

# **VOLCANIC EARTHQUAKE ANALYSIS OF THE YASUR VOLCANO, TANNA ISLAND, VANUATU**

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## **ABSTRACT**

Volcanic earthquakes are related to magmatic processes. For the Yasur volcano, Tanna Island Vanuatu, which is permanently active, its Strombolian activity is observed and studied during high activity period. Three main groups of volcanic earthquakes were identified, according to their arrival time difference between the two observation stations and their dominant frequency, the intermediate frequency, the low frequency and the typical explosion earthquakes. Within the low frequency earthquakes, three types of similarities were identified, the YI type with dominant frequency between 1 Hz and 2 Hz; the YII type with the uniform amplitude and dominant frequency of 1.2 Hz and the YIII type with the dominant frequency of 1.5 Hz. The explosions earthquakes show a long duration between the two phases arrival time indicating the time of transportation of gas bubbles in the conduit from their formation location to the surface.

Keywords: volcano earthquake, waveform, frequency, arrival time, Yasur.

## **INTRODUCTION**

Earthquake activity beneath a volcano always increases before an eruption in most cases because magma and volcanic gas must first force their way up through shallow underground fractures and passageways. When magma and volcanic gases or fluids beneath the volcano rise from the earth's crust, they will either cause rocks to break or cracks to vibrate. When rocks break high-frequency earthquakes are triggered. However, when cracks vibrate either low-frequency earthquakes or a continuous shaking called volcanic tremor is triggered. Most volcanic-related earthquakes are less than 2 or 3 in magnitude and occur less than 10 km beneath a volcano. Volcano seismology is a tool to provide deeper understanding of the driving mechanism of volcanic eruptions though other geophysical methods also exist. In Tanna Island, Vanuatu, the seismic network was set up in 2002 by IRD, the French Institution for Research, for temporary observation to better understand the driving mechanism of the permanent Strombolian activity of the Yasur volcano.

## **GENERALITIES ON THE VOLCANO SEISMOLOGY**

Volcano earthquakes have been studied for the first time in 1910 by Fusakichi Omori during the eruption of Usu volcano in Japan Omori (1911-1913). Studies on volcano earthquakes show different types of

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volcano earthquakes that were classified into 4 groups according to location of their foci, their relationship to eruption and the nature of the earthquake motion (Minakami 1974).

The A-type or high frequency earthquakes are originated between 1 and 20 km. These are generally less than 6 in magnitude and the P and S waves are clearly defined as tectonic earthquakes.

The B-Type earthquakes are located around 1 km around the crater and with several meters of depth beneath the volcano. Their onset is emergent and S-wave is not clear or surface waves are predominant. Earthquakes of this type can be classified into long period events occurring in shallow depth due to hydrothermal flow caused by the heat of magma.

The explosion earthquakes accompany individual explosive eruptions. The amplitude of such earthquakes is related to the magnitude of explosive eruptions. On the seismograms of explosion earthquake disturbance by air shock may be distinguished. The hypocenters are situated beneath the active crater floor.

Volcanic tremors consist of surface waves. The duration is usually longer than that of earthquakes. It continues from several minutes to several hours, sometimes several days.

## **GEOLOGY AND TECTONIC SETTING**

The Vanuatu island arc is located at the limit of two tectonic plates, the Indo-Australian Plate in the west and the Pacific Plate in the east. The subduction of the Indo-Australian Plate beneath the Pacific plate explains the high volcanic and seismic zone of Vanuatu with three volcanic chains that contain the islands of Vanuatu that were erected since late Oligocene to mid Miocene (25 to 10 Ma) for the western chain followed in late Miocene to early Pliocene (10 to 2 Ma) with the formation of the eastern chain and ended since the Holocene with the creation of central chain, which is the site of the recent volcanism.

Tanna Island belongs to the volcanic chain of the central chain of the archipelago. Volcanism started on this island during the ages of Pliocene (2.5 to 2.4 Ma) with the basaltic cones from the north to the central part of the island. Volcanic eruptions were significant from the mid Pleistocene (0.2 Ma) to the end of Pleistocene (10000 years) with the formation of the actual Siwi caldera that lodges the Yasur volcano in the south eastern tip of the island.

## **YASUR VOLCANO AND PREVIOUS WORKS**

Yasur volcano is permanently active with the Strombolian activity. James Cook was attracted by the illumination from this volcano in 1774 when he discovered the island of Tanna. It is believed that its Strombolian activity may have been continuous for 800 years.

