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Observation of the Nyiragongo and Nyamulagira Volcanoes Seismic Activity for the Period from 2011 to 2016

Pascal Matamba[a*], Didier Namogo[b], Delphin Assani[c], Albert kyambikwa[d]

[a,b,c,d]*Goma Volcano Observatory, Goma, DRCongo*
[a]*Email: 1234500pamamu@gmail.com*

Abstract

The Nyiragongo and Nyamulagira volcanoes are two neighboring volcanoes located in the western part of the Virunga volcanic chain and have remained the only active volcanoes of this chain for several decades. The seismic activity at these two volcanoes was evaluated for the period from 2011 to 2016 in order to observe the chronology of seismic events related to volcanic activity that occurs when these volcanoes present a particular specific states. Using softwares of seismic signal processing such as SWAM and SEISAN, and field observations, we found five events during this time period: (1) the eruption of the Nyamulagira volcano in November 2011, (2) the magmatic intrusion at Nyamulagira in April 2014, (3) the appearance of a lava lake at Nyamulagira in June 2014, (4) the appearance of a small eruptive vent in the Nyiragongo crater in February 2016 and (5) the magmatic intrusion at Nyiragongo in November 2016. From this observed chronology, it has been revealed that the seismic activity during the lava lake period is relatively low compared to that observed in the period without lava lake.

KeyWords: Nyiragongo and Nyamulagira volcanoes; seismic activity; chronology of events; lava lake; magmatic intrusion.

1. Introduction

The Nyiragongo and Nyamulagira volcanoes are two active volcanoes of the Virunga chain, located directly north of Lake Kivu.

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* Corresponding author.

Nyiragongo is specifically characterized by eruptions that produce lava flows composed of alkaline rocks less saturated with silica such as melinite-nephelinite, pyroxene-nephelinite, leucite-nephelinite, leucites and leucite-tephrites which are products that differ from the compositions of other volcanoes of the Virunga chain [1], [2], [3]. Other less abundant Nyiragongo rocks exposed in lowlands are Olivine-melilitite, Ankaratrite-basanitic, picrite and Alkaline Olivine Basalt [4]. Nyiragongo has a permanent lava lake; which directly shows the danger to the surrounding cities. The known eruptions of Nyiragongo are those of January 1977 and January 2002. Both eruptions produced lava flows that invaded slopes on the southern flank of the volcano. The 1977 eruption stopped at a hundred meters from the Goma International Airport and the 2002 ones, destroyed more than 13% of the city of Goma, and a large part of Lake Kivu [4]. About Nyamulagira, it is a shield volcano with an elevation of 3056 m of altitude and 1593 m above Lake Kivu. The position of the volcano follows the NW-SW and NW trend of the African rift system. The Nyamulagira volcano is characterized by frequent Hawaiian-type eruptions and highly potassic lavas [5]. An active lava lake persisted in its summit crater between 1921 and 1938 [6]. Most of the eruptions, with the exception of the 1938 summit, occur on the flanks of the volcano. The most recent of these flank eruptions occurred on January 27, 2000, February 5, 2001, July 25, 2002, May 8, 2004 and November 27, 2006 [7]. And more recently on November 06, 2011 and in June 2014, an Intercraterial eruption or lava lake was been observed [6].

2. Data acquisition equipment

The data used in this paper come from the Goma Volcano Observatory database, which includes a range of photoes from scientists' fieldwork and a seismic network for observations of seismic activity. Regarding the seismographic data, the seismograms used were provided by the seismographic network of the Goma Volcano Observatory (GVO). The observation network consists of eight analogue stations: Katale (KTL), Luboga (LBG), Kunene (KNN), Rusayo (RSY), Kibumba (KBB), Goma (OVG), Kibati (KBT) and Bulengo (BLG) installed since 2003, one year after the Nyiragongo eruption of January 2002. Each analog station is equipped with a Kinemetric SS1 Vertical Seismometer (To = 1 sec), PMK-noVKtsujima connected to a PS2 portable recorder. Currently there is a digital network consisting of Broadband 60s and 120s Seismometers, each seismometer is installed in each of the stations where analogue seismometers reside since 2003. Since 2014, this new network has been expanded far from the volcanic field and consisted of 14 stations. The data used here come from only 8 stations located in the volcanic field of Virunga for the monitoring of volcanoes.

