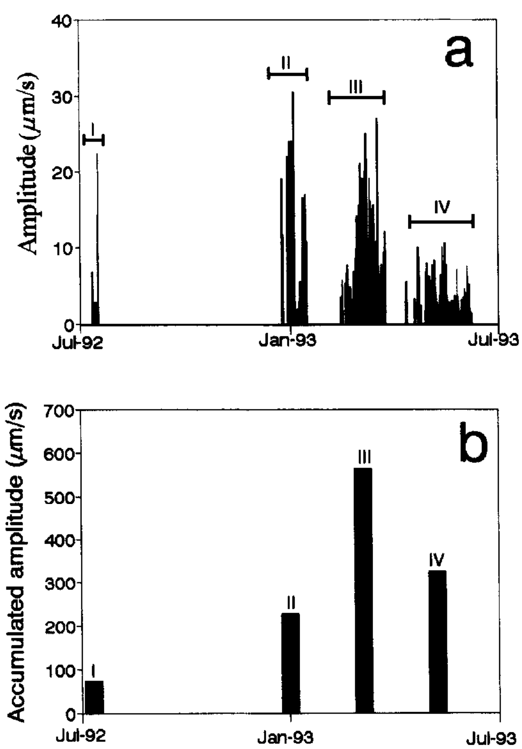

Fig. 7. Vertical ground velocity from July 1992 to June 1993. (a) For individual tornillo signals, the maximum values occurred during episode II. (b) Accumulated amplitudes for each episode; the maximum values occurred during episode III.

7. Period

We have observed that the dominant frequency is maintained at all stations, strongly suggesting that this characteristic is due to a source effect (Torres et al., 1996; Gómez and Torres, 1997). The period of the signal is a function of the geometry of the conduit or crack, the physical properties of the fluid and solid, and the position of the pressure pulse on the crack walls (Chouet, 1992).

The signal periods were determined for the corresponding maximum amplitude value. In Fig. 8, it is possible to observe, particularly for episode IV, an increase in the period of signals, possibly resulting from an increased proportion of gas in the fluid. This interpretation is consistent with the increase in the impedance contrast associated with increase in the duration of tornillo signals.

8. An approach to forecasting the eruption of 7 June 1993

The seismic activity of the volcano in April–May 1993, which was dominated by the presence of tornillos, was similar to that before the 16 July, 14 January and 23 March eruptions. The situation in May also was characterized by a low SO_2 flux, low deformation rates, little superficial activity, and generally low seismicity. Thus, the behavior of the volcano was similar to that before the previous eruptions. The above observations led us to believe that an eruption would occur soon, and we attempted to forecast this event.

The cycle of tornillos that was initiated on 10 April 1993 (episode IV) showed that the duration of tornillos became progressively longer, reaching about 200 s (Fig. 6a). Also, the total number of tornillos during episode IV exceeded that prior to the 23 March eruption (Fig. 4b). Between 10 April and 27 May, 78 tornillos were registered. We believed that the number and the duration could be related to the size of the eruption (Figs. 4 and 6). For episodes I, II and III, the time between each tornillo event decreased as the eruption approached. For the last episode, this situation was also noted.

These observations permitted us to infer that an eruption, similar to or slightly larger than that of 23 March, could occur within a few days or weeks. By 28 May 1993, the tornillo signals of episode IV were characterized by an occurrence exceeding one month, a maximum daily number of six, a progressive increase in the occurrence rate, and a progressive increase in the signal durations.

Differences between May 1993 and the previous pre-eruptive periods included an increase in the surface activity in an annular fissure within the active cone, which could result in large changes in its morphology.

Using this information, we believed at the end of May that it was possible to expect, within one day to some weeks, a sudden explosive eruption (VEI = 1) of short duration which would last several minutes to several hours and which would eject about 10^6 m^3 of material. Because of the fragile state of the active cone due to weakening mainly by the 23 March eruption, there was also the possibility of further changes to the crater morphology resulting from the predicted eruption (widening of craters and fissures, collapse of the crater walls, etc.). Based on the experience of the previous eruptions, on 17 May we alerted authorities to the possible effects of this type of eruption, particularly for people and infrastructure located near the summit of the volcano at the moment of the predicted eruption.

The expected eruption occurred on 7 June 1993, with many of the characteristics forecasted. The volume of material erupted during the eruption was estimated as 1,251,400 m^3, with VEI = 1 (Table 2; Cepeda et al., 1993). On 28 May, six tornillos were recorded, which was the largest daily number before any eruption in 1992–1993. On 5 June, the longest tornillo was recorded, with a duration of 214 s. Between 10 April and 7 June, 109 tornillo signals had been registered, being the largest accumulated number prior to an eruption.

9. Concluding remarks

Most of the Galeras eruptions that have occurred since July 1992 were preceded by tornillo signals. These signals disappear after each eruption. It is believed that the shape of the tornillo signals can be an indication of the physical nature of the fluid and the neighboring solid material. These events occur in discrete groups, within which systematic changes are observed for the tornillo events. We have not observed a characteristic in the pattern of these signals that permit us to establish some type of relationship with the occurrence of eruptions.

This type of signal is believed to originate from the interaction of fluids and the enclosing medium, when a fluid in a crack causes a pressure transient with the following conditions: (1) a strong impedance contrast between the fluid and the confining rock, and (2) a small area over which pressure is applied. The first effect increases the duration of the seismic signal, while the second effect causes a decrease in the signal's amplitude (Chouet, 1992).

Our observations allow us to establish that (1) the progressive increase in the duration and the rate of occurrence could indicate proximity to an eruption and (2) the accumulated number may indicate the possible size of the eruption. On the other hand, our experience with the seismicity at Galeras during the present cycle of activity has shown that the characteristics of the signals are more important than the absolute number of signals recorded.

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