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雑誌名	The science reports of the Tohoku University. Fifth series, Tohoku geophysical journal
巻	29
号	1
ページ	41-56
発行年	1982-06
URL	http://hdl.handle.net/10097/45295

Tôhoku Geophys. Journ. (Sci. Rep. Tôhoku Univ., Ser. 5), Vol. 29, No. 1, pp. 41–56, 1982.

Observations of Volcanic Earthquakes and Tremors at Volcanoes Nyiragongo and Nyamuragira in the Western Rift Valley of Africa

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(Received May 6, 1982)

Abstract: The active volcanoes Nyamuragira and Nyiragongo in the Western Rift Valley of Africa erupted almost stimultaneously on December 23, 1976 and January 10, 1977, respectively. This paper presents the seismicity of volcanic and tectonic earthquakes in and around the volcanoes and the temporal variations of volcanic tremors, based on the seismograms recorded at the permanent station Lwiro (LWI) and at four temporary seismic stations installed near the volcanoes in 1977. The tectonic earthquakes are located in Lake Kivu and at the southern flank of Nyiragongo. Their epicentral distribution shows linear feature along the rift axis. They are also characterized by the shallow focal depths between 3 and 10 km. On the other hand, the volcanic earthquakes are located at the northern part of Nyiragongo and their focal depths are between 15 and 40 km. The composite focal mechanism solution for the volcanic events reveals the normal faulting with the tension axis nearly perpendicular to the strike of the rift axis in this region. On January 6, 1977, the shallow tectonic earthquake with $m_b=5.2$ took place in the rift valley at about 130 km south of the volcano Nyiragongo. The seismograms obtained at LWI clearly indicate that the volcanic tremors with large amplitudes suddenly appeared after the occurrence of this shock and continued about four days until the volcano Nyiragongo began to erupt. The observational evidences that the temporal proximity between the occurrence of earthquake on January 6 and the eruption of Nyiragongo on January 10, the precursary appearance of volcanic tremors and the focal mechanism solution of the earthquake suggest that the eruptive activity of Nyiragongo was triggered by the compressional stress field induced by this shock.

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1. Introduction

Volcanoes Nyiragongo and Nyamuragira belong to the Virunga volcano group located in the central part of the Western Rift Valley of Africa. This group consists of three subgroups of eight major volcanoes; the eastern (Muhavura, Gahinga and Sabinio), the central (Visoke, Karishimbi and Mikeno) and the western (Nyiragongo and Nyamuragira) subgroups. The volcanoes in the western subgroup are most active at present. Although the distance between Nyiragongo and Nyamuragira is only 13 km, some different characteristics have been noted in their rock types and volcanic activities and their magma reservoirs are considered to be located independently (*e.g.* Holmes, 1965).

Nyiragongo had a lava lake in the summit crater (pit) which appeared probably in 1928 (Tazieff, 1977). Since then, the elevation of the lava surface has risen gradually with some fluctuated movements. It reached the first terrace, which apparently represents earlier stages in the development of the lava lake, on March, 1972 (Pouclet, 1973 a) and on December, 1976, one month before the eruption in 1977. The eruption of

Table 1. History of eruption of Nyamuragira.

Date	Place	Lat. (S)	Long. (E)	Activity	Ref. No.
1901				Eruption at NE of Nyamuragira. Lava flow reached Kakomero.	1
1904	Nahimbi	1°31′	29°07′	Eruption near Sake. Lava flow reached Lake Kivu.	1
1905 July	Kanamaharagi	1°24′	29°18′	Sporadic eruption at east of Nyamuragira.	1
1912 Dec. 4	Rumoka	1°35′	29°07′	Eruption continued 6 weeks. Lava flow reached Lake Kivu.	1
1920	Lake Kivu			Undersea eruption in Lake Kivu. Nyamuragira crater was fulled with lava in this period.	1
1938 Jan. 28	Tshambene	1°26′	29°10′	Greatest flank eruption. Continued until June. 1940. Total volume of lava is $4.4 \times 10^8\,m^3$. Three craters.	1
1948 Mar. 1	Gituro	1°32′	29°09′	Two crater along fissure of 5 km. Activity continued until July.	1
	Muhuboli	1°33′	29°07′	Lava flow reached Lake Kivu. Activity continued until April.	1
1951 Nov. 16	Shabubembe	1°23′	29°12′	NW flank of Nyamuragira. Ndakaza cone was built. Activity continued until Jan. 1952.	1
1954 Feb. 20	Mihaga	1°28′	29°14′	Between Nyamuragira and Nyiragongo.	1
1956		1°24′	29°12′	In caldera of Nyamuragira.	2
1957		1°24′	29°12′	In caldera and SE of Nyamuragira.	2
1958 Aug. 7	Kitzimbanyi	1°16′	29°13′	13 km north of Nyamuragira. Activity continued until Nov. 11.	3
1967 Apl. 23	Gakararanga	1°19′	29°13′	5 km north of Nyamuragria.	4
1971 Mar. 24	Rugarama	1°23′	29°09′	NW of Nyamuragira. Activity continued until May. Total volume of lava and ejecta is $9 \times 10^7\,m^3$.	5, 6

Reference (1); Cahen (1954), (2); Thonnard *et al.* (1965), (3); Berg and Janssen (1959), (4); Poulcet and Villeneuve (1972), (5); Pouclet (1973b), (6); Bram (1972).