3. Methodology

Waveforms from the GVO network were manually digitized and analyzed using seismic analysis programs. Observations were made on analog data and digital data. Earthquake counting was done manually on analogue seismograms considering waveform based identification using softwares: [8], [9].
To locate the earthquakes, the arrival times of the P and S waves were manually picked, filtered (0.5-15 Hz) on the vertical and horizontal components respectively. Phase P arrival times were assigned to quality factors of 0, 1, 2 or 3 based on estimates of measurement errors of 0.05s, 0.1s, 0.15s and 0.3s, respectively. S-wave quality factors of 0, 1, 2 and 3 were assigned to arrivals with measurement errors estimated at 0.1s, 0.175s, 0.25s and 0.3s, respectively. The velocity structure used for the location processing is from reference [10]. Only

earthquakes recorded at 4 or more stations and with 4 or more P and / or S arrival time readings were used for the location. To reduce the errors of uncertainty in the reading and phase velocity model, we considered only epicenters with a standard error in latitude and longitude less than 5 km and a RMS (root mean square) of 0.7s. It has therefore been revealed that the maximum accuracy of the focal depth is obtained for erz = 5 km.

4. Chronology of events at Nyiragongo and Nyamulagira volcanoes from 2011 to 2016

During the period from 2011 to 2016, the exploitation of the database of the GVO, shows 5 significant events that were observed:

- The eruption of the Nyamulagira volcano of November 06, 2011,
- The April 2014 volcanic earthquake swarm, which was been interpreted as a magmatic intrusion on the Nyamulagira volcano,
- The appearance of a lava lake at Nyamulagira volcano in June 2014
- The opening of a small eruptive vent at Nyiragongo volcano in February 2016,
- The swarm of volcanic earthquakes in November 2016, which also was been interpreted as a magmatic intrusion at Nyiragongo volcano.

4.1. The November 06, 2011 eruption of Nyamulagira volcano

This eruption was characterized by precursory signs including a swarm of earthquakes composed exclusively of Hybrid earthquakes, volcano-tectonic earthquakes and long period earthquakes.

Volcanic tremors were also observed before the eruption, but it was during the eruption that their magnitude was more remarkable.

The swarm in question had lasted 4 days from 02 to 06 November 2011.

The observation of this swarm also meant that there was a magmatic intrusion that was ongoing.

The location of the swarm gave an idea of the location and depth of the dyke that was taking place.

The observed seismic events were more concentrated in the northeastern part of the Nyamulagira central crater and, during the eruption, the eruptive cone came out about 3 km from the central cone in the north-eastern part of it.

On November 06, 2011 around 5 :30 pm (U.T), the eruption began.

It produced lava flows that were oriented in the North-East direction, invade the Virunga Park and covering

several hectares of surface by destroying vegetation and animals at their passage.

Figure 1: The November 6, 2011 Nyamulagira eruption : view from the Goma city.

4.2. The magma intrusion of April 2014 at Nyamulagira volcano

This intrusion was also characterized by a swarm of volcanic earthquakes but this time the earthquakes that prevailed were long Period earthquakes and Hybrid earthquakes. The swarm was again located in the northeastern part of the Nyamulagira crater.

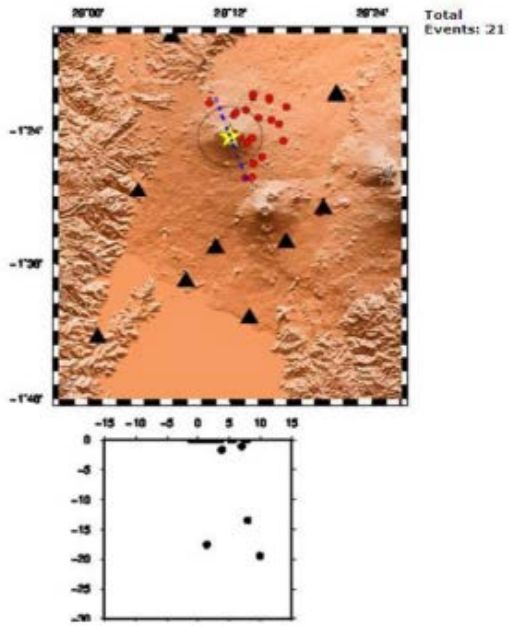

Figure 2: The location Map of the april 7-9, 2014 Swarm at Nyamulagira volcano. All the events are located in the North-Eastern part of the volcano.

