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# Impacts of Tectonic Earthquakes in the Western Rift Valley of Africa on the Volcanic Activity of Nyiragongo, Virunga Region

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## ABSTRACT

This study establishes the impact of regional seismicity on the volcanic activities of an intra-plate and continental volcano Nyiragongo in the Virunga Region. The seismic activity in the East African Rifts is confined in the shallow zone and the focal mechanism of normal faulting type prevails widely in the Western Rift Valley. Nyiragongo volcano is characterized by two types of eruptions, one is a flank fissure eruption conducting to the formation of volcanic cones and another one is intra-crater eruption conducting to the formation of a crater lava lake. It is established that the Nyiragongo is presently in a very active stage, that the tectonic earthquakes occurring within the Western Rift at a certain distance, including those within the Virunga Region have a real impact on the volcanic activities of Nyiragongo. The knowledge of seismic activity in Western Rift should be an important tool for the surveillance of Nyiragongo volcano activities.

**Key words:** Impacts, tectonics earthquakes, volcanic activities, Nyiragongo, Virunga

## INTRODUCTION

The East African Rifts system extends from the Red Sea and Gulf of Aden at Afar triangle, Ethiopia in the North to Mozambique in the South and divided into two branches; the Eastern and the Western which come across at the lake Malawi (Fig. 1). The Western branch also called Western Rift Valley of Africa includes six lakes; namely: Albert (619 m), Edward (912 m), Kivu (1462 m), Tanganyika (771 m), Rukwa (782 m) and Nyasa/ (Malawi) (472 m).

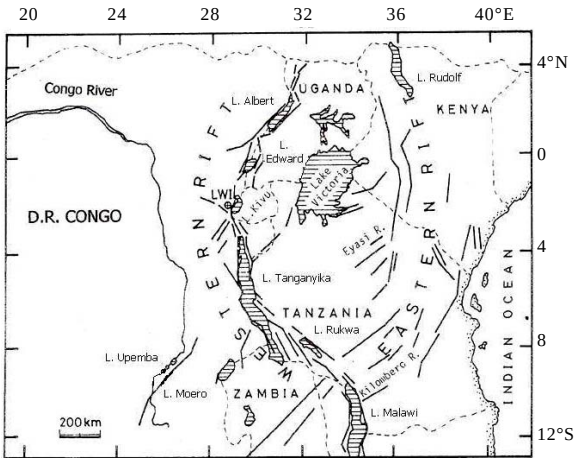


Fig. 1: The East African Rift System with two branches (Eastern and Western)

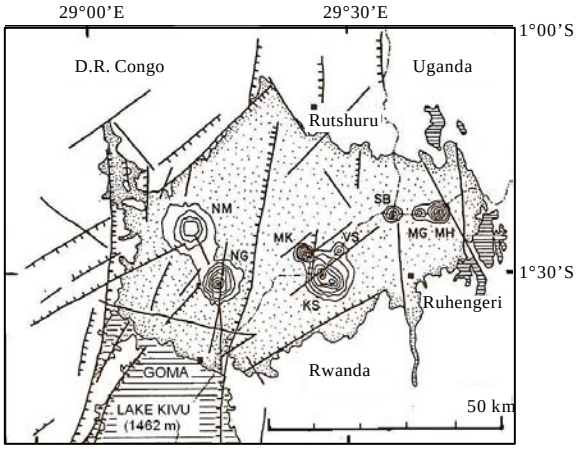


Fig. 2: Virunga volcanic region in the Western Rift. NY: Nyamuragira (3056 m), NG: Nyiragongo (3470 m), VS: Visoke (3911 m), MK: Mikeno (4437 m), KS: Karisimbi (4506 m), SB: Sabinyo (3647 m), GH: Gahinga (3474 m),MH: Muhavura (4127 m). Lines indicate the fissures (Villeneuve, 1980) and the doted area the volcanic fields

The lake Kivu is the highest lake in the Western Rift Valley, implying that the center of doming accompanying the Rift formation must be located around this lake (Hamaguchi and Zana, 1990). The tectonic conditions of the domal uplift, faulting, volcanism and shallow seismicity around the lake Kivu are believed to be the indications of actual rifting and may represent a nascent stage in the development of plate boundary (Wong and von Herzen, 1974).

The Virunga volcanic region located just at the Northern end of lake Kivu (1462 m) in the Western Rift Valley. The Virunga region is composed of eight major volcanoes divided in three groups: Eastern (Muhavura (4127 m), Gahinga (3474 m) and Sabinyo (3674 m)), central (Visoke (3911 m), Karisimbi (4506 m) and Mikeno (4437 m)) and Western (Nyiragongo (3474 m) and Nyamuragira (3056 m)) (Villeneuve, 1980) (Fig. 2). The volcanoes extending about 50 km E-W and about 25 km N-S in an East- ly perpendicular to the strike of the Rift System. The volcanoes in the Eastern and central groups are believed to be in the dormant stage, however the volcanoes in the Western group Nyiragongo and Nyamuragira are in the Rift floor and are among the most active intra-plate volcanoes in the world (Hamaguchi and Zana, 1983).

Nyiragongo has the morphology of stratovolcano (Simkin *et al.*, 1981) and his a complex of three overlapping composite volcanoes aligned in a North-South direction: Baruta (3200m) to the North, Nyiragongo main cone with geographical coordinates 1.31°S and 29.15° E, 1.3 km in diameter at (3470 m) to the centre and Shaheru (2800 m) to the South.