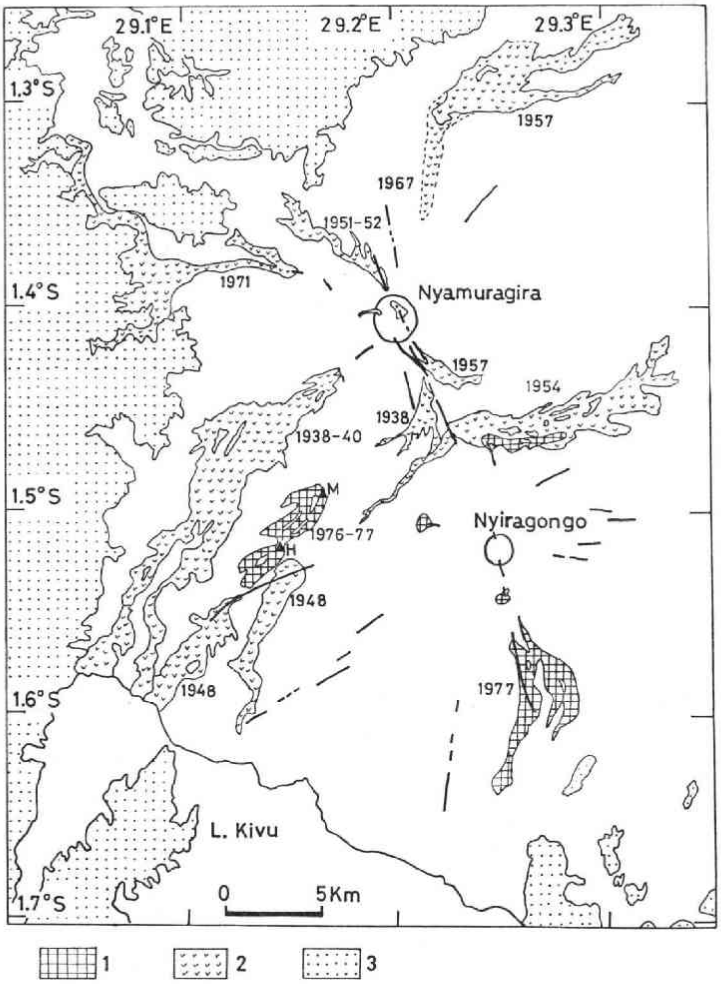


Fig. 1. Lava flows in the volcanic region of Nyiragongo and Nyamuragira. 1: The most recent lava flows in 1976 and 1977. Solid triangles with marks M and H indicate the spatter cone Murara and Harakandi, respectively. No cone in the lava flows from Nyiragongo. 2: Recent lava flows from Nyamuragira. Numerals attached indicate the year of eruption. 3: Precambrian rocks. Solid and broken lines show surface trace of fissure.

Nyiragongo occurred in January 10, 1977, which was 18 days after the eruption of Nyamuragira as stated later. Several new fissures with the direction of about S10°E were observed at the north-western (Baruta side) and the south-eastern (Shaheru side) flanks of the volcano. The lava of the order of 10^7 m^3 in total volume (Tazieff, 1977) flowed out from the new fissures. The eruption itself terminated within one hour, probably within 20 minutes (Kajuga, Conservateur du Parc National des Virunga, Personal communication, 1977). The lava lake persisted in the summit crater since 1928 disappeared after this eruption. Phenomenological description of this eruption is given in detail by Tazieff (1977), although there are some incorrect descriptions in mapping the lava flow and fissures in Fig. 2 in his paper.

Nyamuragira had also the lava lake until it disappeared during the 1938 eruption. Since then, the recent eruptions occurred at the flank of Nyamuragira or in the crater at intervals of several years as listed in Table 1. Each eruption was accompanied by the lava flow and formation of spatter conce. Hereafter the name of cone is given in parentheses after the word Nyamuragira in this paper. Fig. 1 demonstrates the recent lava flows, which are compiled from the maps by Thonnard *et al.* (1965), Pouclet (1973b) and the field sketch of our surveys. An eruption took place at about 10 km SSW of Nyamuragira on December 23, 1976. This activity continued for about three months and resulted in the creation of two spatter cones, called Murara and Harakandi and lava flow (see Fig. 1). During this eruptive activity, Nyiragongo erupted as stated before. This simultaneous eruptions of the neighbour volcanoes give us a paticular interest in the eruption mechanisms, which may be in special reference to the rifting phenomenon.

Seismological observation of earthquakes occurring in the Western Rift Valley has been carried out by L'Institut de Recherche Scientifique du Zaire (I.R.S.), formarly L'Institut pour la Recherche Scientifique en Afrique Centrale (IRSAC). Three seislomogical stations LWI (Lwiro), BTR (Butare) and RUM (Rumangabo) have been operated near the volcanic region. The last station RUM was the nearest to the volcanoes, but it was closed in 1965. The Benioff short period seismographs ($T_0=1$ sec, $T_g=0.25$ sec, Mag.=ca. 100 k) at LWI, which is located at about 100 km south of the volcanoes, recorded many earthquakes having low frequency waves with the period of 0.5–1.5 sec and small *P*- and obscure *S*-phases. Their *S-P* times were about 13 sec at LWI. Their hypocenters were located in the region around volcanoes Nyiragongo and

