THE CHARACTERISTICS OF HYDROTHERMAL ALTERATION AT STEAMING GROUND IN THE NORTHEASTERN PART OF TATUN VOLCANO GROUP, TAIWAN

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ABSTRACT

Geological and geochemical research was conducted to clarify characteristics of hydrothermal alteration of steaming ground located near Mt. Huangtsui, northeastern part of Tatun Volcano Group.

Steaming ground has been altered by acidic hydrothermal alteration to form silicified rocks, which are massive at the Sih-Huang-Ping (SHP) and occurred along NE trending fault zone in the Huang-Shan (HS). The fault zone at the Huang-Shan is accompanied by quartz veins. Alunite zones are developed surrounding the silicified zones, especially at Huang-Shan. The sulfur isotopic ratio of alunite from the Huang-Shan is high and indicates a hypogene origin. Although the hot springs from the Sih-Huang-Ping are steam-heated water at present, volcanic acid fluid with Cl-SO4 type is present in the Huang Shan.

The fluid inclusion temperatures of quartz from hydrothermal breccia at the Huang-Shan show boiling and higher homogenization temperature whereas those from quartz veins show boiling but lower temperatures.

1. INTRODUCTION

Tatun Volcano Group, located in the northern Taiwan is a famous hot spring area. About 30 hot springs such as Beitou, Yangmingshan, Matsao and Chinshan are distributed in a narrow zone with 3 km width and 18 km length along a northeast-southwest trending fault called the Chinshan fault (Figure 1). This area has the largest number of hot springs per unit area in Taiwan (Kishimoto, 1989).

Geothermal investigations have been conducted in the Tatun Volcano Group because this area is thought to be promising development target with a power potential of 500MW (Suto, 2008). However, acidic hydrothermal fluids with a pH of less than 2 are discharging from whole area of the Tatun Volcano Group. This has discouraged geothermal exploitation.

Dobson et al (2018) proposed a conceptual model of the geothermal system of Tatun Volcano Group based on a large number of data, and conducted a geothermal potential evaluation. According to the results, it suggests that the NE marginal portion of the Tatun Volcano Group may be amenable to geothermal exploitation. However, there are two important mitigating factors that need to be considered prior to making any new resource evaluations for this area. The first is to confirm whether or not there are near-neutral fluids present in portions of the deep reservoir, and how much of the reservoir contains these fluids.

The studied areas are located in the northern and Northeastern part of Mt. Huangtsui; studied steaming grounds are the Sih-Huang-Ping (SHP) and Huang-Shan (HS), respectively (Figure 2). The areas are the NE marginal portion of Tatun Volcano Group. The purpose of the study is to clarify the characteristics of geothermal activity based on alteration minerals, and sulfur isotope of alunite and hot springs.

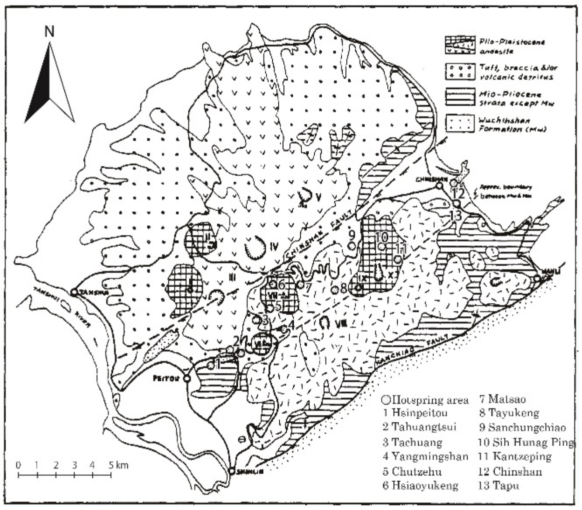

Figure 1: Geologic sketch map of Tatun Volcanic group (modified from Chen 1970).