4.3. Apparition of the Lava Lake in June 2014 at Nyamulagira volcano

From 1921 to 1938, a lava lake was active in this volcano and ended with a very large eruption that lasted 2 years, from 1938 to 1940. After this eruption, lava flows had descended to the south of the volcano devastating the Virunga Park until reaching the city of Sake and Lake Kivu[9].

Since that time, Nyamulagira has remained a volcano with a dynamic activity of eruptions preceded by seismic swarms and no lava lake was observed until 2014. From 07 to 09 April 2014, a swarm of volcanic earthquakes was observed at Nyamulagira volcano. and located in the northeastern part of this volcano. This swarm was interpreted as the precursor, the weakening element of the rocks, which eventually resulted in the formation of a lava lake at Nyamulagira in June 2014. In the night of 21-22 In June 2014, 6 hybrid earthquakes were recorded by the GVO seismographic network and these earthquakes, which are still known as the breakout earthquake were interpreted as the events that completely broke the rocks and caused the opening crater. On 03 July 2016, the NASA (National Aeronautics and Space Administration) published on its official website, the appearance of a new lava lake at Nyamulagira volcano.

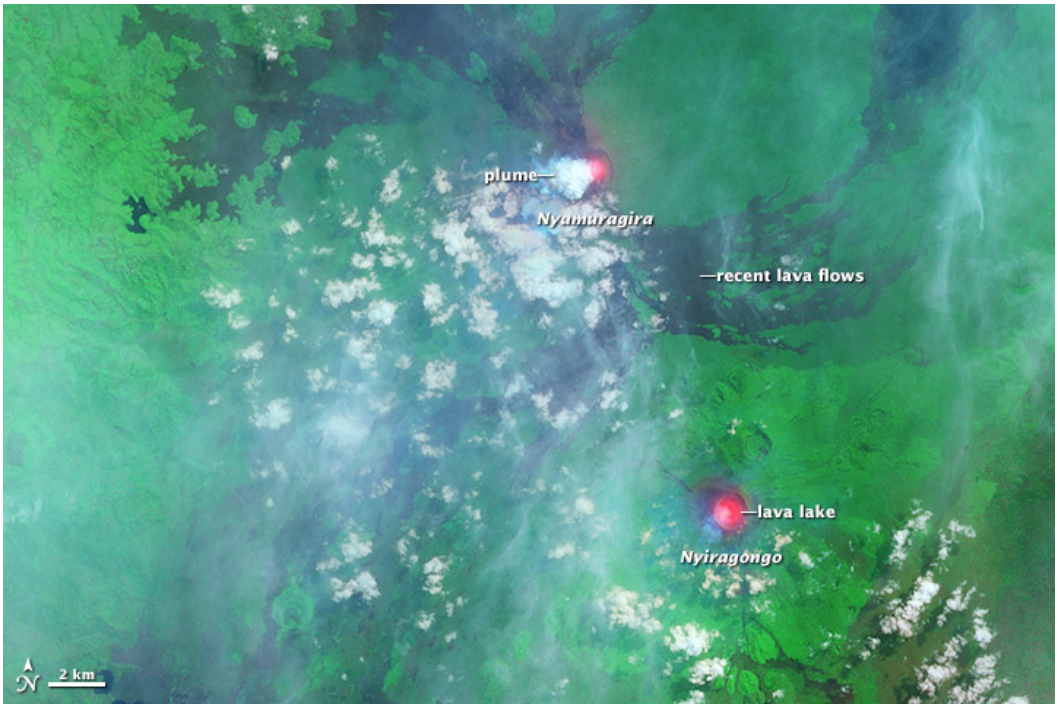

Figure 3: Apparition of the new lava lake at Nyamulagira volcano from June 22, 2014. Source: Reference [11]

The lava lake appeared in the northeastern part of the crater and remained permanent until the beginning of year 2017.