Nyiragongo was well known for its lava lake which had persisted within the summit crater since 1928 (Tazieff, 1977). The persistent lava lake activity is a special type of eruption at an open vent. The level of the lava lake was rising gradually with some fluctuated movements. The inside of the crater is encircled with three platforms called terraces. The first terrace is located at 180 m bellow the crater rim, the second 180 m bellow the first and the third 60 m bellow the second. The level of the lava reached the first terrace on March, 1972 (Pouclet, 1973) and on December 5, 1976. The eruption of Nyiragongo occurred in January 10, 1977 (Fig. 3).

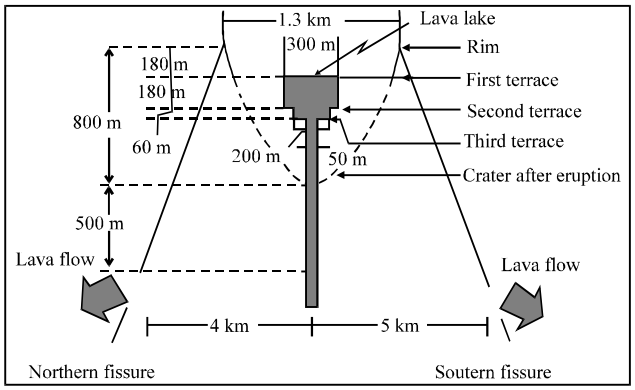


Fig. 3: Schematic cross section of Nyiragongo crater with position of the lava flows

In this study, we would like to establish a clear impact of tectonic earthquakes occurring in the Western Rift Valley on the volcanic activity of Nyiragongo.

## MATERIALS AND METHODS

**Study area:** This volcano is located in the North of Lake Kivu and Goma city at about 20 and 15 km, respectively. Population is estimated about 800,000 people. The city of Goma is connecting to the city Gisenyi in Rwanda with a population about 60.000 people. Several small villages are just located on the Southern flank of the volcano.

**Seismic network:** The seismic activity in and around the Virunga region was observed from Goma Volcano Observatory (GVO) network located around the Nyiragongo and Nyamuragira network. Actually the seismic network in the Virunga region is composed of two types of stations; digital and analogue. The analogue stations are equipped with a short period Kinemetrics vertical component SS-1 ranger seismometer ($T_o = 1$ sec) connected to PS-2 seismic recorder. The digital stations consist of three components; one horizontal and two verticals. The seismic signals are locally digitized and telemeter to Goma base station where they are recorded in continuous files and triggered for the earthquakes (Fig. 4).

**Method of hypocenter determination:** The computer program for hypocenter determination introduced by Wafula (1989) considered the several mathematics aspects described in this chapter.

Let us consider a station (i), the observation equation at this station can be written as follows:

$$t_i = T + T_i(\phi, \lambda, h) \tag{1}$$

where, T is the origin time, $T_i$ is the travel time and $\varphi$, $\lambda$, h ate latitude, longitude and focal depth of the hypocenter, respectively. Applying the Taylor expansion, Eq. 1 becomes:

$$t_i = T_0 + T_i(\phi_0, \lambda_0, h_0) + \left(\frac{\partial T_i}{\partial \phi}\right)\Delta\phi + \left(\frac{\partial T_i}{\partial \lambda}\right)\Delta\lambda + \left(\frac{\partial T}{\partial h}\right)\Delta h + \varepsilon_i \tag{2}$$

where, $T_o$, $\varphi_o$, $\lambda_o$ and $h_0$ are initial assumed origin time, latitude, longitude focal depth, respectively and $\epsilon_i$ is the residual. In the Eq. 2, the number of unknowns is four. In many cases, the number

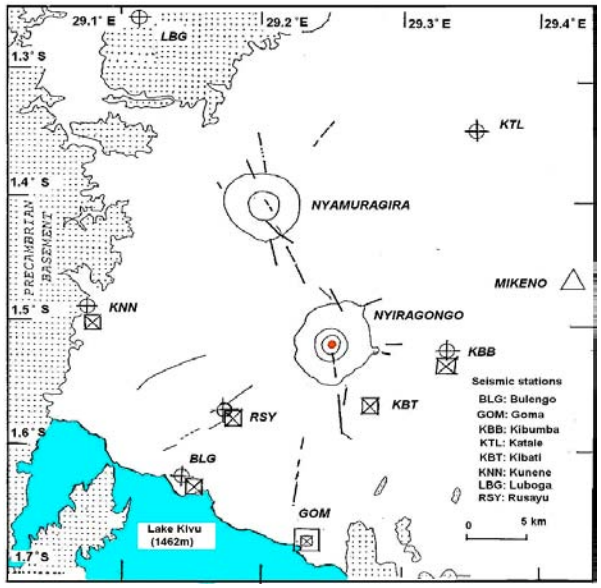


Fig. 4: Seismic network around the Nyiragongo and Nyamuragira field

of stations is greater than the number of unknown parameters, so that the most probable solution $\Delta T$, $\Delta\varphi$, $\Delta\lambda$ and $\Delta h$ can be obtained by least squares method. We defined:

