

Observation of Hybrid Earthquakes at Nyamulagira Volcano in the Democratic Republic of the Congo

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Abstract

The Nyamulagira volcano is located in the western branch of the East African rift (bordered by a many faults) and is often characterized by fissural eruptions of very potassic fluid lavas. These eruptions are preceded by a variety of pre-eruptive low-frequency seismic signals. Hybrid earthquakes are one of these signals. In this short communication, we collected seismic data over a four-year period from 2011 to 2014 (a period during which two eruptions were observed at Nyamulagira: one in November 2011, another in June 2014) at the station of Rusayo and Kibumba which are very close to this volcano (about 10 km), with the aim of analyzing the characteristics of hybrid earthquakes as well as the volcanic activity that they accompany. We found that these earthquakes are characterized by a high frequency occurrence ranged between 3 and 10 Hz, they often occur in swarms and located at shallow depths between 0 and 5 km. They are interpreted as being related to a movement of breakage of rocks by fluids and generally in weakness areas that are the emplacement of cracks and faults of the East African Rift. They therefore accompany magmatic intrusions and precede most of the fissural eruptions observed at Nyamulagira volcano. These hybrid earthquakes are used as indicators of imminent eruptions and their observation is an effective tool for monitoring the Nyamulagira volcano.

Keywords: Nyamulagira Volcano; Hybrid earthquakes; East African Rift; Swarms; high frequency.

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1. Introduction

The Nyamuragira is a shield volcano located at the northern edge of Lake Kivu in the Virunga volcanic 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. Nyamuragira volcano is characterized by frequent Hawaiian-type eruptions and highly potassic lavas [1]. 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 recent flank eruptions occurred on 27 January 2000, 5 February 2001, 25 July 2002, 8 May 2004, 27 November 2006, 02 January 2010, 06 November 2011 and 21 June 2014. Seismic activity associated with eruptions in the Nyamuragira area has been investigated by several authors e.g. [2,3,4,5,6,7,8]. All of these Authors investigated the futures which precede the eruptions of this volcano and attempted to classify the seismic signals from Nyamulagira volcano using waveform pattern. The objective of this work is to analyze the characteristics of the Hybrid earthquakes from the Nyamulagira volcano as one of its seismic signals and to evaluate the role they play in interpreting the dynamics of magmatic activity.

2. Data and Methods

The seismograms used in this study were provided by the seismological network of the Goma Volcano Observatory (GVO). The observation network began in 2002 until now and is composed by eight stations: Katale(KTL), Luboga (LBG), Kunene (KNN), Rusayo (RSY), Kibumba(KBB), Goma (OVG), Kibati (KBT) and Bulengo (BLG). All of these stations are equipped by broadband seismometers, Guralp and Trillium, T₀=40s, 60s and 120s.

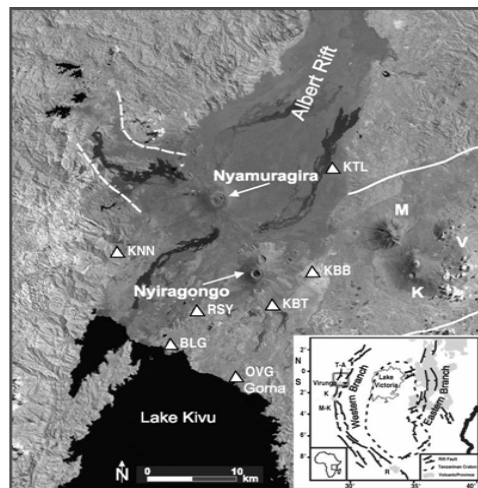


Figure 1: Seismic network of the Goma Volcano Observatory. Seismic stations are marked by white triangles (Goma-OVG, Kunene-KNN, Rusayo-RSY, Bulengo-BLG, Kibumba-KBB, Kibati-KBT, Katale-KTL, Luboga-LBG). Volcanoes: K-Karisimbi, M-Mikento, V-Visoke. Inset shows eastern and western branches of East African Rift System. Volcanic provinces in the western branch: T-A-Toro-Ankole, K-Kivu, M-K-Mwenga-Kamituga, R-Rungwe. Modified after References [9,10].

Continuous waveforms from the GVO array were manually scanned and analyzed using the seismic analysis programs. To locate earthquakes, P and S wave arrival times were picked manually on Butterworth filtered (0.5–15 Hz) vertical and horizontal components, respectively. P phase arrival times were assigned quality factors of 0, 1, 2 or 3 according to estimated measurement errors of 0.05 s, 0.1 s, 0.15 s, and 0.3 s, respectively. S wave quality factors of 0, 1, 2, and 3 were assigned to arrivals with estimated measurement errors of 0.1 s, 0.175 s, 0.25 s, and 0.3 s, respectively. A total of 5374 P and 3863 S wave arrival times were picked from ~2320 local hybrid earthquakes recorded within the Virunga volcanic province from 2011 until 2014 operating period of the analysis. All events were located using a 3-layer one-dimensional P wave velocity model of Reference [4] derived from earlier seismic studies in the Virunga region. Earthquakes recorded on 4 or more stations and with 6 or more P and/or S arrival time readings were used for location. To reduce bias due to uncertainty in the phase reading and velocity model, we considered only epicenters with standard error in latitude and longitude less than 2.5 km and a standard root mean square (rms) error on the travel time residual less than 0.5 s. It was thus revealed that the maximum accuracy on focal depth is obtained for $erz=5$ km.

