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Deposits, character and timing of recent eruptions and gravitational collapses in Tatun Volcanic Group, Northern Taiwan: Hazard-related issues

Alexander Belousov [a,b,*], Marina Belousova [a,b,c], Chang-Hwa Chen [a], Georg F. Zellmer [a,d]

[a] Institute of Earth Sciences, Academia Sinica, 128 Academia Road Sec. 2, Nankang, Taipei 11529, Taiwan
[b] Earth Observatory of Singapore, Nanyang Technological University, N2-01a-15, 50 Nanyang Avenue, 639798 Singapore
[c] Institute of Volcanology and Seismology, Petropavlovsk, Russia
[d] Lamont-Doherty Earth Observatory, 61 Route 9W, Palisades, NY10964, USA

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ABSTRACT

Taipei City, with a population of around 8 million, as well as two nuclear power plants is located in close proximity to the Quaternary, dominantly andesitic Tatun Volcanic Group (TVG) of Northern Taiwan. We have investigated the stratigraphy of the youngest volcaniclastic deposits, as well as the morphology of lava flows and domes of the TVG in order to reconstruct the character and timing of the most recent eruptions and related hazardous events in the area.

Our data indicate that recent eruptions of the group were dominated by long-term, voluminous extrusions of crystal-rich, very viscous lavas. These eruptions formed closely spaced monogenetic domes and lava flows. Based on morphological parameters of the lava flows (thicknesses 80–150 m, lengths up to 5.6 km, and volumes up to 0.6 km^3), average rates of magma effusion ranged from 1 to 10 m^3/s, eruption durations from 500 to 1800 days, and lava front speeds from 0.5 to 6 m/h.

Explosive activity of TVG was diverse, ranging from weak phreatic to highly explosive (VEI 4) Plinian eruptions; vulcanian activity with deposition of lithic ashes was most common. Interaction of rising magma with ground water frequently occurred during the eruptions.

This study presents the first radiocarbon dates of various volcaniclastic deposits of the TVG, which indicate that Cising, Siaoguanyin, and possibly Huangzuei volcanoes had magmatic eruptions in the period 13,000–23,000 years ago. In addition, Mt. Cising had a phreatic eruption 6000 years ago, and possibly an effusive eruption just before that. Gravitational collapses of volcanic edifices with volumes 0.01–0.1 km^3 and H/L 0.16–0.25 were also common. They occurred on intersections with tectonic faults and may have been triggered by seismic activity. The youngest collapses occurred at Mt. Siaoguanyin (23,000 BP) and Mt. Cising (6000 BP).

It is concluded that the TVG should be considered volcanically active. The results of this study provide a basis for volcanic hazard assessment and mitigation in the area.

1. Introduction

The Tatun Volcanic Group (TVG) of Northern Taiwan is located in close proximity to one of the most densely populated areas of the world, with 7,800,000 inhabitants living in Taipei City and its suburbs (GeoNames geographical database). The region has a well-developed modern industrial infrastructure, as well as two nuclear power plants built directly near the foot of the volcanoes. The TVG itself includes the popular Yangmingshan National Park, which is visited by thousands of people every day. The consequences of a volcanic eruption of any type and scale would therefore be devastating for the region, and damage of the nuclear power plants may have a global impact.

The potential for renewed activity of the TVG has been debated for some time (Song et al., 2000a; Konstantinou et al., 2007). Although the group has not had any historical eruptions, its volcanic edifices are well-preserved and are dotted by multiple hot springs and solfataras with temperatures up to 116 °C (Witt et al., 2008). Detailed investigations undertaken in recent years have provided several lines of evidence that an active magma chamber is present below the TVG: (1) compositions of gases from the TVG fumaroles indicate their origin from a magmatic source (Yang et al., 1999; Lee et al., 2005; Lee et al., 2008; Witt et al., 2008); (2) shallow-level seismicity similar to seismicity under active volcanoes has recently been observed (Lin et al., 2005; Kim et al., 2005; Konstantinou et al., 2007); and (3) geodetic measurements (leveling and GPS) reveal steady local ground deformations of the TVG, which may be caused by pressure

* Corresponding author. Current address: Earth Observatory of Singapore, Nanyang Technological University, N2-01a-15, 50 Nanyang Avenue, 639798 Singapore. Tel.: +65 62 913 34 876.
E-mail address: abelousov@ntu.edu.sg (A. Belousov).

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changes at depth, possibly associated with migration of magma and/or hydrothermal fluids (Yu et al., 1997; Konstantinou et al., 2007).

To estimate the probability of future eruptions of the TVG, to predict their character, as well as to estimate eruption-related hazards, the history of volcanism of the area needs to be understood. Investigations of the geology of the group started in the beginning of the 20th century (Oshima, 1907; Deguchi, 1912) and continue to the present day due to the geothermal potential of the area (Chen, 1970, 1975; Yen et al., 1984; Ho, 1986; Chen, 2000). The first studies of the physical volcanology of the group were undertaken by Chen and Wu (1971), and Wang and Chen (1990). Song et al. (2000a) provided a brief description of pyroclastic deposits and suggested a general scheme for the geological history of the group. More recently, the first volcanic hazard assessment for the TVG was provided (Kim et al., 2005).

Here, we present the results of detailed investigations of the physical volcanology of the youngest TVG volcanoes. Special attention was given to the stratigraphy of various volcaniclastic deposits (tephras, lahars, and debris avalanches). In addition, morphologies of lava flows and domes were studied. Our goals were: (1) to date the most recent eruptions; (2) to reconstruct their scales and mechanisms; and (3) to estimate probability of different types of eruptions of the TVG in the future.