4.4. Apparition of an eruptive vent in February 2016 at Nyiragongo volcano

On February 28, 2016, an eruptive vent appears in the Nyiragongo crater. The scientists of the GVO have trouble understanding the phenomenon and are looking to expect a possible eruption because this is the first

time this volcano displays such behavior since its eruption in 2002.

Figure 4: Small eruptive vent born from the Eastern part in the Nyiragongo crater Source: GVO, 2017[13]

Figure 5: The new eruptive vent in the Nyiragongo crater: The activity of the central crater and the one of the new vent are shown on the photo. Source: GVO, 2017 [13]

4.5. Magmatic intrusion in November 2016 at Nyiragongo Volcano

Since its eruption in January 2002, the Nyiragongo volcano has appeared with very low seismic activity (see various reports of the Department of Seismology of the OVG from 2003 to January 2016), given the presence of

its permanent lava lake. Since this eruption until the beginning of the year 2016, the Department of Seismology did not observe long-lived Swarm Periods at this volcano. All the swarms that were observed in the Virunga volcanic field were located at Nyamulagira. In February 2016, the intensity of the Nyiragongo seismic events increased in comparison with the past period, but they are not yet strong. On February 28, 2016, a small swarm of about 30 long-lived earthquakes was observed in the eastern part of Nyiragongo volcano, which was followed by a small eruptive vent in this volcano. The vent has persisted until now, from this time, the seismic activity came down.

On November 12, 2016, a seismic swarm is again observed at this volcano. This time with a hundred of volcanic earthquakes.