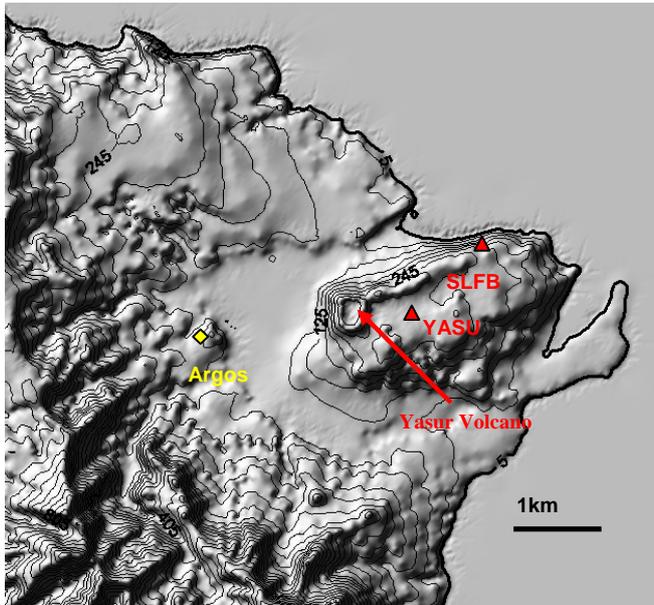
Yasur is the strato-volcano located at latitude 19.52 degree east and 169.425 degree south on the southeastern tip of the island of Tanna. It consists of the volcanic un-vegetated cone of 362 meters high. The summit crater is 400 meters wide and contains three active vents.

Blot and Tazieff (1961) distinguished the existence of superficial explosion earthquakes and the "real volcanic earthquakes". Later Nairn et al. (1988) and Lardy et Willy (1989) showed the existence of 2 types of explosion earthquakes: the first with the lowest frequency of 2 – 2.5 Hz associated with the explosion of one particular active vent and the second case with the dominant frequency of 2 - 4 Hz and the sound wave that would show the gas explosion within the 3 active vents. Naby, et al (1997) highlighted 3 types of seismic signals falling in the frequencies between 1 and 3 Hz that were associated with the Strombolian explosions accompanied by a forerunner signal that occurs several seconds before eruption. This corresponds to the time separating the formation of the gas pocket in the magmatic column at different levels and its reaching the surface when it explodes.

In this study, with the limited information available, I will identify and classify the different type of volcanic earthquakes occurring on this volcano during the limited period. The techniques used for this study will be used for the study of the other volcanoes of Vanuatu.

## DATA COLLECTION

### Observation



The data collection was done in collaboration with IRD (the French Institute of Research and Development) during the months of November and December 2002 with two temporary observation stations, YASU and SLFB (Figure 1). Both stations consisted of broad band seismometers Guralp type CMG3T type, 3 components connected to autonomous Geostar stations. The frequency of sampling is 100 samples per second. The volcanic activity during the observation period is of high Strombolian activity.

Figure 1. Yasur volcano and the temporary observation Station distribution. Red triangles represent the temporary observation stations from October 2002 to 2005. The yellow triangles show the permanent monitoring station that runs since 1992.

### Processing and analysis

The raw data collected was in binary data format. The first processing consisted of extracting this data from the data format and converting them to SAC format so that they can be visualized. To visualize the SAC files extracted, **SWARM**, **Seismic Wave Analysis** and **Real-time Monitor** is the easiest and most appropriate software to use. From the daily data, fifty isolated events were selected and extracted for analysis. The analysis was done by SeisGram2K program.

The analysis of the seismic data collected for this volcano was highly dependant on the quality of data recorded by the 2 stations YASU and SLFB which are located respectively at 735 meters and 2201 meters from the crater. Only YASU station has all the 3 components seismograms. The SLFB only has the horizontal components (E\_W and N\_S components).

With the distance of 1500 meters between the two observation stations, air waves should travel with Sound velocity of 350 m/s from YASU to SLFB stations in 4.3 seconds though some atmospheric factors can cause value to change. Not knowing the amplification factor for each station, the amplitude ratio between the two stations is meaningless. The waveform classification is only based on the frequency contain, the similarities between the different waveforms shapes and the arrival time difference of phases between YASU and SLFB. Specific methods for waveform classifications such as cross correlation methods are not used in this study.