2. Geographical and geological backgrounds of TVG

The Quaternary TVG occupies 400 km^2 in the north of Taiwan Island. The tectonic position of the group is extremely complex (Fig. 1). In this region, two volcanic island arcs, Ryukyu and Luzon, merge (South China Sea and Philippine Sea plates are subducting in almost opposite directions) and simultaneously collide with the Eurasian continent (Kim et al., 2005; Hsu et al., 2009). However, the northern part of the Luzon arc has already been subducted (and partly obducted) under Eurasia and does not play a role in the recent volcanism of the TVG. In addition, ongoing rapid subduction (at approximately 8 cm/year) of the Philippine Sea plate under the Ryukyu arc is highly oblique in the western part of the arc, and therefore may arguably not be the principle cause of volcanism in the area. Moreover, while the Wadati–Benioff zone of the Ryukyu arc plunges at an angle close to 45° under northern Taiwan, the continuation of the zone currently cannot be detected directly below the TVG, which is located slightly off the lateral edge of the subducting plate. Thus, although geochemically the magmas of the TVG bear a clear subduction signature, some researchers have attributed its origin to the opening (gradual westward "unzipping") of the Okinawa Trough, which represents the Back Arc Basin of the Ryukyu arc (Teng, 1996). Others consider the origin of the TVG to be related to extension associated with the collapse of the Taiwan orogen (Wang et al., 1999, 2004).

The TVG is built on an angular unconformity with sedimentary basement composed mostly of Miocene quartz sandstones of shallow marine origin (Chen, 2000). Xenoliths of these sandstones are abundant in products of the TVG (Chen, 1965; Fuh, 1968). The basement is moderately folded and dissected by many faults, including several major thrust faults striking NE. Along the margins of the TVG, the basement rocks can be found as high as several

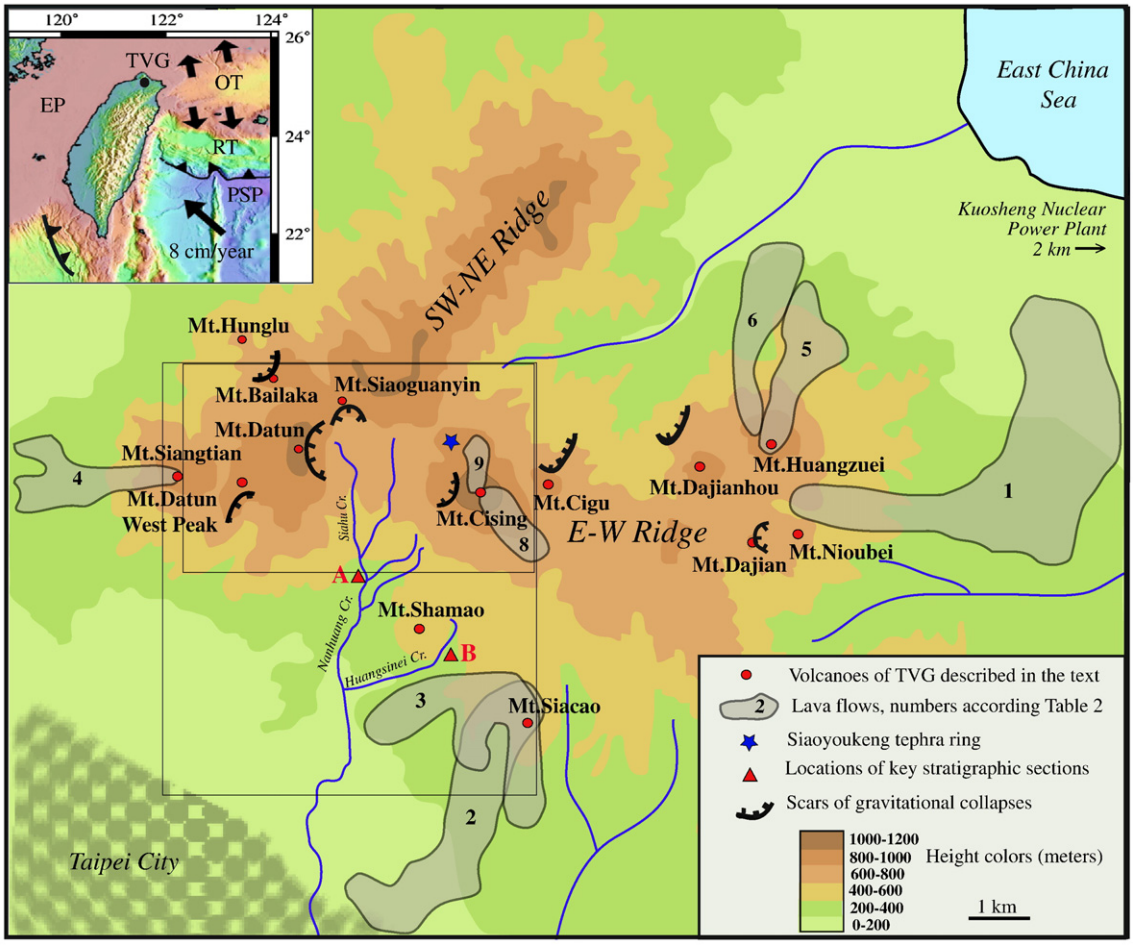

Fig. 1. Sketch map of Tatun Volcanic Group (TVG), Northern Taiwan. Locations of the main volcanic ridges, volcanoes, lava flows, collapse scars and key outcrops are indicated. Wanli lava flow (number 7 in Table 2) is located beyond the frame to the East of lava flow 1. Squares show areas of DEM-based shadow images in Figs. 6 and 7. Location of the TVG as well as the tectonic regime of Taiwan is shown in the inset. EP— Eurasian Plate, PSP —Philippine Sea Plate, OT—Okinawa Trough, RT —Ryukyu Trench.