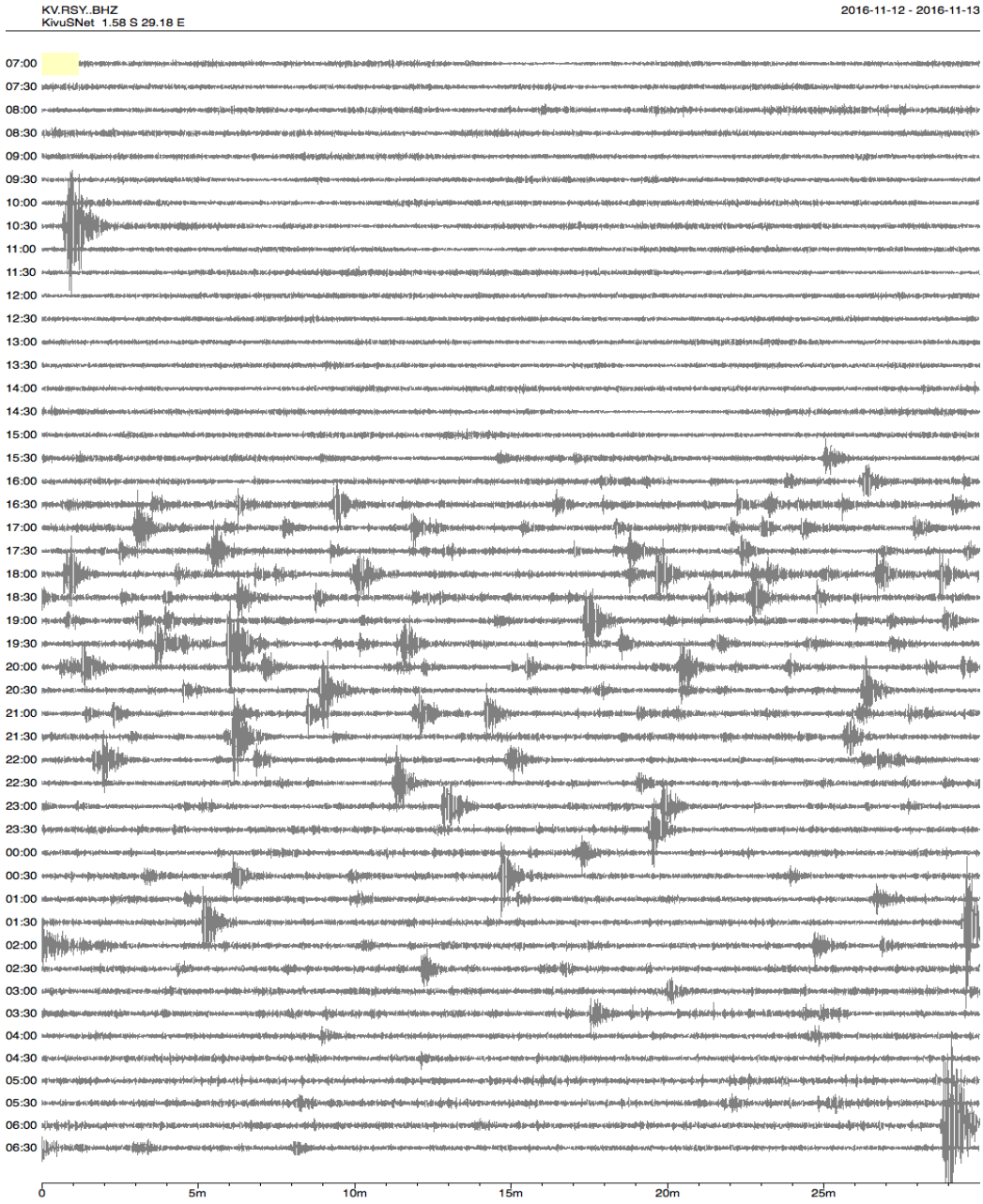

Figure 6: Helicorder of the 12-13 November 2016 records. Almost all the observed earthquakes are hybrid earthquakes

The earthquakes were located in the northeastern part of Nyiragongo volcano and their depth shows some migration from deep to shallow surface depth. It is at this point where the swarm is located, that the previously observed vent had developed. These observations reflect a magmatic intrusion in the northeastern part of Nyiragongo.

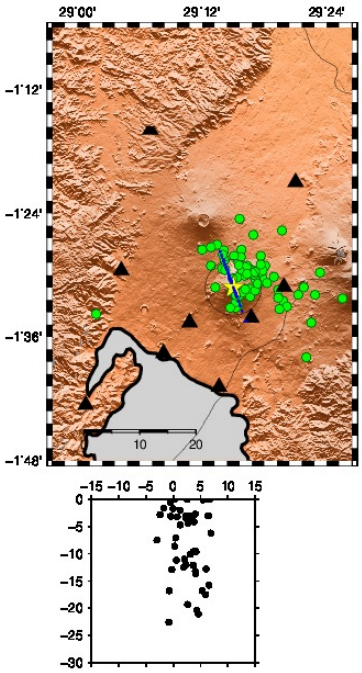

Figure 7: Location Map of the volcanic earthquakes (Long Period, Hybrid and Volcano-Tectonic) observed from the 12 November 2016 swarm. Source: GVO, November 2016 Report. [12]

5. Discussion

5.1. Variation of Nyiragongo and Nyamulagira volcanoes over time from 2011 to 2016

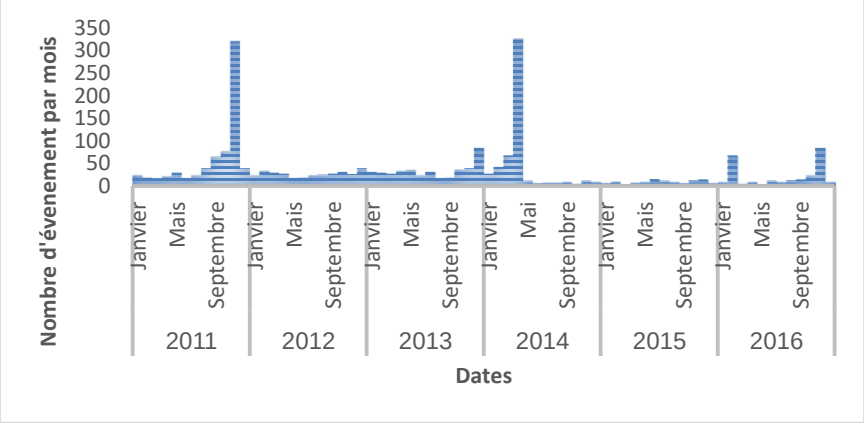

Figure 8: Variation of the number of volcanic earthquakes observed on Nyiragongo and Nyamulagira volcanoes from January 2011 until December 2016.