$$\rho^2 = \sum_i^n \varepsilon_i \tag{3}$$

the minimum of $\rho^2$ is obtained by the condition:

$$\begin{pmatrix} \sum a_i^2 & \sum a_i b_i & \sum a_i c_i & \sum a_i b_i \\ \sum a_i bi & \sum b_i^2 & \sum b_i c_i & \sum b_i d_i \\ \sum a_i c_i & \sum b_i ci & \sum c_i^2 & \sum c_i di \\ \sum a_i & \sum bi & \sum ci & \sum N \end{pmatrix} \begin{pmatrix} \nabla T \\ \nabla\varphi \\ \nabla\lambda \\ \nabla h \end{pmatrix} = \begin{pmatrix} \sum a_i d_i \\ \sum b_i d_i \\ \sum c_i d_i \\ \sum d_i \end{pmatrix} \tag{4}$$

$$\begin{aligned} a_i &= \frac{\partial T_i}{\partial\phi} = \frac{\partial T_i \partial\nabla}{\partial\nabla\partial\phi} = \frac{\cos\theta_i}{v} R\cos\left(A_{zi}\right) \\ b_i &= \frac{\partial T_i}{\partial\lambda} = \frac{\partial T_i \partial\nabla}{\partial\nabla\partial\lambda} = \frac{\cos\theta_i}{v} R\sin\varphi\cos\left(A_{zi}\right) \\ c_i &= \frac{\partial T_i}{\partial h} = \frac{\sin\theta_i}{v} \\ d_i &= t_i - T_i\left(\varphi_0, \lambda_0, h_0\right) \end{aligned} \tag{5}$$

Where:

$\theta_i$ : Emergent angle

$A_{zi}$ : Azimuth

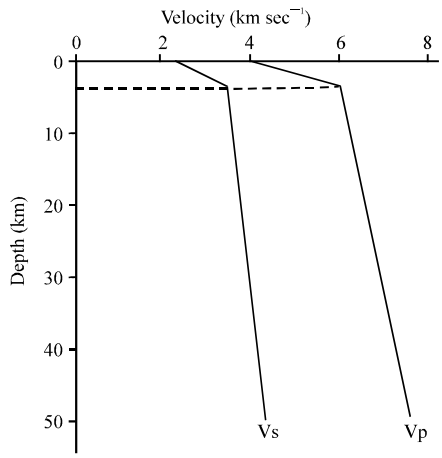


Fig. 5: Velocity structure of P and S waves in the Western Rift valley

$\Delta$ : Epicentral distance
R : Radius of the earth
v : Velocity

In most of case, the focal depth is not determined, so we use damp least squares method by adding some values to the diagonal elements of the matrix in order to reduce the stepping aside between the initial and the calculated location.

**Velocity structure:** In the hypocenter determination, the knowledge on the underground structure (P and S wave velocity models) is a very important parameter. The velocity structure in the Western Rift was investigated by Bonjer *et al.* (1970). The model which consists to two layers, having a P-wave velocity varying linearly with depth, was adopted (Fig. 5). Considering the velocity structure, we defined the following mathematical expression:

$$V = v_0 \left( \frac{R - h}{R} \right)^{\beta} \tag{6}$$

where, $V_0$ is the surface velocity, h is the focal depth, R the radius of the earth and $\beta$ a constant.

**Focal mechanism:** The P-wave analysis for fault plane study is based on the finding by Wafula and Zana (1990). The ground motion due to the first arrival of seismic wave is polarized as repulsive motion from hypocenter called compression (up or push), or attractive motion to the hypocenter called dilatation (down or pull). The polarization pattern (radiation pattern) is systematic so the space around the epicenter can be divided into four quadrants by two lines called nodal lines (planes) (Fig. 6). Two quadrants are compression zones and two others dilatation zones. Let us note, that, one of nodal planes must be the fault plane of the earthquake.

The focal mechanism solution is obtained by projecting the P-wave first motion on the lower hemisphere of the focal sphere with the equal area projection using the azimuth and epicentral distance.

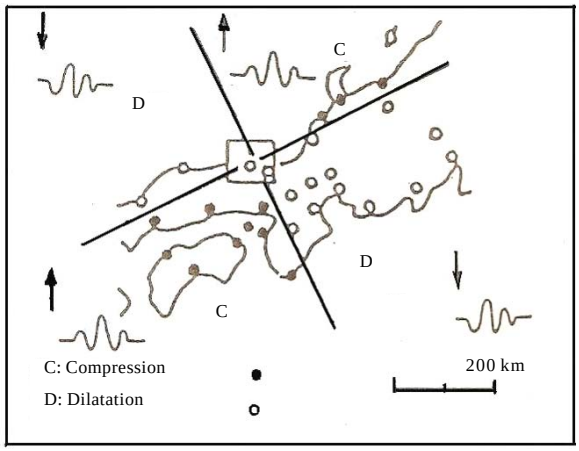


Fig. 6: Polarized area around the epicenter of Tango 1927 earthquake, Japan

**Field observation:** The field observations are carried out on the summit crater of the Nyiragongo volcano and on its flanks. Mostly, along the fractures on Southern flank and on that connecting the Shaheru crater to the Nyiragongo main crater. This study started from October 2001 up to nowadays.

