Japan Geoscience Union Meeting 2014
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SVC51-01 Room:312 Time:April 29 14:15-14:30

Hydrothermal system around the Bandaiko hot spring inferred from a 3-D resistivity structure

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Bandaiko is a hot spring located in the eastern flank of the Kusatsu-Shirane volcano, 3km west from Kusatsu-Onsen. It was discovered in 1967 during excavation of a sulfur mine, and has been utilized as one of the sources of Kusatsu-onsen since 1976. It is presumed that a gush point is located in 505 m west from a tunnel entrance. The ground temperature above the presumed gash point exceeds 80 degrees. About 10 to 20 percent of the hot spring water is always discharged as vapor, so that existence of a two-phase hydrothermal system in a shallow part of tunnel end is considered to be certain. Moreover, since the chemical nature of hot spring is well investigated, Bandaiko is a suitable field which clarifies the resistivity image of a hydrothermal system.

We investigated the shallow resistivity structure around the Bandaiko hot spring using the AMT (audio-frequency magnetotelluric) method. The measurement was done on Oct.19th through Oct.26th, 2013. Five components of EM fields were measured at 19 sites around the presumed gush point: measurements were carried out during the nighttime at 15 of them with sufficient S/N. Because the measuring frequency was 1-10400Hz, information on the resistivity structure from the vicinity of surface to the depths of 1-2km can be obtained. A site for the remote-reference was not installed. Instead, a local-site-reference was applied each other. The 60 Hz noise as well as the 50 Hz noise caused by the local commercial power was extensively seen, because the survey area is located in close proximity to a prefectural border of Nagano where 60 Hz power is used.

Three-dimensional (3-D) analysis was performed in this study. A 3-D resistivity structure model was estimated from the inversion code of Siripunvaraporn and Egbert (2009) using 15 frequencies of all components of impedance data. The inferred model shows low resistivity near the end and the entrance of tunnel. In this presentation, we will report the up-to-date model of the 3-D resistivity structure and discuss the hydrothermal system around Bandaiko in consideration of the measured values of the electrical conductivity of hot spring water, etc.

This study was supported by the Earthquake Research Institute cooperative research program.

Keywords: resistivity structure, Kusatsu-Shirane volcano, hydrothermal system, Kusatsu-onsen, Bandaiko

SVC51-02 Room:312 Time:April 29 14:30-14:45

Resistivity structure around the Jigokudani valley, Tateyama volcano, Japan, inferred from AMT

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Midagahara (Tateyama volcano) is situated in the northern part of the Japan Alps, and fumarolic activity occurs in the Jigokudani valley located in the northeast end of the Midagahara Plateau. Jigokudani valley was formed by the periodically repeated vapor explosions. Increase in volcanic activity is a great concern because of recent events such as a sulfur outflow, a composition change of the fumarolic gases and the emergence of high temperature fumaroles. We investigated the distribution of hydrothermal fluid and gas reservoir beneath Jigokudani using the AMT method to image the 2D resistivity structure and checked the position of fumaroles. In this observation, the AMT sites were installed along the ENE-SWS survey line around the Jigokudani Valley. The final model revealed that there is a conductive body beneath the Jigokudani valley, and that a relatively low resistive body extends through between the high resistivities beneath the conductor. Near-surface conductor is divided into slightly conductive upper part and lower part. The upper part is explained by clay sediments and hydrothermal fluids. The lower part indicates the presence of gases and fluids. Because of clay's impermeability, the upper clay sediments play the role as a cap for gases. The deep resistive layer is estimated to be the basement of granites that are widely exposed around the Jigokudani valley. We inferred that the relativity conductive body separating these granites is a path of the magmatic gases. The most active fumarole in the Jigokudani valley is on extension of this path.

SVC51-03 Room:312 Time:April 29 14:45-15:00

Hydrothermal system at Tatun Volcano Group, northern Taiwan, inferred from resistivity structure

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Tatun Volcano Group is composed of over twenty volcanoes, which were formed within faults at the northern tip of Taiwan. So far, these volcanoes were regarded as extinct because of no historical record of eruption. However, recent studies have found the relatively young ejecta (Chen and Lin, 2002; Belousov et al., 2010), high 3He/4He ratio (Yang et al., 1999; Ohba et al., 2010), and hypocenter distribution suggesting the fluid flow and the high temperature condition (Konstantinou et al., 2007); that suggest the presence of potentially eruptive magma beneath TVG. Further, active heat discharge from fumaroles and springs also suggests a large amount of the volcanic fluids released from magma beneath Chishinshan volcano. Focusing on this phenomenon, Utsugi et al. (2012, JPGU) conducted AMT surveys at the volcano for a better understanding of this magma degassing, and showed the preliminary resistivity structure suggesting the low resistivity region at the depths of 1-2km.