2. GEOLOGICAL BACKGROUND

2.1 Structure

The area of Tatun Volcano Group has undergone a complex tectonic and structural history. Pliocene-Quaternary volcanism at Tatun is interpreted to be related to lithospheric extension in the N. Taiwan mountain belt, with the mantle source modified by subduction-related processes (Wang et al., 1999). While most of Taiwan is currently undergoing crustal shortening; northern Taiwan is experiencing extensional deformation. When the area was under compression, two major thrust faults were formed: the Kanchiao fault (east of Shihlin and Wanli), and the Chinshan fault (west of Peitou and Chinshan) (Chen, 1970) (Figure 1). However, a normal fault, name Sanchiao-Chinshan fault, moved along old Chinshan fault track during late postorogenic extensional event. Many hot springs are ascending along the Chinshan fault.

2.2 Volcanic and Geothermal fumarolic activity

Fumarolic activity is observed around the volcano, including the study areas, Beitou and Hsiaoyukeng. Volcanic activity in the Tatun Volcano Group continued from 2.8Ma to 0.3Ma, but subsequent activity has been weak (Wang and Chen, 1990). On the other hand, it is thought that the magma activity in this area has not declined because an eruption product with the age of 6ka was found (Belousov et al, 2010).

2.3 Geology

The basement rock of study area consists of the Oligocene quartz arenite called the Wuchihshan Formation, Lower tuff breccia, hypersthene hornblende andesite, olivine-bearing hornblende two-pyroxene andesite and upper tuff breccia were deposited in ascending order on the Wuchihshan Formation (Huang, 2005). Among these, andesites and upper tuff breccia are also present at the surface (Figure 2).

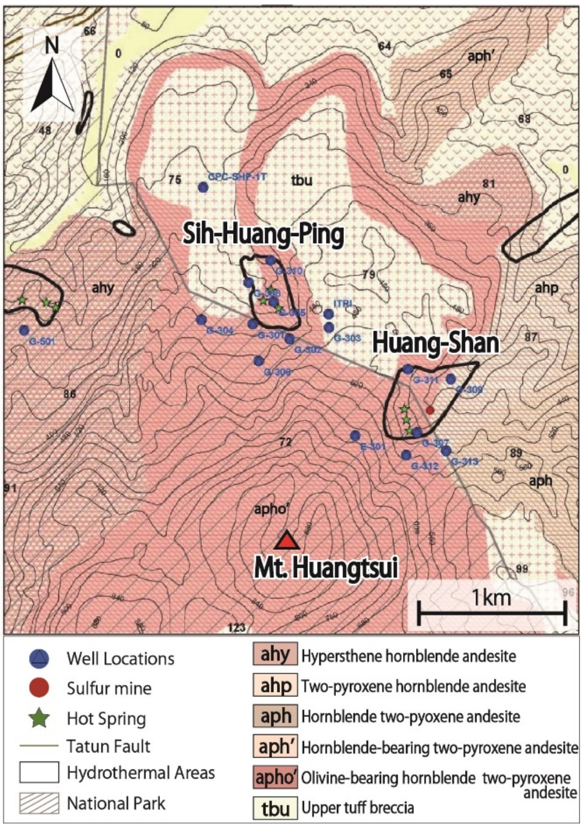

Figure 2: Geologic map of study area with locations of thermal features (modified from Dobson et al, 2018).

2.4 Thermal features

Thermal features at Tatun consist of acid-sulfate, near-neutral bicarbonate, and acid-sulfate-chloride hot springs as well as fumaroles (Liu et al., 2011). According to the Na-K-Mg diagram, not only acidic hot springs widely distributed in immature region, but also neutral hot springs plot in the immature and dilute region (Ohsawa et al., 2013). This indicates that there is no high temperature neutral Na-Cl type fluid at subsurface in the area. In addition, there are many acidic-Cl-SO4 type fluids having a high Cl / SO_4 ratio containing a considerable amount of chloride. Liu et al., (2011) also consider hot spring geochemistry in this study area. The result suggests that thermal water has three components: the meteoric water, magmatic fluids, and pore water from sedimentary rocks from Wuchihshan Formation with evaporation and/or water-clay mineral interaction. Accordingly, the low pH, high temperature, and SO_4 content acidic thermal water formed by mixing magmatic fluid and meteoric water. Subsequently, the thermal fluid in Wuchihshan Formation, where the neutralization did not occur, was released to the surface along with the evaporation by the depressurization.