## THE SEISMIC ACTIVITY PATTERN AND FOCAL MECHANISM IN THE WESTERN RIFT

**The seismic activity pattern:** The Western Rift Valley is seismically very active region in the East African Rifts System. Both the East African Rift System and the mid-oceanic ridge are characterized by the seismic activity confined to shallow depths. However, the seismic belt within which earthquakes occur is narrow under the mid-oceanic ridges, while it is rather broad in the African Rifts (Tanaka *et al.*, 1980).

The different seismic studies on the Western Rift and data reported by international agencies, reveal that the seismic activity is confined in the following zones:

- The South-Eastern part, central part and the Northern end of lake Tanganyika
- Adjacent Ruzizi valley
- The lake Kivu basin, including the Ngweshe, Masisi and Walikale zones
- The lake Edward trough and Mt. Ruwenzori area

These areas have experienced severe earthquake with local magnitude ≥6.0, let us note that:

- The Tanganyika seismicity is presently the most highest in the Western Rift Valley (Fig. 7). The earthquakes showed in Fig. 7 are listed in the Table 1
- The Mt Ruwenzori earthquake of March 29, 1966 ($M_L$ = 7.0) was accompanied with many foreshocks and aftershocks
- Since 1997, the lake Kivu basin has experienced an unusual high seismic activity; many earthquakes are felt by local inhabitants. On October 24, 2002 an earthquake of magnitude $M_w$= 6.2 had struck the Region in the Kalehe territory. The earthquake was accompanied by many aftershocks

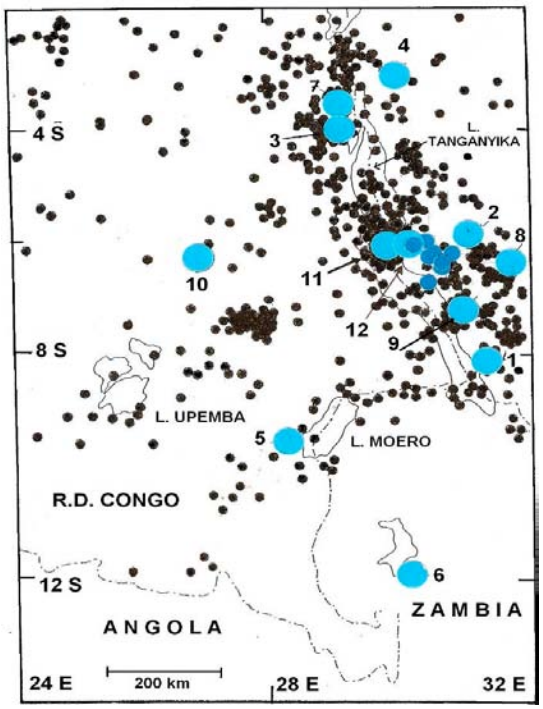


Fig. 7: Seismicity of Tanganyika region (1900-2007). Small black solid circle is earthquakes. Big bleu solid circle is major earthquakes occurring in the region. Small bleu circle are aftershocks associated to the seismic event number 11(2005 December 05)

Table 1: List of major earthquakes around lake Tanganyika region 1900-2007 shown in Fig. 7

| Date | Localisation | Magnitude |
|---|---|---|
| 1910 December 13 | 8.0°S; 31.0°E | 7.3 (ISS) |
| 1945 March 03 | 6.0°S; 31.0°E | 6.0 (ISS) |
| 1952 January 31 | 4.0°S; 29.0°E | 6.3 (G.R) |
| 1952 June 30 | 3.0°S; 30.1°E | 6.0 (G.R) |
| 1958 May 05 | 9.0°S; 28.0°E | 7.2 (IRSAC) |
| 1958 July 16 | 2.0°S; 30.0°E | 6.0 (IRSAC) |
| 1960 September 22 | 3.5°S; 29.1°E | 6.5 (IRSAC) |
| 1961 May 20 | 6.7°S; 31.7°E | 6.4 (IRSAC) |
| 1967 November 11 | 7.0°S; 30.9°E | 6.0 (IRSAC) |
| 1992 September 11 | 5.9°S; 27.1°E | 6.7 (USGS) |
| 2005 December 05 | 6.2°S; 29.6°E | 6.8 (USGS) |
| 2007 March 28 | 6.1°S; 29.7°E | 6.0 (USGS) |

- On February 3rd, 2008 an earthquake of magnitude $m_b = 6.1$ took place on the Western part of lake Kivu in Birava Kabare territory. This seismic event was associated with many aftershocks felt up to September 2008

**Focal mechanism:** In regard to the earthquake mechanism, it is noticed that the focal mechanism of normal faulting type prevails widely in the Western Rift Valley with the tension axis. These axis

are approximately perpendicular to the strike of the East African Rift System as a whole or the local fault trends in detail (Zana and Tanaka, 1981; Wafula and Zana, 1990).

## THE VOLCANISM IN THE VIRUNGA REGION

The volcanism in Virunga Region is an intra-plate volcanism occurring within the African plate. This volcanism is related to the formation of the East African Rift Valley system.