## RESULTS

### Wave classification

There are 3 different types of events identified: the Intermediate frequency events, the low frequency events and the typical explosion earthquakes.

#### *The Intermediate frequency events.*

The arrival time difference of this event between the YASU and SLFB stations is 0.6 seconds.

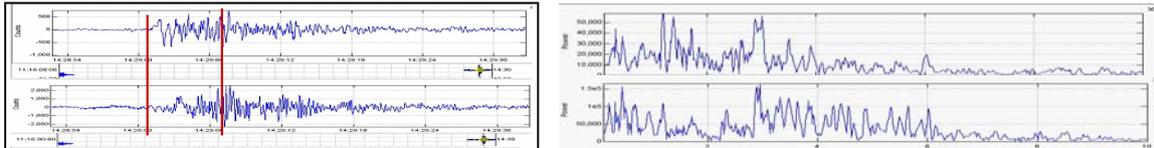


Figure 2. Waveforms showing the arrival time difference pattern between YASU (top left) and SLFB (bottom left) and their respective power frequency spectra (right).

This group of events presents clear frequency peak 3 Hz on all the components of YASU and SLFB (Figure 2). In SLFB the frequency peak also appear in the higher range such as 6 Hz while at YASU the second peak appear in the lower frequency of 1, 2 Hz. In general broad frequency range can be observed for this group of events.

#### *Low frequency events.*

There are 3 types of groups of low frequency events are identified.

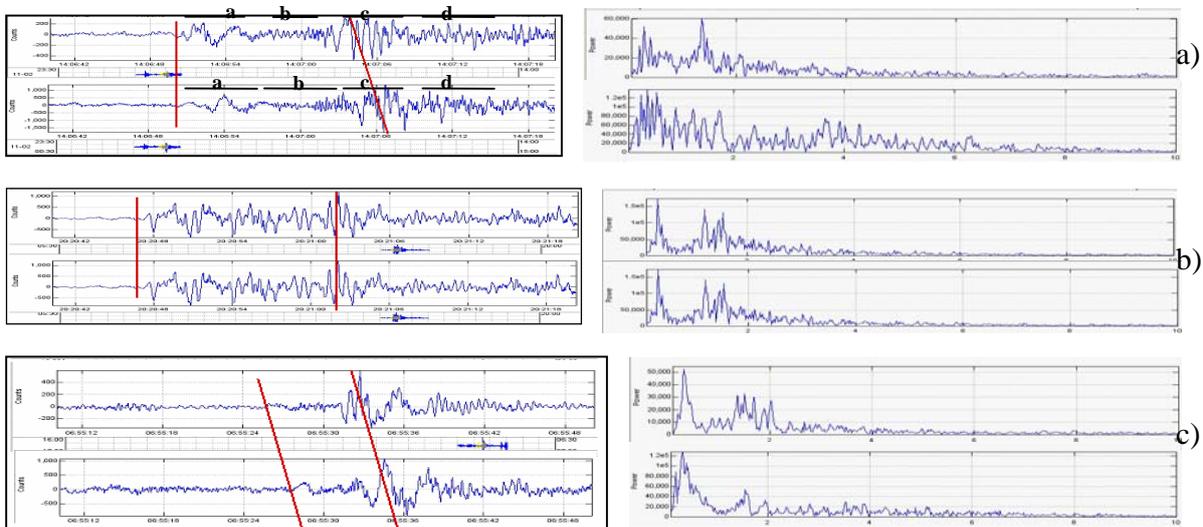


Figure 3. Low frequency events observed on YASU\_E (east-west component) and SLFB\_E (East west component). The waveforms a), b) and c) shows respectively the YI, YII and YIII types of low frequency earthquakes with the arrival time difference pattern between YASU (top left) and SLFB (bottom left) and their respective power frequency spectra (right) for each waveform. Four phases a, b, c and d are observed on the YI type waveform.

The Low Frequency Earthquakes type YI are characterized by Clear frequency peak at 1.5 Hz on YASU and SLFB (Figure 3 a)). On SLFB the frequency range is wider with some peaks at 3.5 Hz and 4.5 Hz. The common characteristic of this group is also clear on the wave form, with the short waves identified as b occurring between 2 series of long wavelet identified as a and c. The first one has the period of around 2.5s on YASU and 2.7s in SLFB. The second series of long waves are around 0.9s on YASU and 2 seconds in SLFB. The duration between these long period waves is about 4 seconds and it has lower amplitude than the long wave phases a and c. Phase d is the normal surface wave. The phases c and d correspond to the shock wave traveling with the sound velocity though atmospheric phenomenon (wind speed and direction) could influence the propagation of the wave.