On the basis of their work, the authors conducted further AMT surveys around Matsao hot spring and Da-you-keng fumarole areas, about 2 km northeast of the volcano. Time series of the electric and magnetic fields were acquired for about 4 hours at each site. Totally 10 observation sites were configured to cover the areas. After data acquisition, the frequency domains were obtained from the time series, using FFT processing. The impedances were estimated for each frequency. The obtained frequency range was between 1 and 10400 Hz. The authors used not only the data of the present study but also those of Utsugi et al. (2012, JPGU).

This study categorized the study area into two areas, mainly from the characteristics of the main axes of the impedance phase tensor ellipse by the method of Caldwell et al. (2004): 1) Mt. Chishinshan area and 2) Matsao and Da-you-keng areas. In this study, two-dimensional resistivity structure was estimated for each area, using the inversion code of Ogawa and Uchida (1996). By incorporating them with the evidences from geochemistry and geophysics (MRSO, 1969, 1970, 1971, 1973; Ohba et al., 2010; Ohsawa et al., 2013; Murase et al., 2013, IAVCEI), the following features of the hydrothermal system was inferred.

Beneath Mt. Chishinshan two-phase fluids are supplied; which is represented by the extremely-low resistivity column (less than 3 Ohm-m) and the deflation pressure source below 1 km depth. As the fluids ascend, their phase is changed into vapor-phase, leading to low to relatively-low resistivities (6-30 Ohm-m) at the depths of 0.3-1 km. The vapor-rich region is covered by the low-permeability cap represented by the extremely-low resistivity layer near the surface (less than 3 Ohm-m). A portion of the vapors is mixed with shallow groundwater, and flows along a topographical relief to form Matsao hot spring; whose area is represented by resistivities less than 10 Ohm-m.

On the other hand, Da-you-keng area has intense fumaroles; whose vapor-dominated fluids are supplied from the region beneath Cing-tian-gang, represented by the low to low-resistivity region (3-30 Ohm-m) and the inflation pressure source below 1 km depth. This vapor-bearing region is covered by the overlying low-permeability cap represented by the extremely-low resistivity region (less than 3 Ohm-m).

This study estimated the horizontally-extending vapor-rich region beneath Mt. Chishinshan, Da-you-keng, and Cing-tian-gang. Actually, this area has experienced a phreatic eruption ca. 6 Ka (Belousov et al., 2010). These suggest that the vapors have been maintained for at least several thousands years, and that there is still a possibility of phreatic explosions.

Keywords: Tatun Volcano Group, Hydrothermal system, Two-phase region, Vapor-dominated region, Pressure sources

SVC51-04 Room:312 Time:April 29 15:00-15:15

Conductivity distribution of the surface layer in Aso Caldera

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Kagiyama and Morita(2008) proposed that volcanism has a wide range of diversity represented by two typical end members controlled by the easiness of magma storage beneath volcano; Eruption dominant (ED) volcanism in difficult condition and Geothermal activity dominant (GD) volcanism in easier condition. In GD volcanoes, magma stagnates beneath volcanoes and maintains geothermal activity. This seems GD volcanoes continue to give much benefit to human society. However, GD volcanoes sometimes have large eruptions after repeated stagnations of magma. This fact suggests it is very important to understand where and why magma stops ascending. Kagiyama and Morita (2008) indicated magma degassing is one of the important factors to control magma ascending. On this aspect, the authors have carried out VLF-MT survey around some active volcanoes in Japan, because electrical conductivity of ground strongly depends on the conductivity of pore water.

Aso Caldera has an acid crater lake in Nakadake, which is one of the post caldera cones, and has many hot springs such as Uchinomaki, Akamizu. Conductivity distribution shows two typical features; caldera floor has almost homogeneous and high conductivity (>10mS/m), while the post caldera cones show wide range.

Most cones such as Kishima-dake and Ohjo-dake have lower conductivity (<3mS/m), except around Naka-dake Craters and western flank of post caldera cones such as Yoshioka, Yunotani and Jogoku-Tarutama (>30mS/m). Kusasenri Volcano, located between Naka-dake and Yoshioka has also rather high conductivity (3-10mS/m). These areas locate along the E-W trend of the major post caldera cones. Most part of the northern flank of the post caldera cones shows low conductivity (<3mS/m). However, higher conductivity was found around Sensuikyo, just north of Nakadake Craters. This suggests down flow of hydrothermal water from Naka-dake Craters to the caldera floor. Similar features are detected in the southern flank; from Nakadake to Shirakawa Hot Spring, from Jigoku-Tarutama Hot Springs to Tochinoki Hot Springs.