3. RESULTS

Four hydrothermal alteration zones were distinguished by the assemblage of hydrothermal alteration minerals which were identified by XRD; silicified zone, alunite zone, kaolinite zone and smectite zone (Figure 3). The characteristics of each zone are as follows.

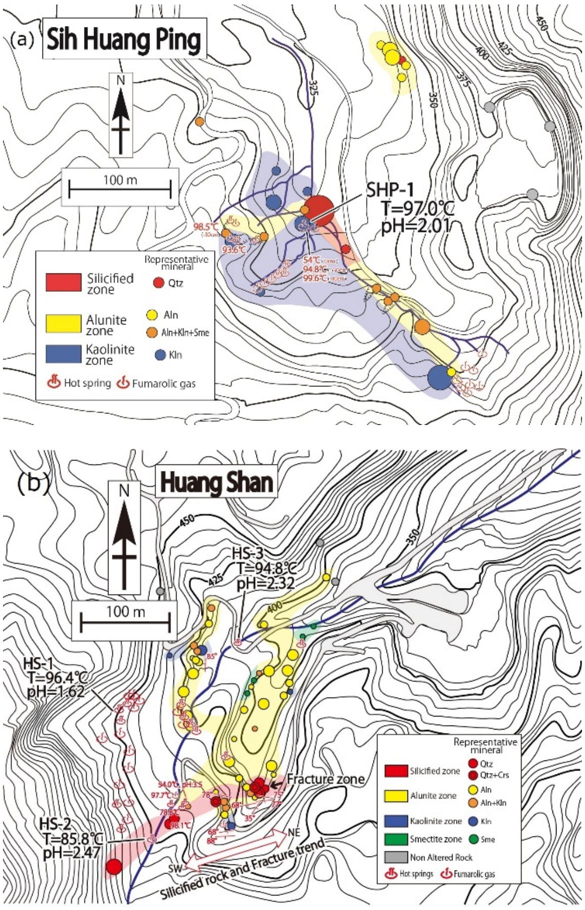

Figure 3: Hydrothermal alteration map of Sih-Huang-Ping(a) and Huang-Shan(b). Contours show above sea level.

(1) Silicified zone: The silicified rock in Sih-Huang-Ping is massive, dark gray, mainly composed of quartz and accompanied by pyrite, native sulfur, rutile and anatase (Figure 4a and e). The silicified rock in Huang-Shan is distributed along NE-trending fracture, white to dark gray, and quartz vein are also associated in the fractures (Figure 4b, c, f). Silicified rock is composed of only quartz, or quartz + amorphous silica, with a small amount of native sulfur, pyrite and anatase. Fine grain microcrystalline quartz (Figure 5a and b) occupies groundmass area with small amount of mosaic quartz (Figure 4c and d) and flamboyant quartz (Figure 4e and f). Mosaic quartz is 200μm and consists of subhedral and anhedral. Flamboyant quartz has a size of 50μm or less and often exists around mosaic quartz. Quartz vein is white and hosted by black sulfide (Figure 6a and b). The vein is composed of quartz, native sulfur, alunite and pyrite. Black part of quartz vein is richer in pyrite than white part. (Figure 6c and d).

