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Some aspect of seismicity prior to the 27 November 2006 eruption of Nyamuragira volcano and its implication for volcano monitoring and risk mitigation in the Virunga area, Western Rift Valley of Africa

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ABSTRACT

The temporal variation in the seismicity in the Nyamuragira area was investigated for the period 1 July 2004–27 November 2006, prior to the 27 November 2006 eruptions of Nyamuragira. It is found that this eruption was preceded by 11 months by progressive increase in number of long-period earthquakes. This pattern of seismicity, integrated with other geophysical, geological and geochemistry data, is useful for volcano monitoring and risk mitigation.

1. Introduction

The Nyamuragira is a shield volcano located at the northern edge of Lake Kivu in the Virunga Province. It rises 3056 m asl and 1593 m above Lake Kivu. The position of the volcano follows the NW–SW trend of the African rift system and is NW of Nyiragongo volcano (Fig. 1). Nyamuragira volcano is characterized by frequent Hawaiian-type eruptions and highly potassic lavas (Hayashi et al., 1992). An active lava lake persisted in the summit crater from 1921 to 1938. Most eruptions, with the exception of the summit eruption of 1938, occur on the flanks of the volcano. The most recents flank eruptions occurred on 27 January 2000, 5 February 2001, 25 July 2002, 8 May 2004 and 27 November 2006.

Seismic activity associated with eruptions in the Nyamuragira area has been investigated by several authors (e.g. Lukaya et al. (1992) and Mavonga et al. (2006).

Mavonga et al. (2006) examined seismicity of the Nyamuragira area for the period 18 August 2002–7 May 2004 prior to Nyamuragira eruption of 8 May 2004. This continuous seismic record, from more than three seismographic stations for the period between two successive eruptions of volcano Nyamuragira, was obtained for the first time since 1983. In their study:

1. On the basis of the waveform pattern, they tentatively classified volcanic events as follows (Fehler and Chouet, 1982; Tanaka, 1983, McNutt, 1992; Lukaya et al., 1992):
   - Short-period (SP) earthquakes: earthquakes having P and S phases discernible as tectonic earthquakes and predominant high-frequency component content greater than 5 Hz. Their S–P times are less than 5 s and are located in the Virunga volcanic area.
   - Long-period (LP) earthquakes: transient signals having weak P and emergent or no S phases with a predominant low frequency content component between 1 and 3 Hz.
   - Volcanic tremor: a sustained occurrence of long-period events appearing on a seismogram as an irregular sinusoid of long duration comparing with a tectonic earthquake of the same amplitude.

The SP events are supposed to be induced by a brittle fracture of the roof rock under a stress due to magmatic pressure (Ohnaka and Mogi, 1982).

The LP events are probably due to the excitation of some fixed cavity under the volcano and/or the migration of magmatic fluid consisting of hot water and/or magma (Fehler and Chouet, 1982; Nishimura et al., 2002).

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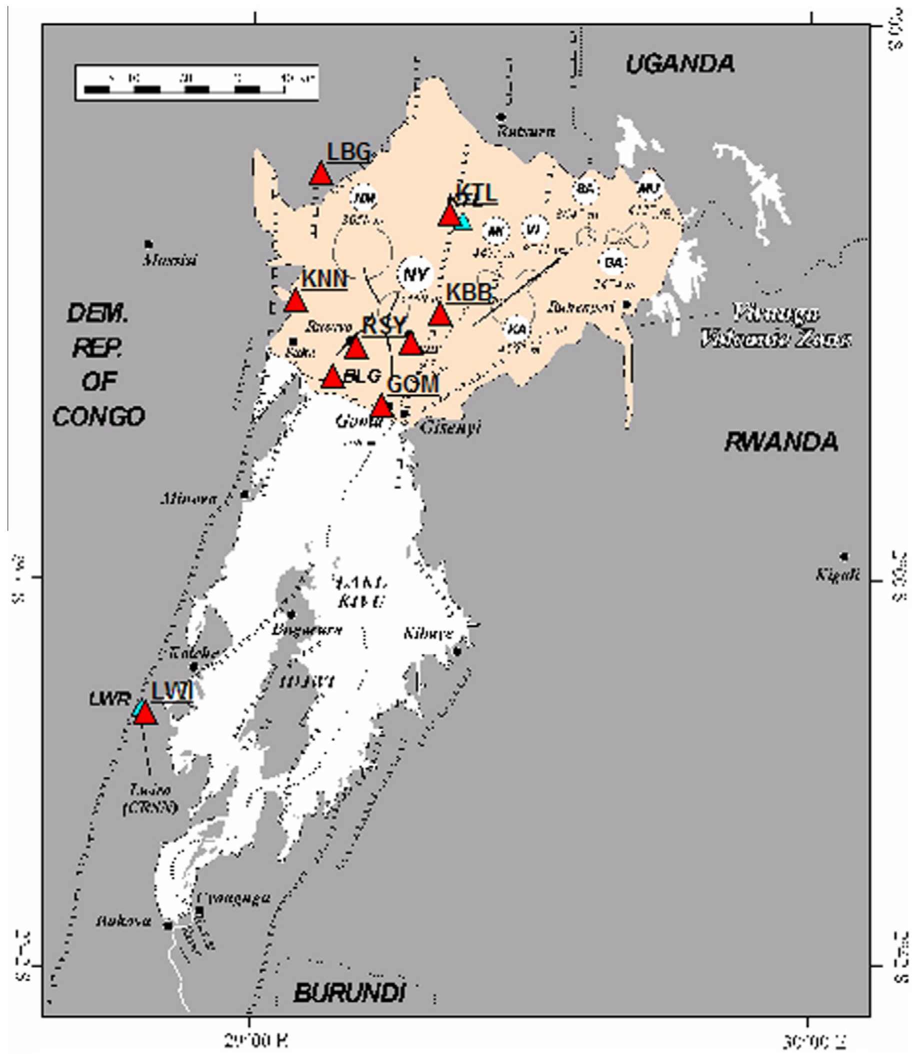