In view of this figure, we notice that the swarms of November 2011 and April 2014 show very high peaks and other average activities like the small swarm of December 2013, the appearance of the small vent in the crater of Nyiragongo in February 2016 and finally the small swarm at Nyiragongo in November 2016, mark average peaks. We therefore understand that despite the awakening of Nyiragongo seismic activity, Nyamulagira appears more seismically active than this one.

5.2. Activity relationship of lava lake to the two volcanoes and the seismic activity

The seismic activity at the Nyiragongo and Nyamulagira volcanoes for the period from 2011 to 2016 can be summarized in 3 episodes as follow: (1) before the appearance of the lava lake at Nyamulagira, (2) the lava lake period at Nyamulagira and finally (3) the period of strong activity at Nyiragongo.

- Before the appearance of the lava lake at Nyamulagira: Only the Nyiragongo had a permanent lava lake, almost all the long-term seismicity was located at Nyamulagira. Seismic activity is observed at an average of 20 earthquakes per day with a regularity of earthquake swarms.

- Period of lava lake at Nyamulagira: from June 22, 2014, date of the appearance of the lava lake at Nyamulagira, the seismic activity becomes very low at the average of 8 earthquakes per day.
- Period of strong activity at Nyiragongo: Since its eruption of 2002, the Nyiragongo had never awakened considerably its seismic activity. In February 2016, disturbances occur in its crater and a small eruptive vent appears. The appearance of this small vent was accompanied by seismicity, not very remarkable, volcanic earthquakes. From then the volcano remained with a pronounced seismic activity.

Shortly, we understand that the activity of lava lakes at Nyiragongo and Nyamulagira volcanoes is characterized by weak seismic activity except in case of a magmatic intrusion, where intense seismicity is still observed.

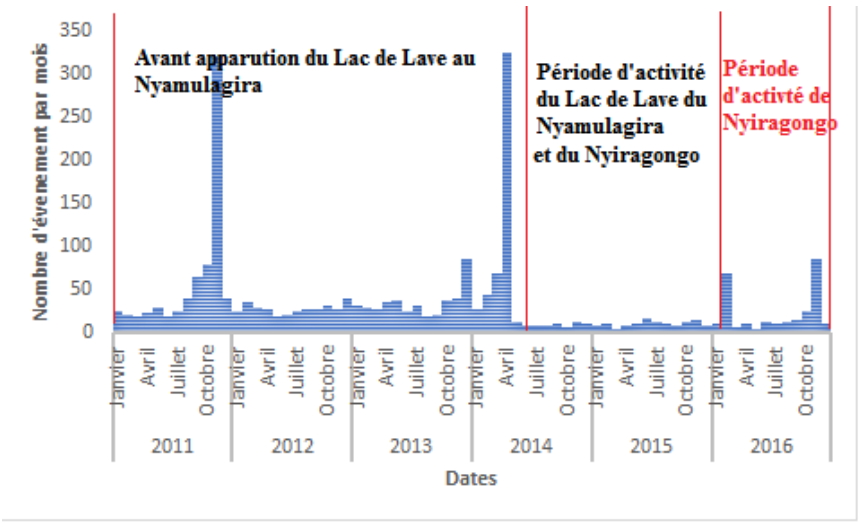

Figure 9: Intermittence of the seismic activity between the priods of lava lake activity and the periods without lava lake activity.

6. Conclusion

The seismic activity at Nyiragongo and Nyamulagira volcanoes was observed for the period from 2011 to 2016. Five remarkable events were observed including the eruption of the Nyamulagira volcano in November 2011, the magmatic intrusion at Nyamulagira in April 2014, the appearance of a lava lake at Nyamulagira in June 2014, the appearance of a small eruptive vent at Nyiragongo in February 2016 and finally the magmatic intrusion at Nyiragongo in November 2016. This chronology of seismic activity at these two volcanoes during a short period like this one, shows how much these volcanoes are very active with very important features. During the lava lake period at both volcanoes, the seismic activity in long period earthquakes is very reduced and the average of earthquakes daily observed does not exceed 8 earthquakes, while during the lava lake period at only one of these volcanoes, seismic activity is observed on the rise and the daily average of long period earthquakes is between 20 and 30. However, during the period of the permanent lava lakes at the two volcanoes, the seismic activity generally becomes intense in case of a magmatic intrusion at one of these volcanoes.

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