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Probable dynamic triggering of phreatic eruption in the Tatun volcano group of Taiwan

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ABSTRACT

On 16 March 2014 (UTC), a small phreatic eruption occurred in the Tatun volcano group (TVG) of Taiwan, although it was not reported until analysis of both seismic and acoustic data revealed that the source was in the vicinity of the Hsiaoyukeng fumarole. A replay of the acoustic data accelerated ~60-fold reveals that the gradual decrease in frequency that was recorded produces a volcanic whistle, similar to the jet of steam released from a heating kettle. The phreatic eruption may have been dynamically triggered by a M6.7 earthquake in Chile. A similar phenomenon occurred on 5 January 2015, when a phreatic eruption was recorded in the TVG immediately after the generation of dynamic seismic waves by an M5.0 earthquake in Japan. This is the first scientific report of a phreatic eruption detected in the TVG, indicating that these volcanoes are still active. As a result, it is important to monitor their volcanic activity and identify volcanic reservoirs beneath the TVG to mitigate future possible volcanic impact.

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1. Introduction

Phreatic eruptions are often more difficult to predict than magmatic eruptions due to the absence of magma movement (Barberi et al., 1992; Maeda et al., 2015). A typically phreatic eruption is an explosion of steam and is usually the result of magma heating ground or surface water. Thus, phreatic eruptions may eject steam and a small amount of volcanic ash, rock and bombs, but no magma. Because of the absence of magma movement before the eruption, it is more difficult to detect volcanic earthquakes, crustal deformation, or other physical precursors necessary for the provision of eruption warnings. An example of this phenomenon was the recent volcanic eruption at Mount Ontake, Japan, in September 2014, which occurred without warning and immediately killed 57 tourists and left six others missing (Kato et al., 2015). Although seismicity increased two weeks before the eruption, it is difficult to identify any other precursor of the eruption that could have served as a warning. In fact, the Ontake volcano was not even recognized as an active volcano until a phreatic eruption occurred there in 1979 (Nakamichi et al., 2009).

Similar to the Ontake volcano prior to 1979, there are no records of the Tatun volcano group (TVG) of northern Taiwan having erupted during human history. Indeed, the TVG was thought to be inactive until some recent studies based on geochemical analyses (Yang et al., 1999), volcanic tremors (Lin et al., 2005a,b; Konstantinou et al., 2007; Pu et al., 2014), geodesy surveys (Murase et al., 2014), and ash dating (Belousov et al., 2010; Zellmer et al., 2015) indicated otherwise. Recently, some notable seismic observations have been made in the TVG, such as very-long-period seismic signals (Lin and Pu, 2016), heartbeat-like seismicity (Lin, 2017), and identification of a deep magma reservoir (Lin, 2016). Although all observations and analyses strongly suggest that the TVG is still active, further research is required to determine whether or not these volcanoes will erupt again.

This paper describes a small-scale phreatic eruption that occurred on 16 March 2014 (UTC), but which was not detected until recently, when both seismic and acoustic data were examined. Based on these data, the eruption was located in one of the largest fumaroles in the TVG. In fact, this eruption may have been dynamically triggered by a M6.7 teleseismic earthquake in Chile. This is the first scientific record of a phreatic eruption in the TVG, and it indicates that this volcano group is still active. The possibility of future eruptions cannot, therefore, be completely ruled out.

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2. Background

The TVG is located at the northern tip of Taiwan, which is just located above the western boundary of the Philippine Sea Plate (a subduction zone). However, it is interesting to note that the TVG may not be part of a typical volcanic arc, according to its geochemical characteristics (Wang et al., 1999), but that it resulted from some degree of melting within an ascending region of the asthenosphere mantle due to the extensional collapse of the northern Taiwan mountain belt (Wang et al., 2004).

Volcanic activity in the TVG is problematic for Taiwan, since the TVG is in northern Taiwan, near the Taipei metropolis (Fig. 1). The exact location of the TVG is between two major cities, Taipei City and New Taipei City (Fig. 1b). Taipei City, with a population of approximately 2.5 million, is the capital of Taiwan, and is surrounded by the larger New Taipei City (Taiwan Population, 2017). The total population of both metropolises is close to 7 million, nearly one-third of the population of Taiwan. The distance between the highest peak in the TVG, Mt. Chihsin (1120 m), and Taipei 101, a 508-m high skyscraper in downtown Taipei City, is only about 15 km (Fig. 1c). Moreover, the densely populated Taipei metropolitan area now extends into the northern part of the Taipei basin, which is even closer to the TVG. It is unusual to have two megacities and active volcanoes in such close proximity. In addition to the dense population, there are two nuclear power plants in operation just north of the TVG, on the northern coast of Taiwan (Fig. 1b). The potential impact of another eruption in the TVG could therefore be devastating.