Fig. 1. Map showing the eight volcanoes of the Virunga volcanic zone (NY = Nyiragongo; NM = Nyamuragira; KA = Karisimbi; MI = Mikeno; VI = Visoke; SA = Sabinyo; GA = Gahinga; MU = Muhavura). The filled triangles and small circles indicate seismographic stations and cities, respectively. The coloured pinkish zone is the limitation of the Virunga area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. They showed three stages of seismicity characterisics of that eruption based on temporal variation of depth distribution of long-period (LP) earthquakes. The pattern of depth distribution of LP events for the period prior the eruption provided in Mavonga et al. (2006) is one aspect useful for monitoring volcano and risk mitigation due to eruptions of this volcano.

However, the locations of these LP events may be biased for the following reasons:

a. Theses signals have weak P and emergent or no S-phases.
b. The problems of earthquake location and of velocity structure determination are inter-dependent (Chiarabba et al., 2000; Zhang and Thurber, 2003; Stephen, 2005). In the computation of earthquake hypocentres, it would desirable to consider a P and S velocity structure specific for the Virunga area. As, these parameters were not available, they used a combination model obtained from a simple two-layer model that is the average model of Bonjer et al. (1970), Bram (1975), Nolet and Mueller (1982) for the Western Rift Valley of Africa.

To reduce bias due to uncertainty in the phase reading and/or velocity model, they considered only the well located LP earthquakes.

Therefore, it is necessary to complement that result by using another aspect in counting all locatable LP volcanic earthquakes (registered at least by three stations) on the basis of their waveform pattern.

In this short communication, the authors examine the monthly occurrence rate of long-period earthquakes prior to the 2006 eruptive episode recorded by the Goma Volcano Observatory seismic network.

2. Temporal variation in seismicity

The seismograms used in this study were provided by the permanent stations operating at Katale (KTL), Luboga (LBG), Kunene (KNN), Rusayo (RSY), Kibumba (KBB), Goma and Bulengo (BLG) as shown in Fig. 1. For the study period, these stations were equipped with a short-period Kinemetrics vertical SS-1 ranger seismometer ($To = 1$ s) connected to a PS-2 portable seismic recorder instrument, three component short-period Lennartz (LE-3D/5 s) seismometers and Nanometrics Trillium 40 broadband seismometer at KNN and KBB stations.

Signals from the kinemetrics seismometer are amplified and filtered in the amplifier module. The amplifier module has control for amplifier gain and filter setting. During the study period, the low-pass and high-pass filter were set to 12.5 Hz and 0.1 Hz, respectively. The amplifier gain varied from 36 to 66 dB according to