3. Results

Common eruptions at the Nyamulagira volcano are generally fissural and are characterized by very fluid lavas. They result from the magmatic extrusions made possible by strong pressure that magma exerts on rocks in weakness areas of (usually in faults). The seismicity associated with these extrusions is characterized by shallow, periodic earthquakes, commencing with high frequency onsets and transitioning to codas with spectral peaks at 3–10 Hz and durations longer than is typical for earthquakes of the same magnitude in a standard tectonic setting. The high-frequency onsets, and long-period, long-duration codas are features shared by hybrid earthquakes seen at other volcanoes such as Montserrat, Redoubt, and Deception Island [11].

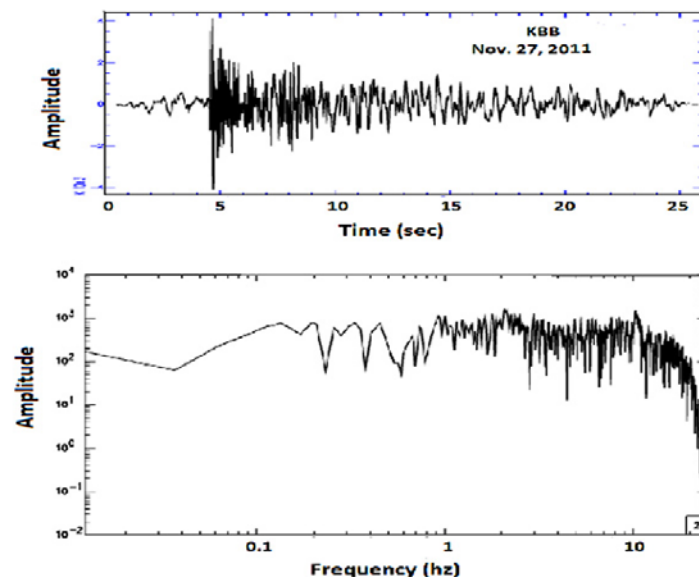


Figure 2: Example of a typical hybrid earthquake recorded at Kibumba(KBB) station on 27th November 2011. The frequency corner shows a large spectral band up to 10 Hz.

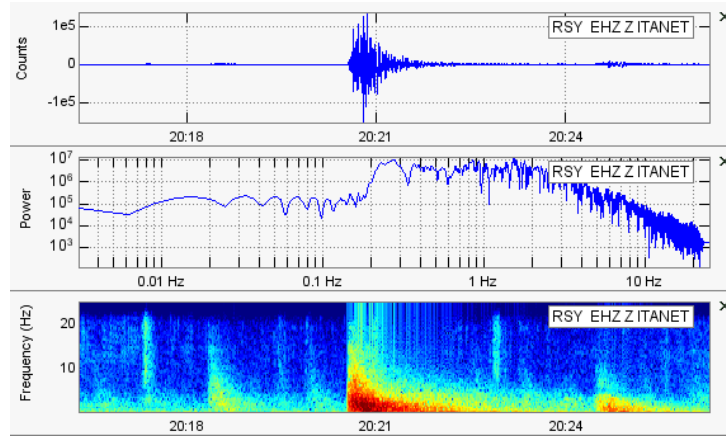


Figure 3: seismogram, spectrogram and spectrum of at typical Hybrid earthquake recorded at Rusayo station (RSY) on 6th November 2011, the day of Nyamulagira eruption.

The coda duration of the Mount Nyamulagira hybrid earthquakes decreases sharply with distance, suggesting that some, if not all of the protracted duration is due to path effects rather than an extended source. A mantle of abraded gouge surrounds the base of the spines and shows many features seen in shallow fault zones of mount Nyamulagira. Although we cannot definitively co-locate the seismic sources with gouge formation, contemporaneous seismic and acoustic data suggest that most of the earthquakes occur at or very near the surface. The decreasing coda durations with distance from the source and the presence of gouge at the base of the spines suggest that the seismicity associated with the spine extrusions could result from brittle failure between the spine and the surrounding rock.