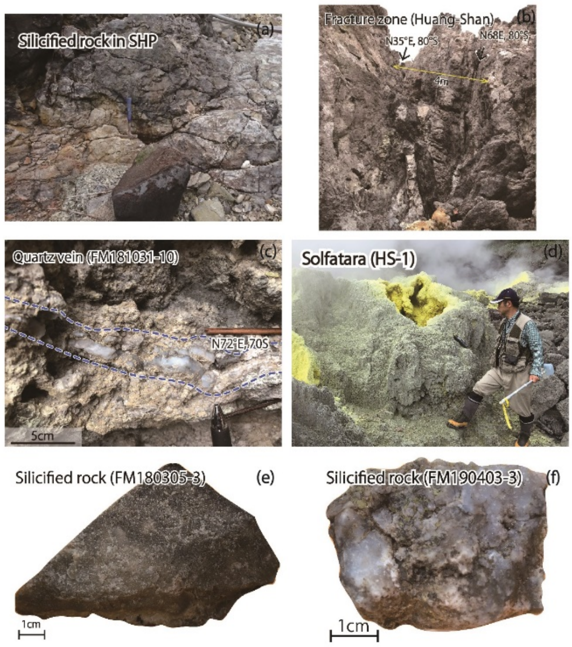

Figure 4: Characteristics of surface outcrops: (a) the occurrence of massive silicified rock in SHP, (b) NE-trending fracture containing silicified rock of HS, (c) quartz vein in the fracture, (d) big solfatara of HS, (e) silicified rock of SHP, (f) silicified rock of HS.

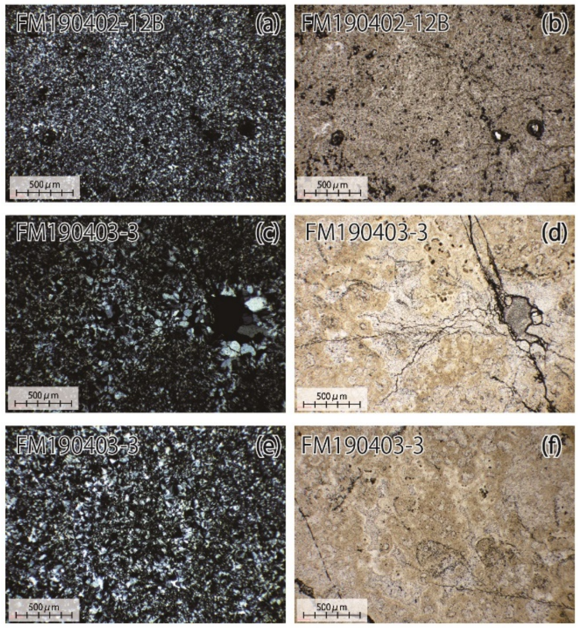

Figure 5: Photomicrographs of silicified rocks: (a) and (b) fine grain microcrystalline quartz, (c) and (d) subhedral and anhedral mosaic quartz, (e) and (f) flamboyant quartz.

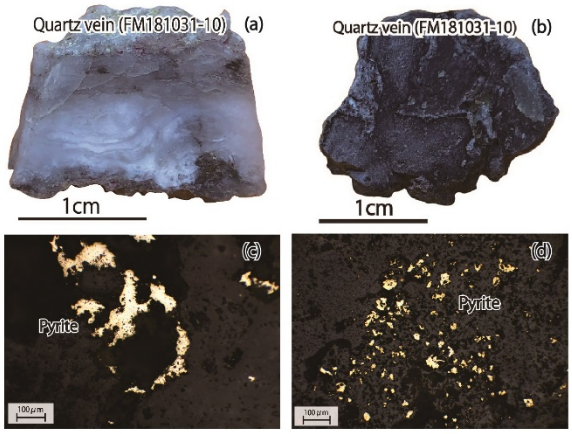

Figure 6: Photographs of quartz vein (a and b) and photomicrographs under reflected light (c and d).

(2) Alunite zone: Alunite zone is widely distributed around the silicified zone in the both areas of steaming ground as white to grayish white, sometime dark gray rock. The composed minerals are alunite, Na-alunite and minamiite as alunite group coexisting with quartz and sometimes cristobalite. Some samples contain kaolinite, smectite, native sulfur, pyrite, anatase and rutile.

(3) Kaolinite zone: The altered rocks of this zone are soft and often argillized. Kaolinite coexists with quartz and/or cristobalite and sometimes with small amount of smectite, pyrite and native sulfur. It is rarely accompanied by gypsum in Sih-Huang-Ping. One kaolinite sample coexists with pyrophyllite and amorphous silica near the silicified zone along the fractures of Huang-Shan.