Furthermore, according to Macdonald (1972) table of active volcanoes of the world and the Bulletin of Volcanic Eruptions (No.18), the long-lived lava lake activities were confined to the following five volcanoes in the world: (1) Kilauea volcano in Hawaii, (2) Nyiragongo/ Nyamulagira in the Western Rift Valley, (3) Mt. Erebus in Ross Island, (4) Antarctic and Iceland. These volcanoes are all considered being hotspots (Hamaguchi and Zana, 1990). The lava lake activity is interpreted as special variety of long-continued eruption at an open vent with a high magma level (Macdonald, 1972). Except the Mt. Erebus in Antarctic, the three hotspots Hawaii, Nyiragongo-Nyamulagira and Iceland which are the most actives volcanoes in the World, are characterized by mantle plumes bringing up heat and primordial material from the core-mantle boundary. So it is important to notice that the volcanism of Nyiragongo and Nyamulagira have two origin.

The eruptive activity of the Nyiragongo volcano is considered to be mainly of Hawaiian type, dominated by effusive and passive emission of low viscosity lava at high temperature. The low viscosity is due to the basaltic composition of lava with low content of silicate, so the lava flows generated have high speed.

Recently, the Nyiragongo volcano was characterized by two types of eruptions, one is a flank fissure eruption conducting to the formation of volcanic cones and another one is intra-crater eruption conducting to the formation of a crater lava lake.

## RESULTS AND DISCUSSION

The earthquakes occurring in the Western Rift are acting on the volcanic activities of Nyiragongo. Several cases can be pointed out.

On January 6, 1977, an earthquake of magnitude $m_b = 5.2$ occurred about 130 km in the South of the volcano (Fig. 8). After the occurrence of this seismic event, the continuous Volcanic tremors with high amplitude started, the recording has been at Lwiro station Located about 90 km South of the volcano until the occurrence of eruption on January 10, 1977 (Hamaguchi *et al.*, 1992). The long-lived lava lake in summit crater had completely disappeared. All the lava was drained through several fissures opened on the flanks of the volcano.

On January 14, 1982, just at the end of Nyamulagira eruption on December 25, 1981 a long duration series (Jan.14, 1982-Feb. 20, 1982) of A-type or tectonic events were recorded and located from the crater of Nyiragongo along the main fissure the main fissure connecting the two volcanoes Nyiragongo and Nyamulagira in the Direction (NNO-SSE) up to the North of Nyamulagira (Tanaka, 1983) (Fig. 9). This fissure is considered as the main line of weakness of Nyamulagira volcano (Pouclet and Villeneuve, 1972). On June 21, 1982, the lava lake which was not seen for about five and half years since January 10, 1977, suddenly re-appeared at the bottom of the crater and rose over 400m between June and September 1982 (Hamaguchi *et al.*, 1992).

It was observed, that very small amplitude tremors appeared in November 1990 after the occurrence of a 4.8 magnitude earthquake on November 20, 1990, on the South slope of the volcano (Fig.9). This activity was considered as precursor of the June 23, 1994 lava lake rejuvenation.

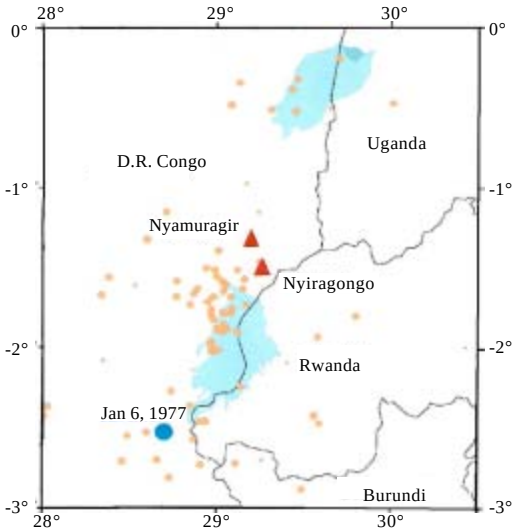


Fig. 8: Seismicity of the central part of the Western Rift from 1977 to 2007 ≥ 3.8 reported by NEIC. The red triangles indicate the volcanoes Nyiragongo and Nyamulagira. The blue solid circle indicates the seismic event on Jan. 6, 1977. Orange solid circles indicate the earthquakes

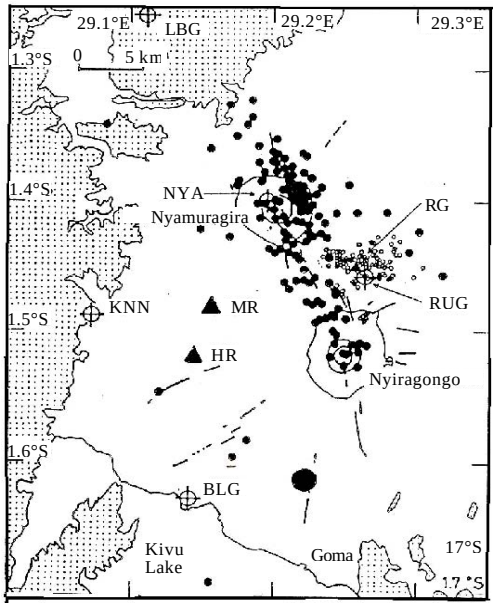


Fig. 9: Seismic activity after Nyamulagira eruption in 1981 (Tanaka, 1983). Solid triangle: Eruption site of Nyamuragira eruption in 1976, MR: Murara, HR: Harakandi and RG: Rugarambiro Nyamulagira cones. Small solid circle indicates A- type earthquakes after Nyamulagira eruption on Dec. 25, 1981. Open circle indicates volcanic earthquakes associated to the eruption on Dec 25. Great solid circle indicates the tectonic earthquake on November 20, 1990. Cross and solid circle indicate the position of seismic station

The occurrence of moderate earthquakes $M_l$ = 4.5, on October 7, 2001 in the North of the volcano about 140 km at the Northern part of lake Edward lake, triggered; volcanic tremors, vibrations and grumbling were also felt by local population and there was occurrence of black smoke from the summit crater.