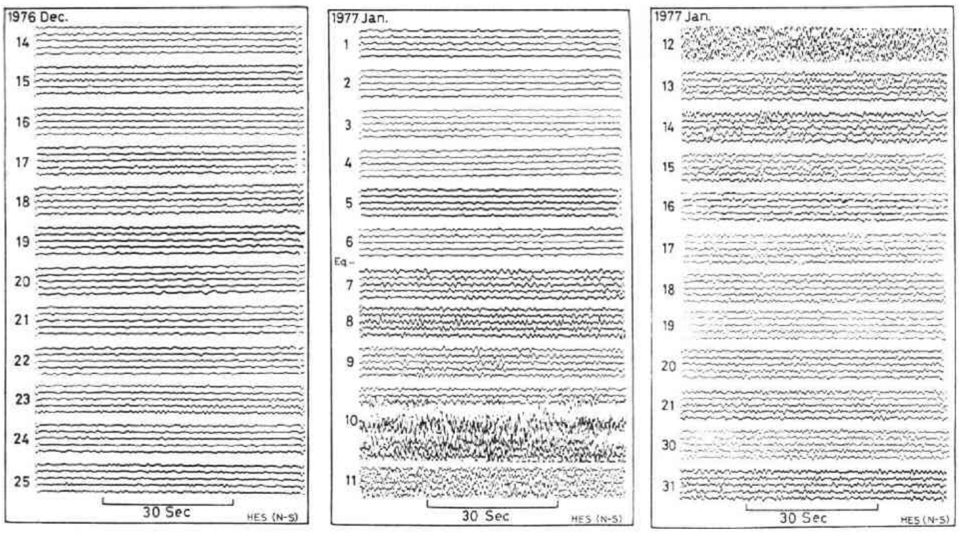


Fig. 2(a). Seismogram of HES (N-S component) at LWI. No significant increases in amplitudes of volcanic tremors are recognized at the Nyamuragira (Murara) eruption on December 23, 1976. The distinct increases in amplitudes are observed just after the occurrence of earthquake ($m_b=5.2$) on January 6, 1977 and this state continued up to the eruption of Nyiragongo on January 10, 1977, when the high frequency and large amplitudes of volcanic tremors are noticed.

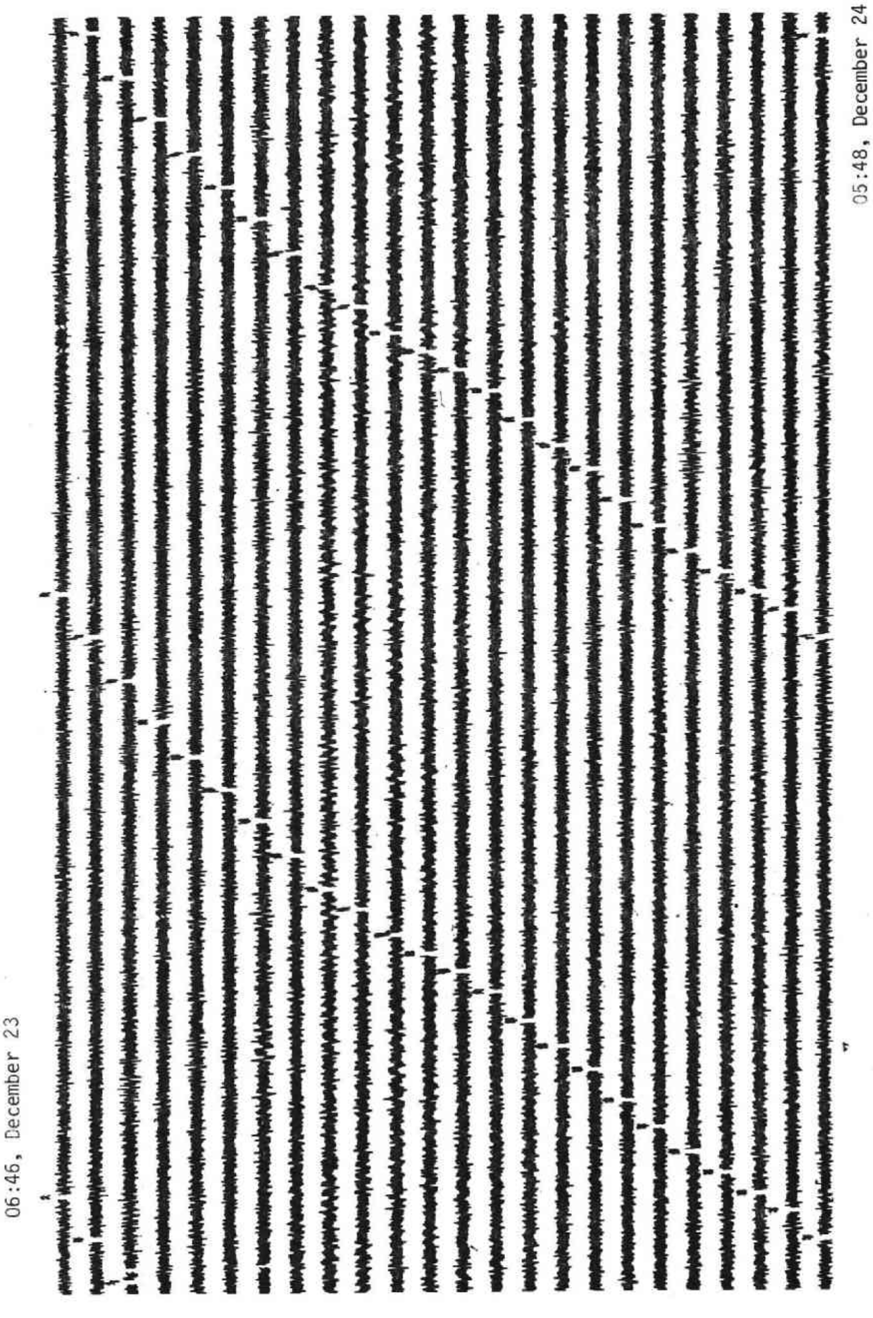


Fig. 2(b). Sample of record of the vertical component of the Benioff short period seismometer obtained at LWI during the period December 23 and 24, 1976. The marks shown are minute mark. The variations in amplitude and period of tremors are not conspicuous on these days.

