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Volcano-hydrothermal activity detected by precise levelling surveys at the Tatun volcano group in Northern Taiwan during 2006–2013

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ABSTRACT

Precise levelling surveys were conducted from 2006 to 2013 on three levelling routes in the Tatun volcano group (TVG) located approximately 15 km northeast of Taipei, to detect deformation in relation to the volcano-hydrothermal activities of the TVG. Uplift was detected around the most active fumarole, Tayoukeng fumarole, throughout the period 2007 to 2011; the uplift rate throughout the period from March 2009 to March 2011 was reduced in comparison to the rate between 2007 and 2009. Following this, a dormant state or a small amount of subsidence was detected in the period March 2011 to March 2013. And throughout the period from June 2006 to March 2013, subsidence was centred on an area 0.5 km east of the summit of Mt. Cising, the highest peak in the TVG. A model of two spherical sources was therefore estimated from the deformation recorded from August 2007 to March 2011, using a genetic algorithm. A deflation source was obtained about 0.5 km northeast of Mt. Cising at a depth of 2 km; and an inflation source was situated approximately 1 km south of the Tayoukeng fumarole at a depth of 0.7 km. Based on previous seismic and AMT studies, the estimated sources are interpreted as being hydrothermal reservoirs. Because almost all the benchmarks around Mt. Cising show subsidence at a constant speed, we conclude that the deeper hydrothermal reservoir at a depth of 2 km may have been releasing hydrothermal fluid at a constant rate throughout the period from 2006 to 2013. However, it was suggested that in 2011 the shallower hydrothermal reservoir at a depth of 0.7 km changed from an inflation state to a dormant state (or small deflation) based on temporal vertical changes around Tayoukeng fumarole. A possible model for the volcano-hydrothermal system is therefore proposed. It is considered that the hydrothermal fluid may be supplied intermittently from the magma chamber to the deeper hydrothermal reservoir at a depth of 2 km (although this type of fluid input event may not have occurred during our research period), and that the hydrothermal fluid upwelling between Mt. Cising and Tayoukeng fumarole flows transversally into a highly cracked and fluid-saturated area that continues to Tayoukeng fumarole. The existence of a shallower hydrothermal reservoir at a depth of 0.7 km in the highly cracked and fluid-saturated area is therefore plausible.

1. Introduction

The Tatun volcano group (TVG) is located at the northern tip of Taiwan and is composed of at least 20 Quaternary volcanoes; the geographic centre of which is located approximately 15 km northeast of Taipei, the largest city in Taiwan (with a population of more than seven million). The northern Taiwan region not only has a high population density, but also modern industrial infrastructures (such as nuclear power plants) constructed on the mountainside of the TVG (Fig. 1), and therefore, any volcanic activity poses a serious threat to the surrounding area. The TGV itself, designated as the Yangmingshan National Park, is a popular tourist attraction. Thus, volcano monitoring and research are extremely necessary to gain an understanding of recent volcanic activity, and for detecting any early signs of unrest in the TGV.

A valid and feasible method of detecting such early signs of unrest is by monitoring activity using geodetic, geophysical, and geochemical techniques. Seismic monitoring has recently observed micro-seismic activity such as volcano-tectonic earthquakes, tremors, multichromatic events, and long-period earthquakes in and around Mt. Cising, the highest peak of the TVG (at 1120 m) (Lin et al., 2005b; Konstantinou et al., 2007), and from the composition of fumarolic gases, geochemical monitoring suggests that they originate from a magma source (Yang et al., 1999) Lan et al., 2007; Lee et. al., 2008).

Understanding eruption history is as important as monitoring in the mitigation of volcanic hazards. From detailed geological and