The occurrence of moderate earthquakes $M_l$ = 4.8, on January 4th, 2002 with about the same location than that on October 7, 2001, triggered; volcanic tremors with large amplitude, vibrations and grumbling felt by local population, there was occurrence of black smoke from the summit crater and the increase of temperature on the flank of the volcano.

The Nyiragongo flank fissure eruption occurred on January 17, 2002. All the lava lakes were drained out through several fissures on the flanks of the volcano. Very high tectonic activity was associated to this eruption.

Many earthquakes were felt up to more far cities such as Bukavu and Kigali located about 100 km from the volcanic region. Probably, because of this high seismic activity, volcanic tremors were still recorded in the Nyiragongo volcano after the eruption on January 17, 2002. On April 2002 fresh scorias were observed in the bottom of the crater.

On October 24, 2002 an earthquake of magnitude $M_w$ = 6.2 occurred about 40km in the South of the volcano several days late, the bottom of the Nyiragongo crater became active, fresh lava appeared in the crater bottom in the beginning of November. Since then the lava lake was present in the Nyiragongo crater and its activity is gradually increasing. Recently the lava lake is characterized by the lava fountain in the crater, gases, scoria's and Pele's emission and fluctuation of the lava lake level in the formed well. Sometimes overflowing are observed from the well.

On February 3rd, 2008 earthquake of Magnitude $m_b$ = 6.1 occurred in the South-Western part of lake Kivu (Fig. 10, 11). The earthquakes in Fig. 10 are listed in Table 2. This earthquake in 2008

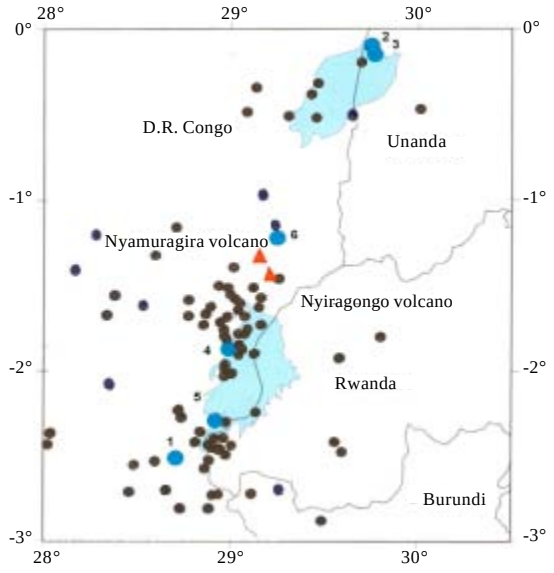


Fig. 10: Seismic activity in the central part of the Western Rift Valley with magnitude≥3.8, reported by NEIC. The red triangles indicate the volcanoes Nyiragongo and Nyamulagira. The blue solid circles indicates the earthquake with impact on the volcanic activity of Nyiragongo. Black solid circles indicate the earthquakes

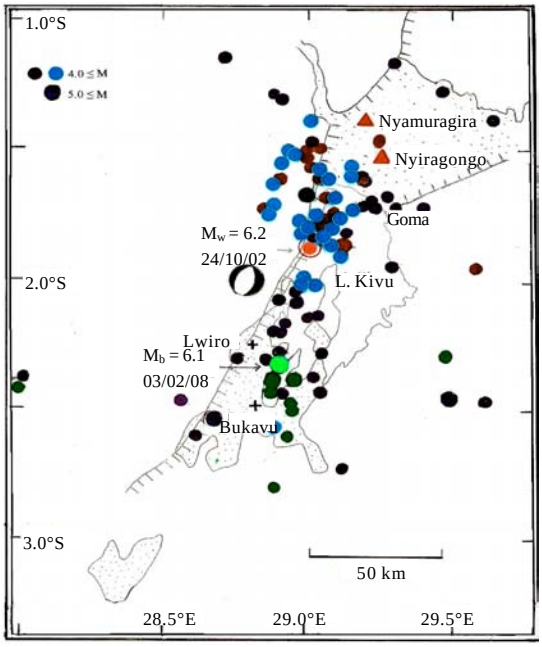


Fig. 11: The seismicity of lake Kivu basin for earthquakes with magnitude ≥ 4.0 for the period from 1960 to 2008. Blue solid circles are aftershocks associated to the October 24, 2002 earthquake, encircled red solid circle. Green solid circles are aftershocks associated to the February 3rd, 2008 earthquake green solid circle. Dark blue circles are earthquakes occurring in the basin in other periods

Table 2: List of earthquakes (M›4.0) with impact on Nyiragongo volcano 1977-2008 shown in Fig. 10

| Date | Localisation | Magnitude |
|---|---|---|
| 1977 January 06 | 2.51°S ; 28.7°0E | 5.3 (USGS) |
| 2001 October 7 | -------- --------- | 4.5 (OVG) |
| 2002 January 04 | 0.14°S ; 29.76°E | 4.8 (USGS) |
| 2002 October 24 | 1.88°S ; 29.00°E | 6.2 (USGS) |
| 2008 February 03 | 2.30°S ; 28.90°E | 6.1 (USGS) |
| 2008 October 05 | 1.21°S ; 29.25°E | 5.3 (USGS) |

was associated with many aftershocks felt up to six months late. The seismic event generated many fluctuations in the Lava Lake in the crater. Big difference can be observed on the level of Lava Lake before and after this seismic event (Fig. 12a, b). Lava overflows could be noticed in Fig. 12b that means the level of the lava lake increased just after the earthquake.