To monitor volcanic activity in the TVG and improve understanding of its volcanic characteristics, the Taiwan government established the Taiwan Volcano Observatory (TVO) at Tatun in 2011. The TVO systematically collects seismic, acoustic, geodetic, geochemical, thermal, and other data via either real-time transmission systems or repeated surveys. The monitoring system includes a dense broadband seismic network (Fig. 2), the Tatun Volcano Broadband Seismic Network (TVBSN), which was established in 2011 and is operated by the TVO to monitor volcanic earthquakes and tremors in the TVG. The TVBSN comprises 40 seismic stations and covers an area of ~100 km^2. The most closely spaced stations, with a distance of ~1 km between stations, are deployed around Mt. Chihsin, where the seismicity is most intense (Fig. 1a; Lin et al., 2005a; Pu et al., 2014) and where volcanic tremors have been detected (Lin et al., 2005b). Each station is equipped with a three-component broadband sensor (Guralp CMG-6TD) and continuously records seismic data at a sampling rate of 100 Hz. Seismic signals generated by a variety of volcanic earthquakes and tremors are thus effectively recorded frequencies of 0.03–50 Hz at each seismic station.

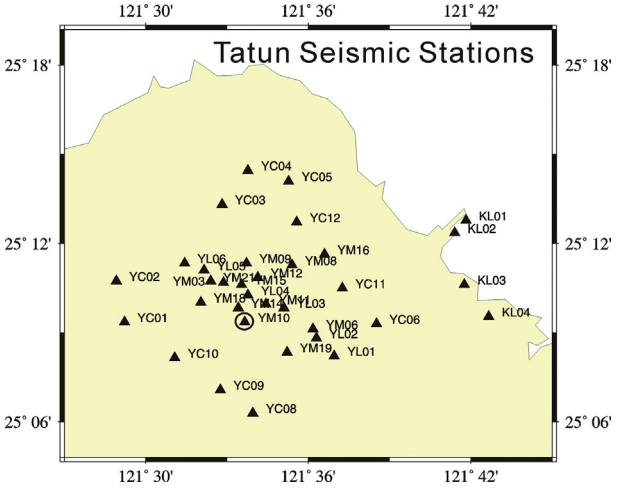

Fig. 2. Locations and names of the seismic stations (triangles) and an infrasonic station (circle) in the TVG.

3. Seismic data and analyses

In addition to routinely detecting volcanic earthquakes during the last decade (Lin et al., 2005a,b; Pu et al., 2014), the TVBSN recorded an unusual seismic tremor with extremely high frequencies on 16 March 2014 (UTC). A spectrogram recorded at seismic station YM03 clearly shows that the seismic energy was dominated by frequencies higher than 30 Hz (Fig. 3). In general, such high-frequency seismic signals are not observed simultaneously at different seismic stations, because seismic waves often decay rapidly within a short distance due to extreme crust heterogeneity in a volcanic area. However, band-pass filtering at frequencies between 30 and 45 Hz of the seismic energy recordings showed that those high-frequency waves were clearly recorded at more than ten stations (Fig. 4). Most of the seismic stations that recorded this high-frequency energy are situated around Mt. Chihsin, which is probably where the last eruption in the TVG occurred (Belousov et al., 2010).

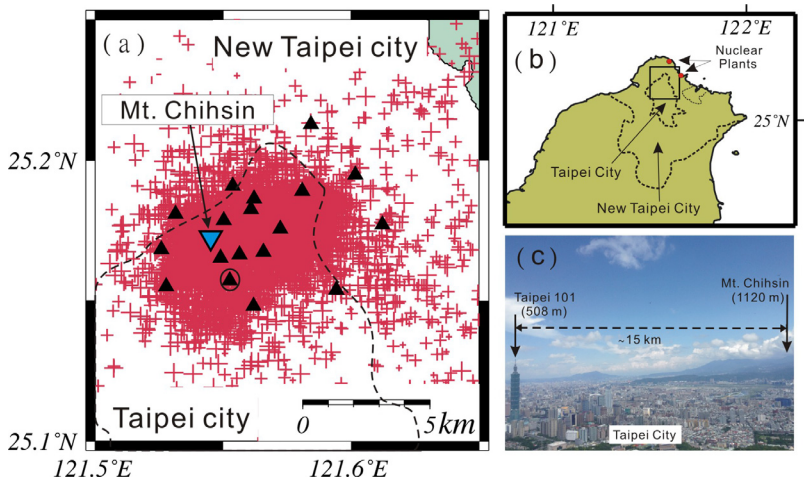

Fig. 1. (a) Locations of seismic stations (triangles), Mt. Chihsin (blue triangle), infrasonic station (circle), and seismicity (red crosses) recorded in the TVG from since 2003. (b) The study area (box), the borders of the two cities (dashed lines), and the locations of nuclear power plants (red dots) in northern Taiwan. (c) Photograph taken from the south of Taipei of the volcanoes.

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