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Families of similar events and modes of oscillation of the conduit at Yasur volcano (Vanuatu)

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ABSTRACT

We examined one year of seismic recordings collected in 2008 during a temporary experiment at Yasur volcano (Vanuatu). The volcano has a permanent Strombolian activity that was at a relatively high level during most of our experiment with commonly at least one explosion per minute. Associated with this activity, the network recorded intense seismicicity with hundreds of transients per day. Video recordings indicate that most of the high frequency transients are directly related to the strombolian explosions. They also outline the presence of fewer signals which are not accompanied by any surface activity. The classification of transient events recorded at a station close to the summit indicates that a significant part of the events exhibit waveform similarity. This technique allows the identification of characteristic repeating events among the hundreds of thousands of transients recorded during the experiment. Most of the families of similar events are groups of explosion quakes (EQs) but a few are groups of Long Period events related to deeper processes. By scanning the 9 months of continuous data available at the summit station with master events extracted from these families we reconstruct their temporal evolution. Our results show that several families dominate the activity with a few of them lasting for several months. We show that their temporal evolutions can be used to probe changes in the structure or activity of the volcano. We observe that a major change was induced by a M = 7.3 subduction earthquake which occurred on April 9, 2008 about 80 km from the volcano. While this event did not change significantly the surface morphology of the volcano nor the intensity of the eruptive activity, it interrupted the families as none of them is present both before and after the event. This change in the waveforms can be explained by a drop in the seismic velocity of the volcano caused by the distal event. Numerous other transitions between families are observed, sudden or progressive. These can be interpreted as representative of changes in the eruptive dynamics. The presence of similar EQs, especially for impulsive explosions, indicates that the source mechanism is reproducible and has a stable location for some periods. This favors a source process based on the oscillation of the conduit or oscillation of the edifice in response to the explosive decompression of gas slugs at the free surface of the conduit. Our results suggest that the seismic activity of Yasur is characterized by the presence of dominant modes of resonance of the conduit which may be influenced both by external and internal factors.

1. Introduction

Yasur volcano is located in the south-eastern part of Tanna island, in the south of Vanuatu (South-West Pacific). It is part of an island arc related to the subduction of the Australian plate below the Pacific plate. Yasur is a small basaltic scoria cone (360 m a.s.l.), which is part of a larger structure: the Yenkahe resurgent dome. The dome is characterized by a discontinuous uplift with a mean rate estimated by coral dating of 15.6 cm/year over the last 1000 years (Carney and Macfarlane, 1979; Chen et al., 1995). The dome is located inside the 24 km^2 Siwi caldera (Coulon and Maury, 1981; Robin et al., 1994; Allen, 2005). Yasur volcano has a permanent Strombolian to Vulcanian type of activity since at least 300 years (Simkin et al., 1981), which makes it one of the rare open vent systems with permanent activity. A crater, 400 m in diameter occupies its summit, with 2 sub-craters including 3 vents named A, B and C (Fig. 1). Frequent explosions are observed with commonly at least one explosion per minute.

The seismicity observed at Yasur is comparable to other volcanoes with open vent conditions with Strombolian or Vulcanian activity, permanent like Stromboli (Italy) or Erebus (Antarctica) or more discontinuous like Etna (Italy) or Tungurahua (Ecuador) for example. This activity is accompanied by a wide variety of seismic signals generally recorded especially at a close distance (several kilometers) to the vents. Explosion Quakes (EQs) are observed directly associated with the explosions (Ripepe, 1996). In the short period range (>0.5 Hz) most of their energy

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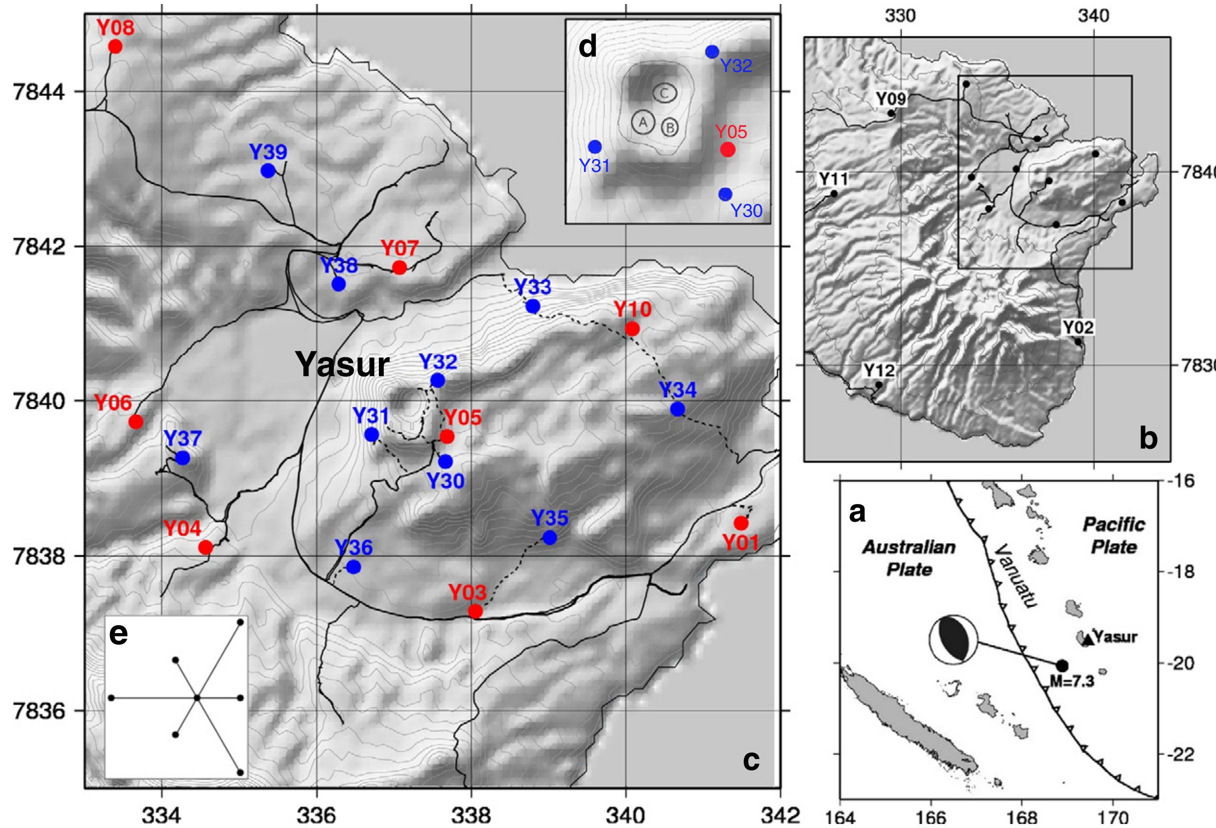