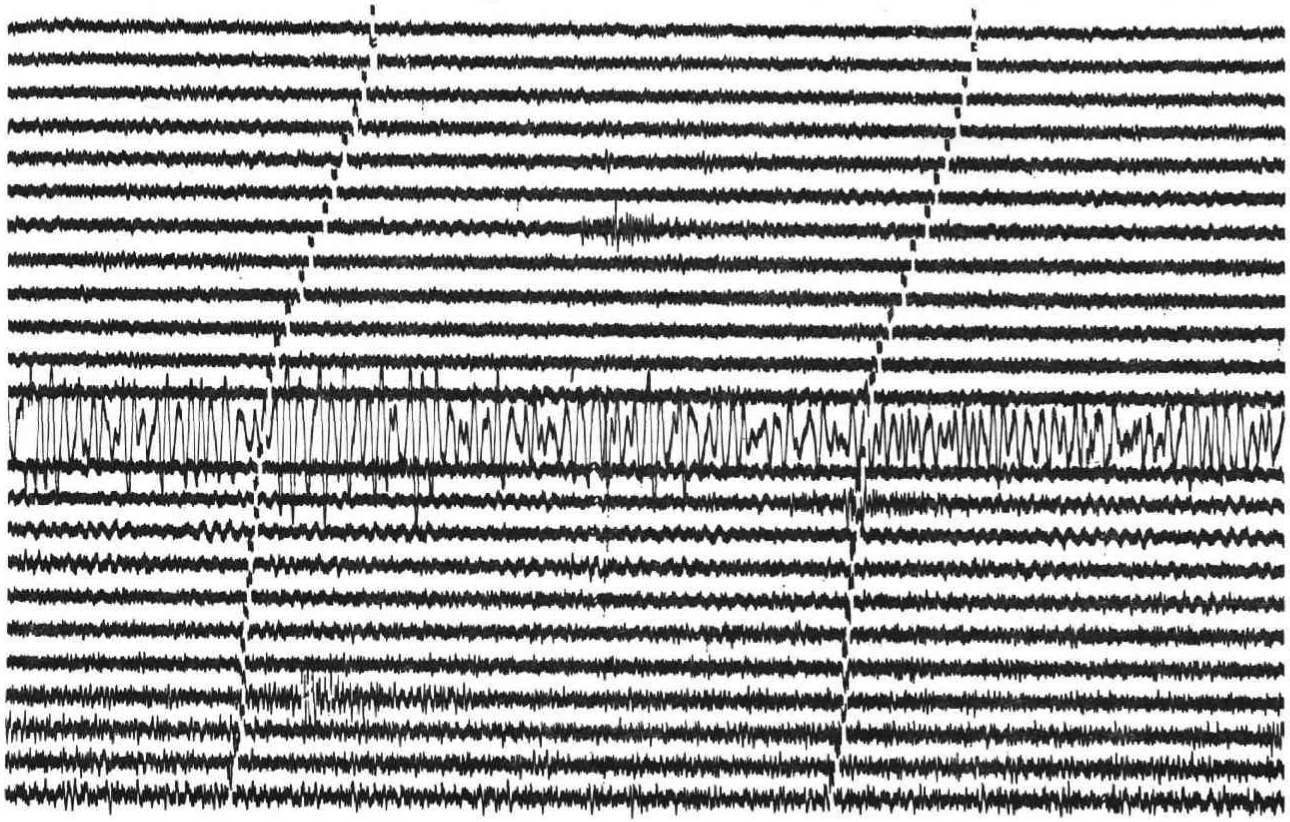


Fig. 2(c). The same for (b) during the period January 6 and 7, 1977. Waves with large amplitudes in the middle part is the coda of earthquake of January 6, 18 h 33 m 42.3 s. After appearance of this event, the characteristic variations in amplitude and period of the tremors are distinctly recognized; waves with low-frequency component appeared at the beginning followed by those with high-frequency component.

Nyamuragira from the *S-P* times at the three stations. The seismograms obtained at RUM and BTR, which are located at about 20 km north-east of Nyiragongo and at 120 km south-east, respectively, show the same features as those at LWI. These same characteristics at the independent stations with different epicentral distances and azimuths strongly suggest that the low frequency characteristics of these earthquakes reflect the source condition of shocks but not the path effect. The earthquakes with the features mentioned above have been called "volcanic earthquakes" at LWI.

Berg and Janssen (1960) and Bram (1972) studied the seismic activities of the volcanic earthquakes at the time of eruption of Nyamuragira (Kitzimbani) in 1958 and Nyamuragira (Rugarama) in 1971 using the data of IRS stations. Seismological studies using the temporary stations near the volcanoes have been done by a few researchers. Shimozuru and Berg (1961) observed amplitudes and periods of the volcanic tremors at the terrace in the summit crater of Nyiragongo in 1959. They found that the predominant periods of the volcanic tremors were between 0.1 and 0.5 sec and made a discussion with special reference to the tremor's origin, based on the longitudinal vibration of a viscous lava column in the vertical conduit. Recently, Hamaguchi (1978) studied the seismicity in the volcanic region using the data from three temporary stations installed around the volcanoes and tha data at LWI when the elevation of lava lake of Nyiragongo reached to the first terrace in 1972. He demonstrated that the tectonic earthquakes clustered only in a small area at the north-western flank of Nyiragongo and that the volcanic earthquakes with low-frequency waves were distributed along the fissures across the Nyamuragira crater.

Despite many volcanological interests exhibited by these two active volcanoes, geophysical investigations are still rather poor. Therefore, geodetic and geomagnetic surveys as well as seismological observations were carried out in this volcanic region in the period of August to September, 1977, five months after the end of eruptive activities. This paper presents the results of seismological studies and discusses some features of seismicity, earthquake generating stress and correlation between major earthquake and eruption. The results of geomagnetic and geodetic surveys were already reported by Mishina *et al.* (1981) and Kasahara *et al.* (1982), respectively.