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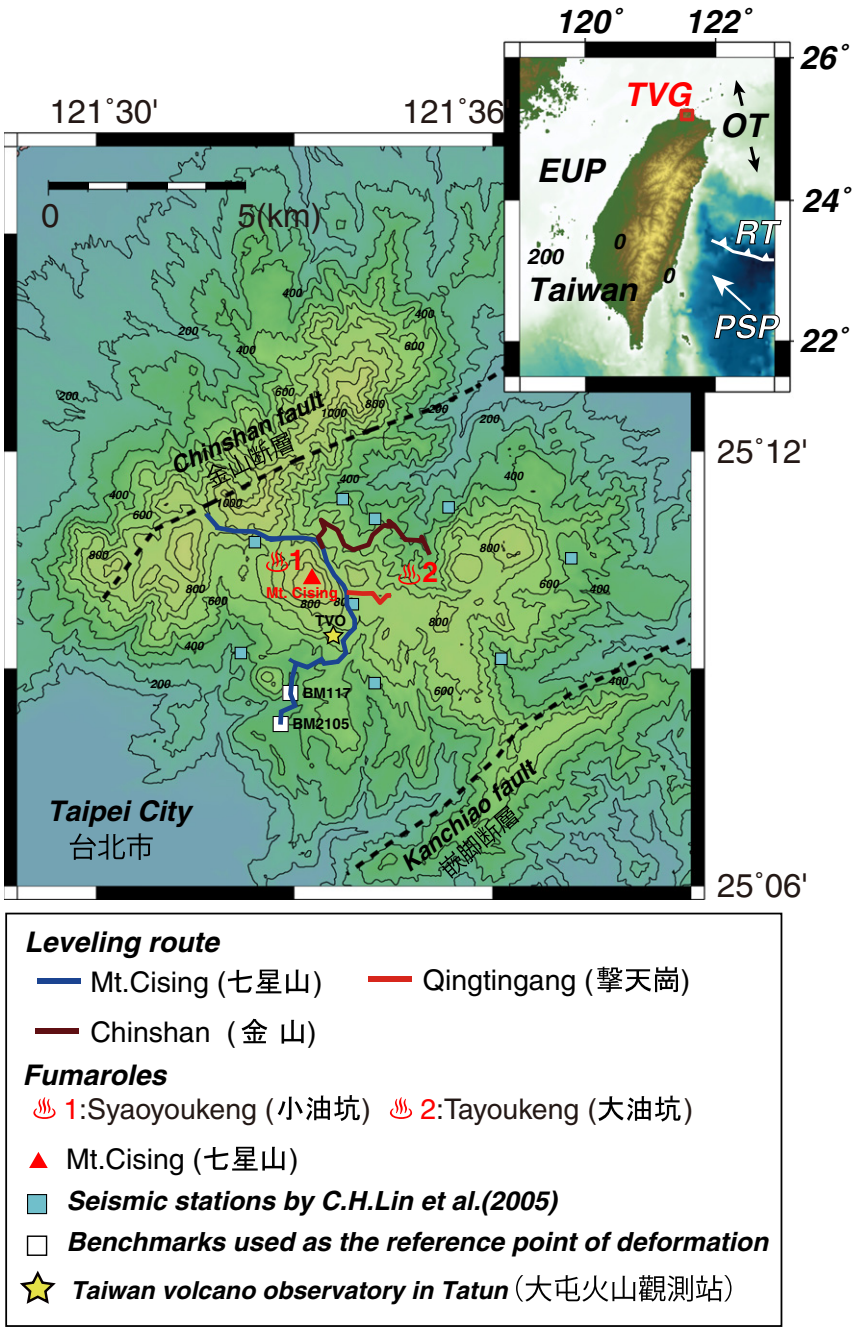

Fig. 1. A location map of the Tatun volcano group (TVG) showing the Mt. Cising, Qingtingang, and Chinshan levelling routes. Locations of Mt. Cising, main faults, main fumaroles, seismic stations, benchmarks used as reference points of deformation, and the Taiwan volcano observatory in Taiwan are indicated. Location names are shown in both English and Chinese. Inset map is the location of the TVG and the tectonic setting of Taiwan; the red rectangle shows the area of the location map. The relative motion between the Philippine Sea Plate (PSP) and the Eurasian Plate (EUP) is indicated by an arrow. The Okinawa Trough (OT) and Ryukyu Trench (RT) are also indicated.

geomorphological studies, the TGV is known to have produced several magmatic eruptions over a period between 23,000 and 13,000 years ago, and a phreatic eruption possibly as recently as 6000 years ago (Belousov et al., 2010). Mt. Cising is the youngest volcano in the TVG, and based on the above-mentioned results it is considered to be potentially active. Therefore, in 2011, the Taiwanese government established the Taiwan volcano observatory (TVO) in Tatun to monitor the volcano's activity.

Although recent activity in the TVG has been widely monitored and researched using seismic and geochemical techniques, recent deformation in the area has not been extensively studied. Certain GPS stations installed in northern Taiwan (including the TVG area) have not shown any clear deformation caused by volcanic activity (Yu et al., 1997).However, as part of the volcano-seismic swarm seems to only occur around some fumaroles, it is strongly suggested that micro-seismic activity and hydrothermal activity are closely related. The swarm activity around volcanos is often accompanied by deformation (Kimata et al., 2004; Daita et al., 2009), but such deformations may be difficult to detect using GPS measurements because they are at times too small and are localized to a very small region.

Some studies have reported ground deformations associated with volcano-hydrothermal activity at active volcanoes. On Volcano Island, Italy, electronic distance measurement (EDM) surveys were used to estimate an ellipsoidal source model as the best-fit model beneath the