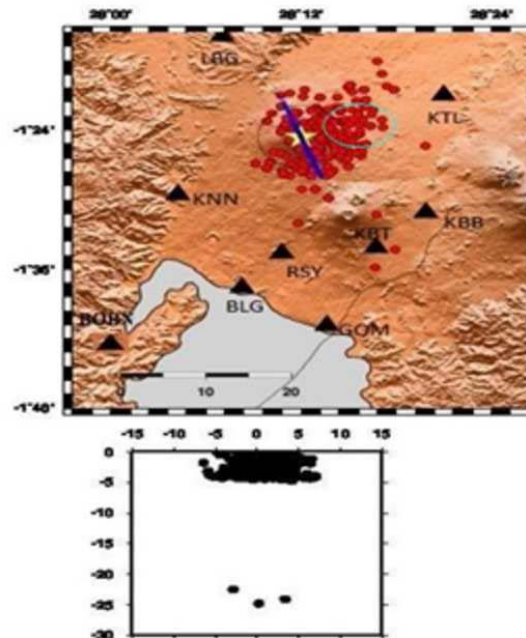


Figure 4: Location of hybrid earthquakes which preceded the 06 November 2011 eruption of Nyamulagira volcano. Almost all the events are shallow, suggesting the shallow location of these events.

Swarms at the Nyamulagira volcano are generally composed of Long Period (LP) and Hybrid Earthquakes. When the movement becomes so strong, volcano-tectonic earthquakes accompany them. During swarms, the number of earthquakes increases. The number of hybrid earthquakes increases with the movement of the magmatic intrusion. In any case, the number of hybrid earthquakes is lower than the Long periods earthquakes ones.

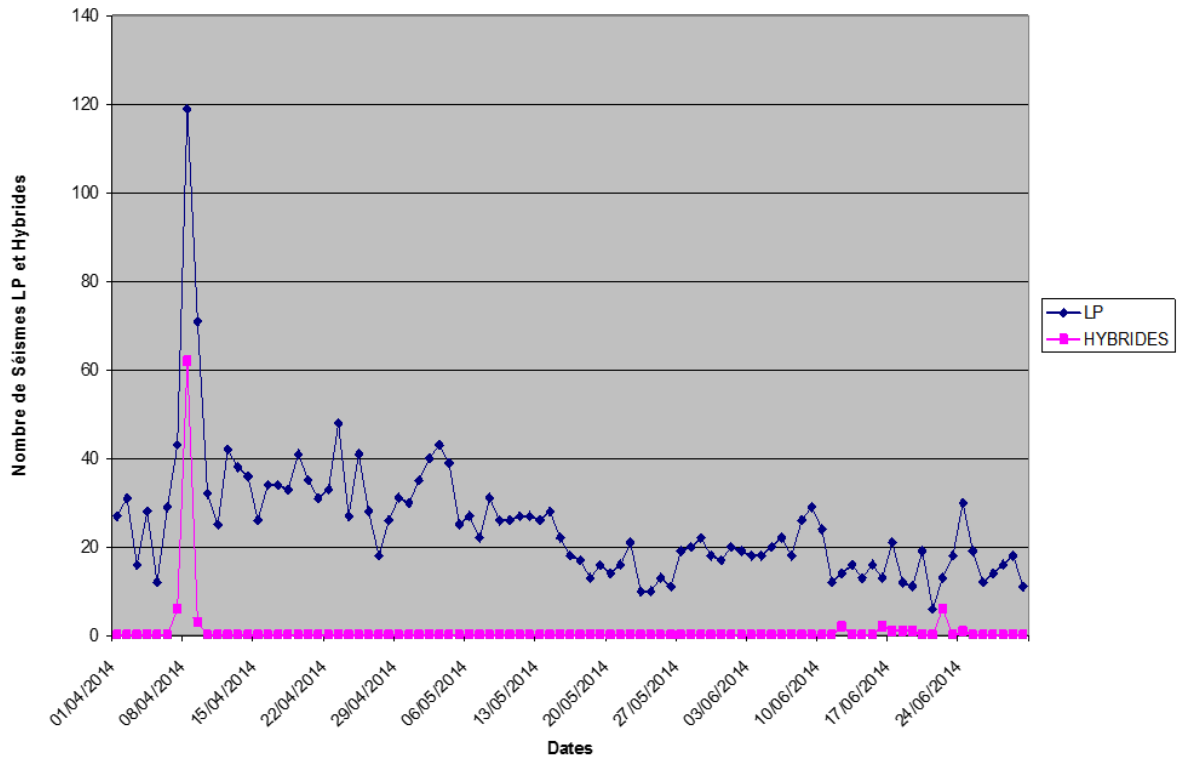


Figure 5: Counting diagram of volcanic earthquakes recorded at the Rusayo station from April until June 2014. The high pick indicates the April earthquake swarm, from which up to 60 hybrid earthquakes were observed.

4. Conclusion

The eruptions at Nyamulagira Volcano are always preceded by swarms of Hybrid earthquakes with a characteristic frequency corner between 3 and 10 Hz or up. These earthquakes are surface locations and are linked to magmatic intrusions that usually pass through weakness areas resulting from faults and Cracks of the East African Rift. Particular attention should be paid to these kinds of earthquakes because they are direct enunciators of imminent eruptions at Nyamulagira volcano.

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