2. Volcanic Tremors and Seismic Activity before and after the Eruptions

Variations of amplitudes and periods of the volcanic tremors were observed to be correlated with the eruption activities. The portions of seismogram of HES (T_0=1 sec, T_g=1 sec) obtained at LWI are shown chronologically for the period between December 14, 1976 and January 31, 1977 in Fig. 2(a). Sample records of the Benioff seismometer at LWI are also shown for December 23, 1976 and January 6, 1977 in Figs. 2(b) and (c), respectively. It is noticed from these records that the first eruption of Nyamuragira (Murara and Harakandi) on December 23 did not affect on amplitude and period of tremors on December 23. However, it is clearly shown in the figures that amplitudes of tremors obviously increased by about twice after the occurrence of shallow tectonic earthquake with m_b=5.2 on January 6, 1977. This event took place at 2.54°S, 21.66°E and 13 km in depth (ISC) near the rift axis, which is about 130 km south of Nyiragongo. This was the greatest event among those occurred in the graben near the volcanic region since 1953, when the seismic observation by IRS started. This tremors with large amplitudes continued for about four days until Nyiragongo began to erupt on January 10, when the definite increase in amplitudes of short period volcanic tremors was observed as well.

Information obtained by the inquiry of local residents near Nyiragongo indicates that many small felt shocks, which were not registered at LWI, had occurred for three or four days before the eruption of Nyiragongo. These two facts suggest that the precursory shallow seismic activity near Nyiragongo began on January 6 or 7 in accordance with the initiation of volcanic tremors.

3. Temporary Seismic Observation

3.1 *Instrumentation*

Four temporary seismic stations were installed at Luboga (LBG), Kakomero (KKM), Kunene (KNN) and Mont Goma (MTG) (Table 2 and Fig. 6). One vertical component seismometer with a period of one second was used at each station. Two

Table 2. Observation period and other references for stations.

Name and Code	Lat. (S)	Long. (E)	Foundation	Observation period (1977)	Eigen period & component of seismo-meter	Recorder
Mont Goma (MTG)	1°40.8′	29°13.5′	volcanic deposit	Aug. 18–Sept. 16	1.0 sec (V) 1.0 sec (H)	smoked paper 35 mm film
Kunene (KNN)	1°29.3′	29°04.4′	recent lava	Aug. 24–Sept. 15	1.0 sec (V)	smoked paper
Kakomero (KKM)	1°25.9′	29°19.5′	recent lava	Aug. 31–Sept. 15	1.0 sec (V)	smoked paper
Luboga (LBG)	1°15.5′	29°06.7′	precambrian rock	Aug. 24–Sept. 17	1.0 sec (V) 1.0 sec (H)	35 mm film

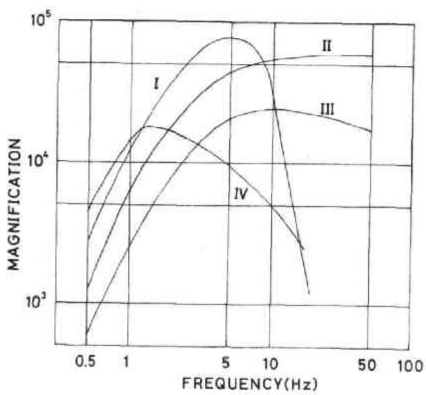


Fig. 3. Overall magnification curves for vertical component. I; KNN, II; KKM, III; MTG and IV; LBG.

horizontal component seismometers were also operated at MTG and LBG. Earthquakes were registered on smoked paper at KKM and KNN stations and on film at LBG. Both smoked paper and film were used at MTG. The overall magnification versus frequency is shown in Fig. 3. The maximum magnification is more than 5×10^4 at KKM and KNN. The seismometers at KNN and LBG do not have high magnifications in his frequency range because of the response of galvanometers used. A crystal-clock was used at each station to facilitate the precise determination of P-wave arrival times. The radio time marks from BBC (London) were put on the record once a day to calibrate the clock rate. Type of instruments, observation period and other references for each station are listed in Table 2.

3.2. *Type of earthquakes and their S-P times*

Two types of earthquakes were registered at these temporary stations. The first type has similar characteristics to ordinary local earthquakes having clear P- and S-phases and rather high frequency components. Most of the earthquakes of the first type have S-P times less than five seconds. It is clearly indicated that the S-P times of one to two seconds are most frequent at MTG, while those of four to five seconds are most frequent at LBG (Fig. 4). This suggests that active area of these events is closer to MTG, south of Nyiragongo, than to LBG, north of Nyamuragira.

The second type earthquakes have obscure P- and S- phases and little high frequency components. Their S-P times are larger than five seconds at all the temporary stations in general. These earthquakes had been frequently observed at the permanent station of LWI as well and called volcanic earthquakes as mentioned in the previous section. This type of events is apparently similar to that of the B-type volcanic earthquake, which was classified and named by Minakami (1960) for the volcanic earthquakes in Japan. The focal depths are, however, generally much deeper than those of the B-type events in Japan, as mentioned later. We will call temporarily the

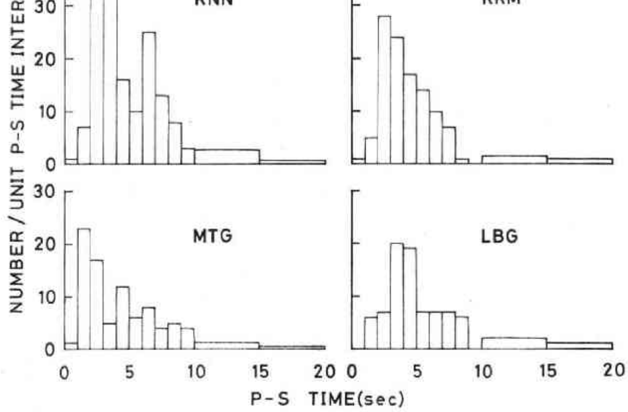


Fig. 4. Frequency distribution of S-P times at the four temporary stations.

first type shock a tectonic earthquake and the second a volcanic earthquake in the present paper according to the naming by IRS.