On August 18th, 2008, an earthquake on magnitude 4.0 occurred in the Southern part of Nyiragongo volcano field. This earthquake was followed by the occurrence of volcanic tremors of large amplitude correctly recorded at Goma seismic station (Fig. 13a, b). It is observed that the period of volcanic tremors became short after the earthquake (Fig. 14a, b).

An earthquake of magnitude $M_w$ = 5.3, occurred on October 5, 2008 on the Northern part of Virunga, about 15 km only from Nyiragongo volcano as shown in Fig. 10.

Several felt earthquakes followed this seismic event. Several B and C type earthquakes with magnitude ≥3.0 were recorded in the Virunga volcanic region.

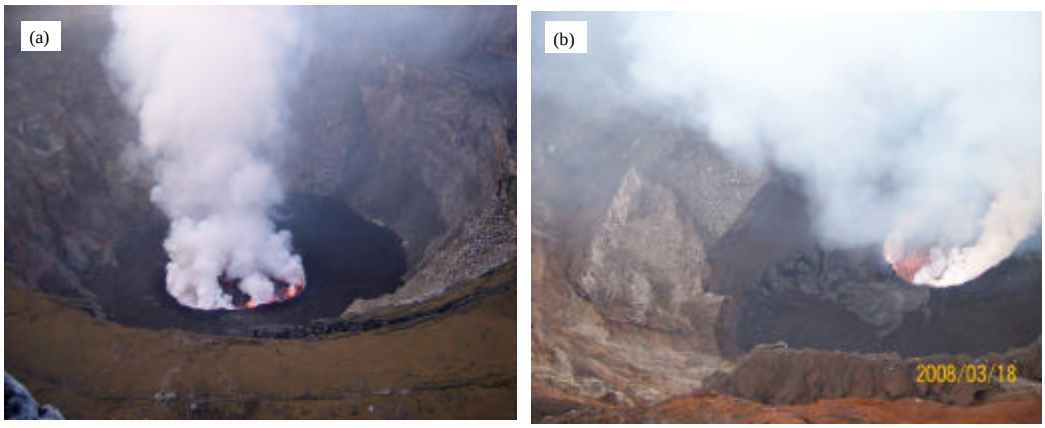


Fig. 12: (a) New lava lake in the Nyiragongo crater, June 19, 2007 Goma volcano Observatory (GVO). (b) Lava lake in the Nyiragongo volcano crater, March 18, 2008 (GVO)

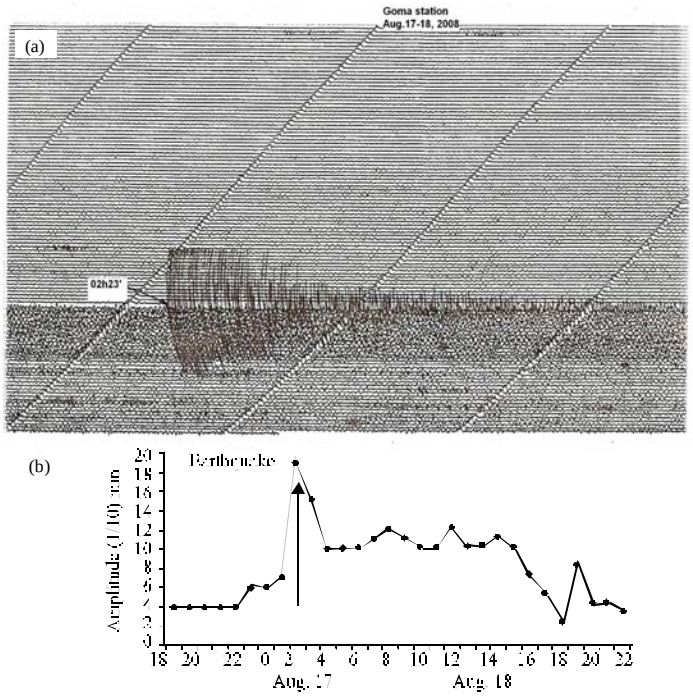


Fig. 13: (a) Variation of volcanic tremors at Nyiragongo volcano after an earthquake of magnitude 4.0 on August 18th, 2008 in the Southern part of Nyiragongo volcano field. (b) Amplitude variation of volcanic tremors observed at Goma station, August 17 to 18, 2008, due to an earthquake of magnitude 4.0 ($\Delta A = \pm 0{,}1$ mm)

The most impressive change in the volcanic tremors occurred when a C- type event occurred on October 7, 2008, followed by volcanic tremors of Nyiragongo with large amplitude lasting about half day (Fig. 15).