For the Low Frequency events of type YII the arrival time difference of the seismic phases of this type of events between the 2 stations is about 0.1 to 0.2 s (Figure 3 b)). The amplitude of this waveform is stable. The dominant frequency for this type of earthquakes appears between 1 and 1.5 Hz. On the N\_S component, several peaks appear on a wider range of frequency between 1 and 2 Hz).

The Low Frequency events types YIII are observed daily along the recording period. They show clear frequency peaks between 1 and 2 Hz both on SLFB and YASU (Figure 3 c)). This group is characterized by a very long period wave that is identified and is found to be more significant on the E-W component (around 3 s) than the N-S component (around 0.6 s for YASU and 1.6 s for SLFB). This group of events usually has shorter duration than the other type of earthquakes observed on this volcano and they represent more than 60% of the events analyzed.

### ***Explosion Earthquakes***

This group is identified by the clear arrival of the first and the second phase with the clear onset especially in YASU station (Figure 4). The duration between the occurrences of the 2 phases is extremely long. The time difference between the 1<sup>st</sup> and the second phase is around 15 seconds recorded on both stations and the arrival time difference of the highest amplitude is observed between the 2 stations at 4.8s interval. This group of earthquakes is characterized by a wide range of frequency from 1 Hz to 4.5Hz at YASU and between 2 HZ and 6 Hz at SLFB (Figure 4).

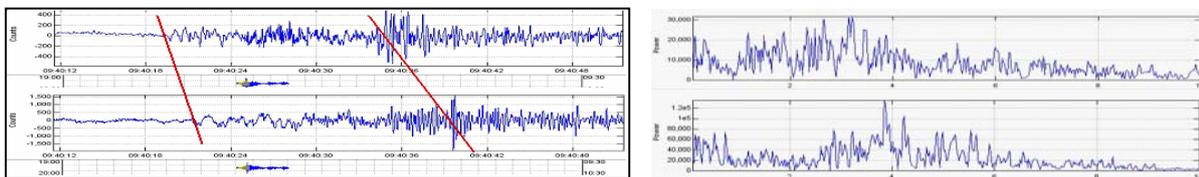


Figure 4: Waveforms showing the arrival time difference pattern between YASU (top) and SLFB (Bottom) of the explosion earthquakes.

## **DISCUSSION AND CONCLUSION**

The Intermediate frequency events characteristic shows that the first arrival is the P wave. The Broad frequency range can suggest that this group consist of B-type events which are known to be the hybrid or mix frequency events.

Within the Low frequency events identified, 3 groups of events with remarkable similarities are selected. This similarity between the different earthquake events means that each group of events has common processes that govern the generation of these signals. Low frequency seismic signals recorded on active volcanoes are used to be interpreted as the direct consequence of magmatic activity beneath the volcano. We can thus suggest 3 types of mechanisms played in the triggering of the eruptive activity of Yasur in 2002. The YI type low frequency group with its four observed phases a, b, c and d is almost

similar to what was observed in Stromboli (Nabyl et al. 1997). The phase a of this signal was regarded as the formation of gas bubbles in the conduit, the b phase might correspond to its travel to the surface and the c and d the explosion phase. In this study with the limited information we can only identify the c and d phases as the explosion phase base on the arrival time difference between the 2 stations. The other types of low frequency events identified are type YII with the stable amplitude along the waveform and the dominant frequency between 1 and 2 Hz. The YIII type is the most frequent low frequency events observed during the observation period. It is characterized by its low dominant frequency at around 1.5 Hz and the remarkable broad peak between 0.1 and 1 Hz. This kind of event may be referred to the continuous explosion of gas bubbles in the conduit.

The typical explosion earthquake can be compared to the type YI events with the longer time separating the offset of the signal and the actual explosion. This time lag can also be explained as the time of transportation of gas bubbles from the source to the surface where it explode and emitting the sound wave of explosion. The understanding of these identified phases is essential to study and monitor the Yasur volcano activity in future as well as the other volcanoes of Vanuatu. In this study the background noise was not considered.

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