3.3. *Distribution of Hypocenters*

The locations of hypocenters of tectonic and volcanic earthquakes were obtained from the data at the temporary stations and LWI using the velocity model of crust (Fig. 5) derived from the results by Bonjer *et al.* (1970) and Bram (1975). In this model, the crust consists of two layers, each having a *P*-wave velocity varying continuously with depth. Forty five hypocenters were located for the earthquakes occurred in the central part of the Western Rift Valley including the volcanic region (Fig. 6(a)). It is clearly shown in the figure that the epicentral areas of the volcanic and tectonic

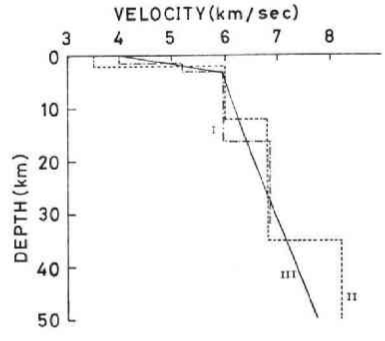
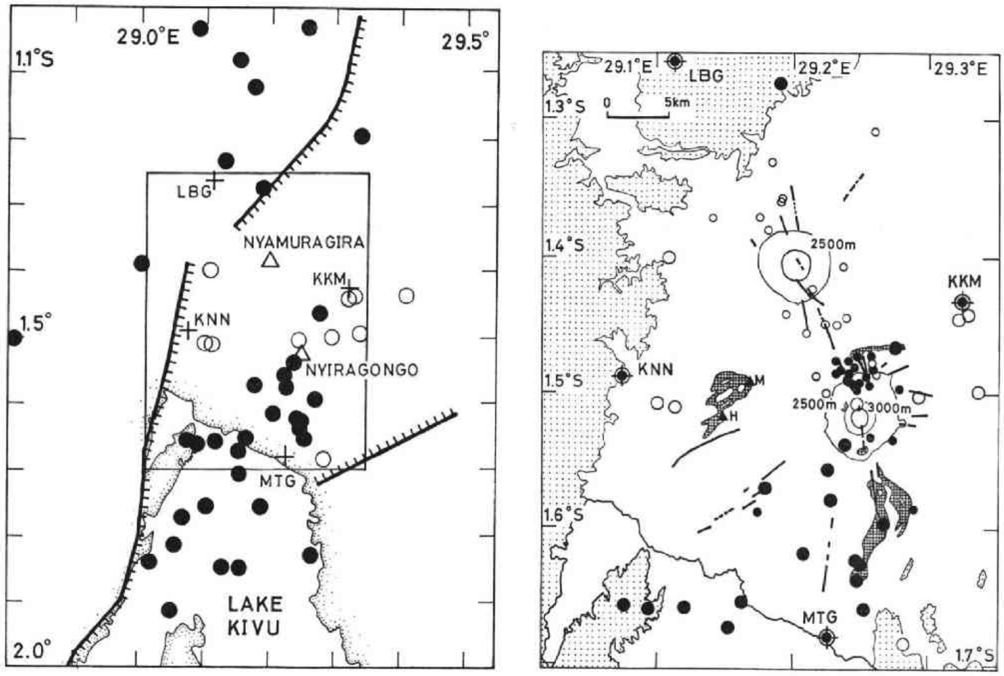


Fig. 5. *P*-wave velocity models of crust. Model I was presented by Bonjer *et al.* (1970), II by Bram (1975), and III is adopted in this analysis.

earthquakes do not overlap spatially. Most of the volcanic earthquakes clustered at the northern flank of Nyiragongo, whereas the tectonic events mainly occurred in the areas south of Nyiragongo and north of Nyamuragira. The earthquakes located north of Nyamuragira are out of the rift escarpment and may not be volcanic origin. The earthquake located south of Nyiragongo and off the coast of Lake Kivu are distributed along the rift axis and may be associated with the tectonic activity of the rift system. The northern end of epicentral distribution is terminated just at the summit of Nyiragongo (see Fig. 6(a)). The local seismicity monitored at LWI indicates that the northern part of Lake Kivu had been seismically inactive stage before the occurrence of Nyiragongo eruption in 1977. After the eruption, the increase in seismic activity along the rift axis was detected as mentioned already. These facts suggest the existence of a relationship between the eruptive activity of Nyiragongo and the seismic activity along the rift axis. It is worthy of special mention that no tectonic and volcanic earthquakes were located near the new spatter cones, Murara and Harakandi in the 1976 Nyamuragira eruption.

The epicentral distributions of volcanic and tectonic earthquakes observed in 1972 (Hamaguchi, 1978) show different featurs: The volcanic events occurred mainly along the fissures in NNW-SSE direction at the flank of Nyamuragira, whereas the



(a) (b)

Fig. 6(a). Distribution of epicenters in the central part of the Western Rift Valley for the period from August to September, 1977. Open circle indicates volcanic earthquakes with long-period components. Solid one does tectonic earthquakes. The epicenters in the small framework are shown in Fig. 6(b).

Fig. 6(b). Large open and solid circles indicate the epicenters of the volcanic and tectonic earthquakes in 1977, respectively and small ones do those in 1972 by Hamaguchi (1978).