Fig. 1. Geological setting and layout of the seismic network. (a) Location of Yasur volcano and epicentral location of a magnitude 7.3 subduction earthquake, which occurred on April 9, 2008 (longitude–latitude coordinates in degrees). (b) Location of the seismic stations in the Southern part of Tanna island and (c) around Yasur volcano (UTM coordinates in km). Seismic antennas are indicated as red circles and broadband stations as blue circles. (d) Summit area of Yasur volcano with the approximate location of the crater rim is indicated by a dotted line as well as the rough location of the 3 active vents A, B and C. (e) Typical sensor distribution for a 7-sensor (9-component) seismic station.

is often found between 1 and 5 Hz. They frequently also include a high frequency (>5 Hz) acoustic air wave (Braun and Ripepe, 1993; Ripepe and Braun, 1994) but this phase is sometimes unclear or not visible. At frequencies below 0.5 Hz, Very Long Period signals (VLP) are often observed with EQs (Neuberg et al., 1994; Rowe et al., 1998; Chouet et al., 2003). The source of VLP signals is typically attributed to the coalescence (Ripepe et al., 2001) or ascent (James et al., 2006; Chouet et al., 2008) of gas slugs but no clear consensus is found in the literature about their source mechanism. In the short period frequency range more or less permanent tremor (Wassermann, 1997; Gordeev, 1999) accompanies degassing, fountaining, sloshing and bubbling in the eruptive vents. In between tremor and clear short duration EQs related to impulsive explosions, volcanoes emit various intermediate signals related to jetting and longer duration material emissions.

Short period signals described in the previous paragraph can be included in the larger family of Long Period seismicity related to fluid transfers and resonances of fluid filled volumes commonly observed on volcanoes. Long Period (LP) transients are commonly interpreted as the response of a fluid-filled resonator to the excitation of a triggering mechanism (Chouet and Matoza, 2013). Various resonating sources have been proposed such as a spherical source (Crosson and Bame, 1985), a cylindrical pipe (Chouet, 1985) or a crack (Chouet, 1988). Various triggering mechanisms have also been proposed. They are summarized by Chouet and Matoza (2013) into 5 categories: (1) self-sustained fluid oscillations, (2) magma-hydrothermal interactions, (3) magmatic degassing, (4) brittle fracture of melt, and (5) solid extrusion dynamics and plug stick-slip. LP events are observed at active volcanoes as well as quiescent ones. They may be very shallow when related to surface processes like degassing for example but deeper LPs have also been observed, sometimes precursory to eruptions (White, 1996). Repeating similar LP events have been observed on volcanoes like Kilauea (Battaglia et al., 2003; Matoza et al., 2014), Etna (Lokmer et al., 2007) and Shishaldin (Petersen, 2007).

Seismicity of Yasur has been previously studied by Nabyl et al. (1997) who found a good similarity with the seismicity observed at Stromboli volcano. Kremers et al. (2013) located and inverted the source mechanism of 24 EQs using a multi-parameter dataset and found mostly isotropic source mechanisms. In present paper we examine the seismicity recorded during a one-year experiment carried in 2008–2009. We first examine the temporal evolution during the entire experiment of parameters such as the number of detected transient events, the average seismic RMS amplitude and the amplitude of individual events. We next correlate several hours of video recordings with the corresponding seismicity to identify the origin of the seismic transients. Then, to simplify the analysis of the hundreds of thousands of events recorded during the experiment, we search for characteristic repeating events as they might have specific importance for understanding the eruptive dynamics. We recompose the temporal evolution of such repeating events and use them to probe changes in the volcanic structure or eruptive dynamics.

2. Data

We use data collected by a temporary network, which was installed around Yasur volcano in 2008 for a duration of one year. The network included up to 22 stations with an installation done in 2 parts. At the end of January 2008, 12 seismic stations were installed. Nine of which had a star-like geometry (Fig. 1e) and included 9 short period components with one three component sensor surrounded by 6 1-component sensors distributed every 60° at 20 or 40 m distances from the center. The peripheral components are named clockwise C00 to C05 with C00 being roughly oriented