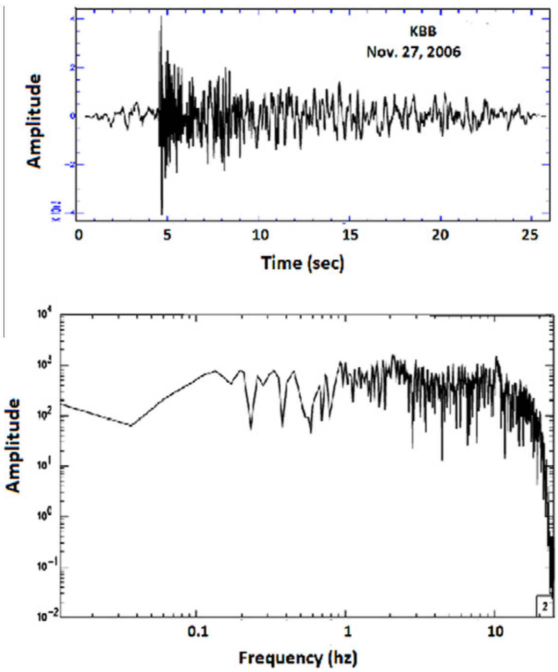

Fig. 2. Velocity spectra of typical hybrid (LP + short) events (27 November 2006). The lower and upper corner frequency of the instrument (Trillium 40) are 0.025 Hz and 50 Hz, respectively. The Nyquist frequency is 25 Hz.

the response of the site. The lower and upper corner frequencies of the Trillium 40 are 0.025 Hz and 50 Hz, respectively. The Trillium transfer function is approximately flat from 40 s (0.025 Hz) to 50 Hz and rolls off at 40 dB/decade bellow the lower corner frequency (Nanometrics, 2003). The natural frequency of the Lennartz (LE-3D/5 s) is 0.2 Hz and its upper corner frequency is 40 Hz. The deviation of measured transfer function of Lennartz (LE-3D/5 s) from ideal transfer function expressed in dB is as follow (Lennartz, 2003):

Component	0.2 Hz (dB)	10 Hz (dB)	40 Hz (dB)
Z	0	0	−0.1
N	+0.2	0	−0.2
E	+0.2	0	−0.2

From the frequency characteristics of these digital instruments, it is evident that the Trillium 40 and Lennartz (LE-3D/5 s) constraint well the LP events in the frequency range 1–3 Hz.

Signals from the digital stations were locally sampled with a frequency of 50 Hz and an A/D resolution of 24 bits.

For counting events recorded at least by three stations, both records (analogue and digital) were used. Furthermore, the digital records were used to estimate the predominant frequency of the waveforms used in this study (Fig. 2).

Fig. 3 shows the monthly count of locatable (i.e. registered by three or more stations) and located volcanic earthquakes in the 11 months prior to the 27 November 2006 eruptions of Nyamuragira. A progressive increase in number of LP earthquake has been observed. This increase is due to many swarms composed mainly of LP events observed during that period.

Further studies, including both LP and SP events, with new velocity models will examine longer-term time series and causative mechanisms.

3. Summary of observations

Eleven months before the 27 November 2006 eruption of Nyamuragira, an increase in seismicity related to the number of long-period events was observed.

This new aspect on changes in the frequency of occurrence of LP events coupled with that of depth distribution obtained in Mavonga et al. (2006), integrated with other available data (e.g. INSAR, GPS, geochemical, geological etc.) can be used to characterize volcanic processes and forecasting volcanic eruption in the Virunga area.

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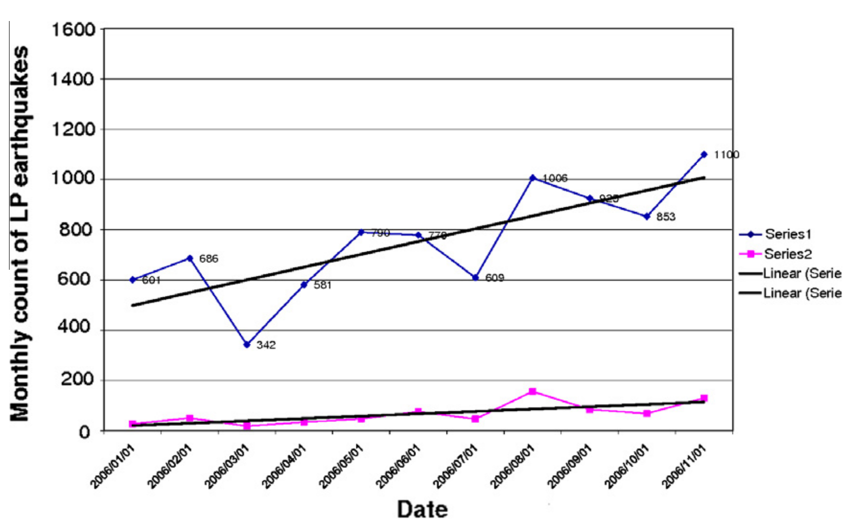

Fig. 3. Monthly count of locatable (series 1) and located (series 2) long-period volcanic earthquakes 11 months before the 27 November 2006 eruption of Nyamuragira.

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