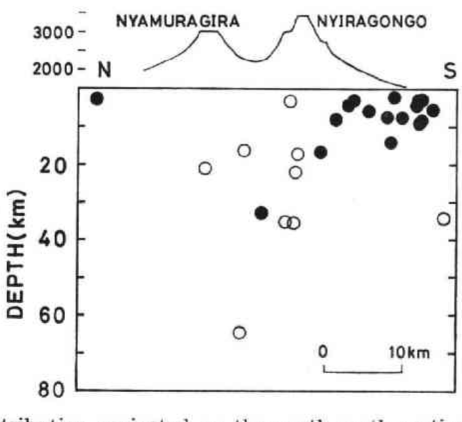


Fig. 7. Focal depth distribution projected on the north-south section. Open and solid circles indicate the volcanic and tectonic earthquakes in 1977, respectively.

tectonic ones occurred in a small area of the northern flnak of Nyiragongo (Fig. 6(b)). One of the most remarkable features in the epicentral distributions of tectonic earthquake obtained in 1972 and 1977 is that the activity is found only in the region covered by the lava flow from Nyiragongo but not in the region of Nyamuragira.

A characteristic difference between the volcanic and tectonic earthquakes is cleary recognized also in their focal depth distributions. Fig. 7 shows that most of volcanic earthquakes are located in the depth range of 15 to 40 kilometers, while most of the tectonic ones are between 3 and 10 kilometers. The concentration of volcanic earthquakes around the central volcanoes and their deep focal depths suggest that they are probably caused by a deep magmatic activity such as magma-hydraulic fracturing and/or jerky movement of magma through channels. On the other hand, the linear epicentral distribution and the shallow focal depth of tectonic earthquakes suggest that they are associated closely with the superficial tectonic phenomenon such as fissuring and/or faulting.

3.4. *Focal Mechanism*

Focal mechanisms of volcanic and tectonic earthquakes are invstigated by using the initial motions of *P*-waves. Composite mechanism solutions for the two types of earthquakes show that they have different mechanisms as shown in Fig. 8. The mechanism for the volcanic earthquakes is a normal faulting type with the tension axis nearly perpendicular to the strike of the rift system. The mechanism for the tectonic earthquakes is not so clear, partly owing to some uncertainty of focal depth and/or crustual structure. However, the mechanism is likely to be such as shown by dotted lines in Fig. 8, which indicates a reverse fault.

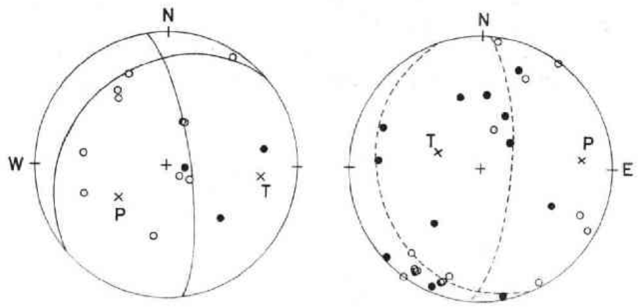


Fig. 8. Composite mechanism solutions projected on the upper hemisphere for two types of earthquakes. The right figure is the volcanic earthquakes and the left is the tectonic ones. The nodal lines for the tectonic ones are tentative.

4. Discussion and conclusion

The seismicity of the volcanic region of Nyiragongo and Nyamuragira in the Western Rift of the East African Rift System was studied in detail based on the data from the temporary seismic station network and those from LWI station. A general conclusion obtained is that the volcanic earthquakes, which are characterized by a substantially low frequency content, occurred in the region near the summits of Nyiragongo and Nyamuragira and had deeper focal depths than those of tectonic earthquakes. The frequency of focal depth of the volcanic earthquakes is predominant in the depth range between 15 and 40 km, though the number of located events is not sufficiently large. This depth range corresponds to the lower crustal layer with the P wave velocity of about 6.8 km/sec (see Fig. 5).

Under the active volcanoes Kilauea and Mauna Loa in Hawaii, two types of short- and long-period earthquakes are identified in the mantle underlying the island of Hawaii. The long-period earthquakes are characterized by lower frequency content of 2 to 5 Hz and followed by outbursts of tremor originating in the upper mantle (Koyanagi *et al.*, 1975; Ellsworth and Koyanagi, 1977). This characteristic feature is similar to those of volcanic earthquakes found in Nyiragongo and Nyamuragira, in spite of the difference in crustal structure, that is oceanic in Hawaii and continental in Africa. It is interesting that these long period earthquakes were similarly found in the volcanic activity at the basaltic volcano with low viscous lava such as Hawaii and Virunga volcanoes.

The frequency distribution of the long-period volcanic earthquakes before and after the eruptive episodes in 1976 and 1977 registered at LWI is shown in Fig. 9, which clearly indicates that there were two significant increases in number of volcanic earthquakes on December 11–12, 1976 and January 13–17, 1977. The former activity preceded twelve days to the surface outbreak of an eruption of Nyamuragira (Murara and Harakandi) and the latter followed immediatly after the Nyiragongo eruption. This suggests that these volcanic earthquakes have a close relationship with deep magmatic activity such as sudden magma ascent from deep source.