(4) Smectite zone: Smectite is accompanied by quartz with a small amount of pyrite. It is located away from the silicified zone.

Fluid inclusion analysis was conducted from hydrothermal breccia of the alunite zone and quartz vein of the silicified zone. Homogenization temperature (Th) and salinity were measured on fluid inclusions of quartz. The results are shown in Figure 7. The fluid inclusions of quartz in hydrothermal breccia from Huang-Shan consist of liquid-rich (Type A) and gas-rich inclusions (Type B), and measured on two grains. Although all Th values range from 245 to 320°C, grain 1 has a peak around 255-260°C and grain 2 around 310-315°C. The salinity is 0.7 to 2.5 wt% and 0.2 to 1.0 wt% NaCl eq. for grain 1 and grain 2, respectively.

Fluid inclusions from the quartz veins at the Hunan-Shan mainly consisted of liquid rich (Type A) and gas-rich inclusions (Type B), with subsidiary type C, in which more liquid-rich inclusions containing smaller proportion of gas phase were also observed. The fluid inclusions show the fluid was trapped at boiling because gas-rich and liquid-rich inclusions are coexisted along mineral growth zone. The Th shows a temperature range of 115 to 230 °C. Type A has a peak at around 190-195 °C. And Type C has a peak at around 115-145 °C. The salinity is 0.2 to 1.0 wt% NaCl eq.

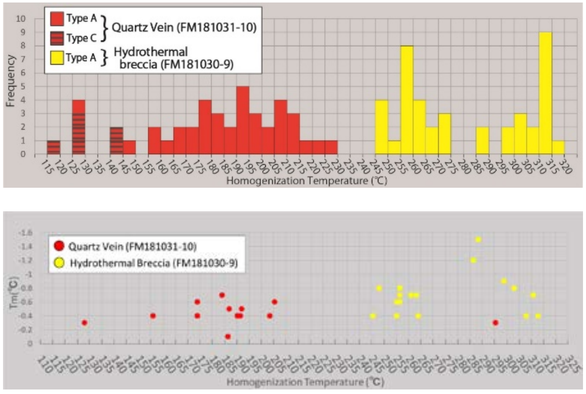

Figure 7: Distribution of homogenization temperature and ice melting temperature (Tm).

The sulfur isotopic ratios were measured on 13 samples from alunite (5 from SHP, and 8 from HS). The $\delta^{34}S$ values of alunite are -7.0 to 5.3% and 8.3 to 27.2‰ from SHP and HS, respectively.

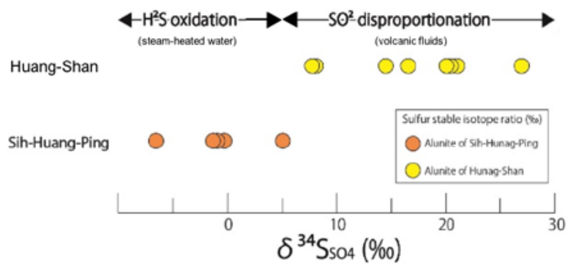

Figure 8: $\delta^{34}S$ value of alunite. The upper horizontal axis show the origin of fluid in each $\delta^{34}S$.

One and three hot springs were collected from Sih-Huang-Ping and Huang-Shan, respectively. The hot spring from SHP has a temperature of 96.4°C, pH of = 2.0 and high SO_4 concentration (SO_4 =1,866 mg/L, Cl =2.54 mg/L) indicating a steam-heated water origin. Hot springs from HS have a temperature of 85.0 to 96.4, pH of = 1.62 to 2.47, and being SO_4 dominant. However, the hot spring with pH=1.62 is higher in Cl (Cl=487mg/L, and SO_4=2,146). This hot spring is Cl-SO_4 type indicating magmatic hydrothermal fluid which is volcanic gas related.

4. DISCUSSION

Silicified rocks are found in the Sih-Huang-Ping and Huang-Shan steaming grounds. To form silicified rocks volcanic acid fluid with pH<2 is required volcanic acidic fluid with pH<2 (Hedenquist et al., 1994a).