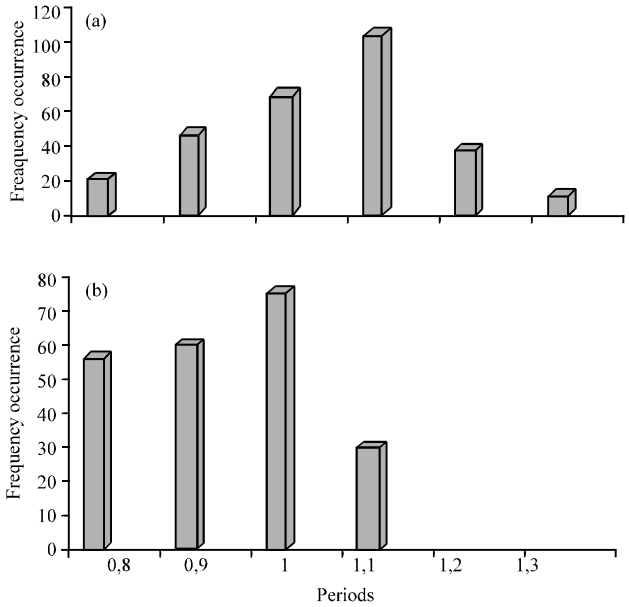


Fig. 14: (a) Periods of volcanic tremors before earthquake of magnitude 4.0 in the south of Nyiragongo field, on Aug.18, 2008. (b) Periods of volcanic tremors after earthquake

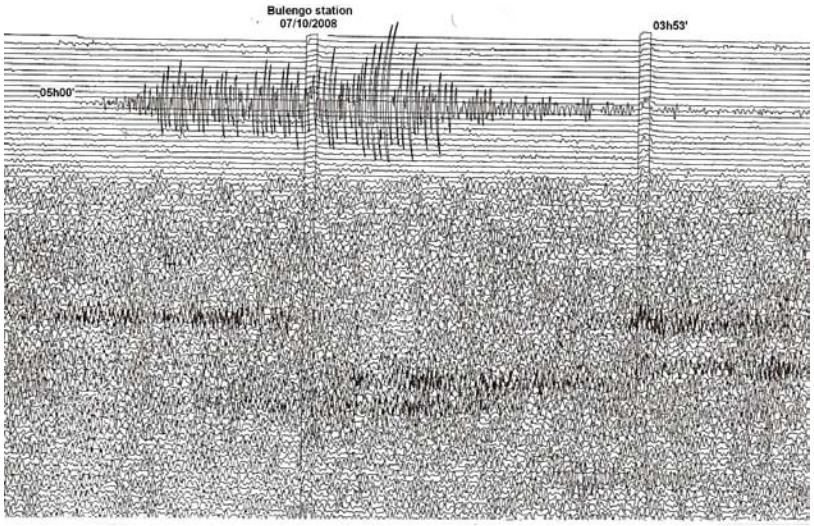


Fig. 15: C-type volcanic earthquake recorded at Bulengo seismic station, followed by volcanic tremors with large amplitude on October 07, 2008

## CONCLUSION

In this study, we studied the seismic activity in the Western Rift Valley with its correlation to the volcanic activity of Nyiragongo volcano in the Virunga Region located in the Western Rift of Africa. It was found that the occurrence of tectonic earthquakes in the Rift at a certain distance generated several phenomena in the behavior of the volcano. Some of these phenomena might be considered as the precursor of Nyiragongo eruptions. We have noticed the following facts:

- A generation of volcanic tremors with high amplitude in the Nyiragongo volcano during the existence of Lava Lake in its summit crater in 1977. This state of volcanic tremors conducted to the flank fissure eruption of the volcano four days late
- The occurrence of black smoke in the summit crater of the volcano
- An occurrence of grumbling and vibration felt by local population on the flank of the volcano
- A generation of the lava lake in the bottom of the Nyiragongo crater pit
- An important change in the lava lake activity
- A triggering of volcanic events with long period within the Virunga Region generating remarkable volcanic tremors

Since, the volcano Nyiragongo is located in the active Western Rift its activity is ultimately associated to the movement of this Rift.

The effect of the earthquakes in analyzed cases should as effect to squeeze the magma reservoir under the volcano as suggested by Hamaguchi *et al.* (1982) for the January 6, 1977 moderate earthquake with $m_b = 5.2$. This suggested that the location of the volcano in the analyzed cases might be in the compressional zones of the earthquakes. The activity of Nyiragongo volcano triggered by tectonic earthquake is not yet clearly established for the neighboring volcano Nyamulagira. Probably this interaction between the tectonic earthquakes in the Western Rift and the volcanic activity is related to the condition of Nyiragongo characterized by the lava lake in the crater directly connected to a dip magma reservoir through a conduit. In the other condition the presence of dip magma reservoir with a conduit connecting to the crater bottom which is considered as a zone of weakness.

In conclusion, It is worthy to notice that the Nyiragongo volcano is now in a very active stage characterized by the presence of a lava lake inside its crater. It is clearly established that the tectonic earthquakes occurring within the Western Rift at a certain distance, including those within the Virunga Region have a real impact on the volcanic activity of Nyiragongo.

The monitoring of Nyiragongo volcanic activity as well as a good knowledge of the seismic activity in the Western Rift should be considered together as an important working tool.

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