Extensive surface fissuring or faulting occurred on January 6 when Nyiragongo erupted. The main fissure was about 5 km long and 1 m wide and extended from near the south-eastern rim of Nyiragongo in S10°E direction (Fig. 1). The main epicentral

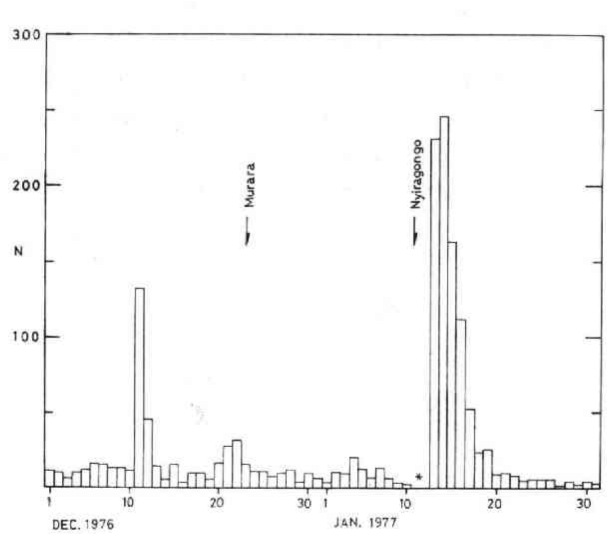


Fig. 9. Daily frequency distribution of the volcanic earthquakes with amplitude greater than 3 mm at LWI. Asterisk means no count of events due to the high activity of volcanic tremors. Arrows indicate the onset time of eruption of Nyamuragira (Murara) and Nyiragongo.

zone of the shallow tectonic earthquake extended from the summit of Nyiragongo to the Idjwi island in Lake Kivu in S 25°W direction. This orientation is not coincident with that of the surface fissure but with that of the rift axis in this volcanic region. As stated in the previous section, the seismic activity along the rift axis became active after the eruption of Nyiragongo. This spatial and temporal relationships between seismicity of tectonic earthquakes and the eruption strongly suggest the existence of mutual connection with the activity of central volcano to the rifting episodes.

The focal mechanism of the tectonic earthquakes along the rift axis seems to be a reverse faulting type (Fig. 8), which is different from that of tectonic earthquakes occurring in other region in the Western Rift Valley (Tanaka *et al.* 1980). This discrepancy may be due to some uncertainty of hypocenter determination and/or due to the localized of stress filed in the very shallow depth of crust where the tectonic shocks occur. The focal mechanism of the volcanic earthquakes at deeper depth is normal faulting with the tension axes which are nearly horizontal and perpendicular to the strike of rift system. In the volcanic region where tectonic structure at shallower depth are complicated by a number of factors, the stress field associated with rifting is probably reflected in the focal mechanism of the deep volcanic earthquakes.

One of the most interesting findings in the present study is that the volcanic tremors were cleary registered at LWI for about four days before the eruption of Nyiragongo and that small shocks were frequently felt by the local inhabitants near the Nyiragongo in the same period. These two activities are supposed to be the precusive phenomena to the eruption of Nyiragongo. This implies that movements of mobile magmatic body are responsible for generations of continuous tremors and felt earthquakes with high frequency signals. Such correation between tremors and earthquakes has been noted for several other volcanoes such as Aso as Mihara-yama (Izu-Oshima) in Japan (Kubotera, 1974).

The earthquake of January 6 ($m_b=5.2$) in the Western Rift Valley may have a trigger effect on the eruption of Nyiragongo. Such a trigger effect of earthquake on volcanic activities or the correlation between volcanic and seismic events was discussed by several authors (Yokoyama, 1971; Latter, 1971; Nakamura, 1975). They suggested

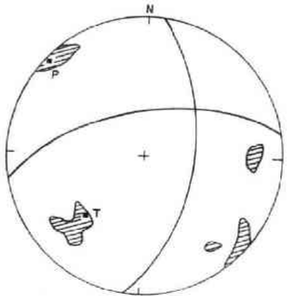


Fig. 10. Mechanism solution (equal area projection on the lower focal hemisphere) for the earthquake of January 6, 1977. Hatched region indicates variabilities of the P and T axes with 10% inconsistent stations.

that dynamic excitation of magma was caused by seismic waves and that squeeze-up and drain-back of magma were caused by volumetric strain or hydrostatic pressure associated with an earthquake motions. Yamashina and Nakamura (1979) discussed that changes of differential strain, probably tensile strains as well, caused by earthquake motions may also effect the state of volcano. According to them, there is a possibility that an earthquake occurrence can either increase or decrease a volcanic activity, depending on the relative locations of earthquakes and volcanoes and the focal mechanism. The mechanism solution of the earthquake on January 6 shows that the orientation of pressure axis is nearly horizontal in the south-east to north-west direction and that the tension axis is in the direction of south-west to north-east (Fig. 10). The volcano Nyiragongo is situated in the compressional region on the focal sphere of this event. This means that the effect of the earthquake is to squeeze-up the magma under the volcano.

Acknowledgements: Field observation was carried out in 1977 as the geophysical expedition of the Volcanoes Nyiragongo and Nyamuragira in Zaire. Financial supports to the field work were received from Oversea Scientific Research Fund from Ministry of Education, Science and Culture, Japan and from the special fund from l'Institut de Recherche Scientifique, Zaire. The authors wish to express their heartly thanks to I.R.S., Institut Zairoirs pour la Conservation de la Nature (I.Z.C.N.) and local government offices in Zaire for their logistic supports and assistances during our field survey.

We thanks to Dr. Ntika N'kumu and Prof. Kama Funzi Mudindambi (Former Directors of I.R.S.), Profs. A. Takagi, Z. Suzuki and T. Hirasawa (Tôhoku University), Profs. K. Tazime and I. Yokoyama (Hokkaido University) and Prof. T. Nabetani (Hirosaki University) for their various helps given in preparation for the field works.

Assistances in the field observations provided by Messrs Th. Janssen, M. Akumbi, M. Bagalwa, K. Kiroha, M. Shamavu and B. Taba (Department of Geophysics, I.R.S) are also greatly acknowledged.

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