At Sih-Huang-Ping, the silicified rock was found at the central part of the steaming ground. The pH of hot spring near the silicified rocks has a pH of = 2.01 with Cl=2.54 mg/l and SO4=1,866 mg/l; so called steam-heated water of SO4 type. The silicified rock is mainly composed of quartz. This suggests that the rock was eroded out by weathering. So, the occurrence of silicified rock at SHP suggests that the silicified rock was formed under the volcanic fluid with a pH less than 2 at subsurface in the past, then eroded out to the surface. This is supported also by sulfur isotope of alunite. Although most alunite shows low values of $\delta^{34}S$ indicating the steam-heated environment for alunite formation, an alunite with $\delta^{34}S$=5.3 ‰ suggests it was formed in hypogene origin, by condensation of volcanic gas. So, alunite with low $\delta^{34}S$ generated by the oxidation of H_2S probably under present condition, and the alunite with high. $\delta^{34}S$ values formed under magmatic hydrothermal conditions.

The silicified rocks at the Huang Shan occurred along a fault. This suggests volcanic fluid with pH<2 ascended along the fault and formed the silicified rocks. The silica mineral of silicified rocks are mainly quartz and/or quartz + amorphous silica. This suggests the rock formed a depth shallower than that of SHP. The fluid inclusions from the quartz vein in the silicified rock of the fault zone indicate that the fluid was boiling; it was boiling at 119°C estimated by the lowest homogenization temperature. The boiling depth is estimated to be about 10 m below the surface indicating a very shallow formation depth.

Alunite surrounding the silicified rocks shows larger $\delta^{34}S$ ranging 8.3 to 27.2‰ suggesting that the sulfur is mainly originated from hypogene acidic fluid due to disproportionation of SO_2. The fluid inclusion of quartz from the hydrothermal breccia has a temperature of higher than 255°C but does not show boiling. So some alunite is probably derived from much deeper by hydrothermal eruption. These are interpreted as follows; quartz of alunite rock was formed under magmatic hydrothermal fluid as the fluid rising, then temperature decreased and a quartz vein was formed near the surface. During the hydrothermal activity at HS, hydrothermal brecciation occurred, the alunite was formed at depth, and then was brought to the present surface. The magmatic hydrothermal fluid had higher temperature (255 to 260°C, 310 to 315°C) in the past, but now has changed to lower temperature (115 to 145°C) by some influences, such as decline of volcanic activity and dilution by meteoric water.

Therefore, we can refer hydrothermal activity occurred in SHP as; at the early stage of magmatic hydrothermal fluid formed silicified rock, subsequently eroded out to the present surface. However many alunite rocks were formed under acid SO4 steam-heated water, probably under near present conditions. On the other hand, magmatic hydrothermal fluid also contributed to the formation of silicified rocks and alunite at Huang-Shan.

It is inferred that the big difference in magmatic hydrothermal activity between the two areas of steaming ground is that magmatic hydrothermal fluid ascended along fault and fractures. This is because silicified rock of HS is present along the fractures, as opposed to the massive occurrence in SHP.

5. CONCLUSION

The characteristics of hydrothermal activities in Sih-Huang-Ping and Huang-Shan steaming grounds in the eastern part of Tatun Volcano Group were discussed based on alteration mineralogy fluid inclusion and sulfur isotopic ratios of alteration minerals and hot springs.

Silicified rock from both field, the SHP and HS, was formed under magmatic hydrothermal fluids. However most of alunite was formed under SO_4 steam-heated water dominant environment at SHP, on the contrast the Cl-SO_4 magmatic hydrothermal fluid at ~~in~~ HS based on sulfur isotope of alunite.

Especially, the Cl-SO_4 magmatic hydrothermal fluid was supplied along the fractures, and silicified rock was formed along the fractures at HS. The depth of the formation of the present silicified rock along the fractures was shallow and the temperature was 115~145°C. However, alunite in the hydrothermal breccia may have been derived from the deep based on the fluid inclusion temperatures.

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