Caldera floor has almost homogeneous conductivity. This feature is explained by the fact that the caldera floor was under the lake until 9 ka and is covered by lake deposit. However, extremely high conductivity was found at three areas (>50mS/m). Two of them correspond hot spring areas; Uchinomaki in the north and Akamizu in the west. The third area is distributed around old post caldera cones, Mietsuka. The age of these cones was estimated around 46 ka, and no hot spring is distributed. High conductive zones, Uchinomaki, Mietsuka and Naka-dake are located along the NNW-SSE line. Hydrothermal water may be supplied along this line.

These results suggest that hydrothermal water is supplied along the E-W trend crack from Naka-dake to Yoshioka, mainly supplied beneath Naka-dake, and expanded to the northern caldera floor. The NNW-SSE trend from Naka-dake to Uchinomaki may suggest a tectonic fault. Aso has wide high conductivity area and degassing in Aso might be large to be GD volcano.

Reference: Kagiyama and Morita, First steps in understanding caldera forming eruptions, J. Disaster Res., 3, 270-275, 2008.

Keywords: Electrical conductivity, Geothermal activity, Failed eruption, Aso Caldera

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The thermal expansion model and the Mogi model for volcanic ground deformation

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(1) Basic aspects of the thermal expansion model, which was proposed by the author in this meeting of the last year (Kitsunezaki and Muraoka, 2013), is reorganized in relation to the Mogi model (Mogi,1958). In the Mogi model, the earth's crust is assumed to be a semi-infinite isotropic homogeneous elastic solid with the horizontal free plane (the ground surface). Displacement of the ground surface caused by a spherical pressure source set up in the earth's crust is evaluated. Gravity change associated with the deformation was estimated by Hagiwara(1977). Basically, the inside of the spherical source of this model is void (or material different from the surroundings). As a special case, we assume that the inside is filled with the same material as the surroundings and that temperature in the inside is raised (keeping the outside temperature constant). Thermal expansion of the sphere behaves as a pressure source, and the Mogi model is transformed to the spherical thermal expansion model (ST model). In this case, as the mass of the sphere does not change, the change in gravity on the ground surface is caused by the free-air effect (FE) due to uplift of the ground surface alone.

(2) The above ST model can be extended to the case in which the temperature-rise region (T region) has arbitrary shape. Let the T region be subdivided into a large number of small cubic cells. Every cell effectively behaves as a spherical thermal element. Its outputs (displacement and gravity change on the ground surface) are given by the ST model. The output of the entire T region is given as a sum of the output of each element. Hence in the T region with any shape, the change in gravity is caused by the FE due to the vertical displacement of ground surface alone.∗

∗[Note] The related description in Kitsunezaki and Muraoka(2013) has been corrected here.

(3) Shallow regions of actual volcanoes may be regarded as porous media. Let's assume that the pores are saturated by water and are in open condition. In the thermal expansion model described in (1) and (2), the earth medium is replaced by such a water-saturated porous medium. In this case, pressure of pore water is kept constant. Hence the solid part (skeleton of the medium) behaves in deformation independently from pore water. Thermal expansion of the solid part causes the displacement of the ground surface and the gravity change due to the FE as described in (2). On the other hand in the T region, the pore water expands freely responding to the temperature-rise (below the boiling point), hence its density decreases. (Thermal expansion coefficient of water is more than ten times larger than that of solid part (rock)).This effect causes negative gravity change, which is added to the FE so as to amplify the total gravity reduction to some degree. This example is numerically demonstrated in gravity variation observed in Akita-Komagatake volcano after the 1970-eruption.

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Kitsunezaki, C., and Muraoka, A. (2013): Gravity variation in Akita-Komagatake volcano and thermal expansion model, Japan Geoscience Union Meeting, SVC52-04 .

Mogi, K.(1958): Relations between the eruptions of various volcanoes and the deformations of the ground surfaces around them, Bull. Earthq. Res. Inst., Vol.36.99-134.

Keywords: thermal expansion model, Mogi model, gravity change, ground deformation, Akita-Komagatake, porous media

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El Cobreloa: A geyser with two distinct eruption styles

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We performed field measurements at a geyser nicknamed “El Cobreloa”, located in the El Tatio Geyser Field, Northern Andes, Chile. The El Cobreloa geyser has two distinct eruption styles: minor eruptions, and more energetic and long-lived major eruptions. Minor eruptions splash hot water intermittently over an approximately 4 minute time period. A major eruption begins with an eruption style similar to minor eruptions, but then transitions to a voluminous water-dominated eruption, and finally ends with energetic steam discharge that continues for approximately 1 hour. We calculated eruption intervals by visual observations, acoustic measurements, and ground temperature measurements. All measurements consistently show that each eruption style has a regular interval: 4 hours and 40 minutes for major eruptions, and approximately 14 minutes for minor eruptions. We develop a model, in which the geyser reservoir, connected to the surface by a conduit, is recharged by the deep, hot aquifer. More deeply derived magmatic fluids provide the enthalpy to heat the reservoir. Boiling in the reservoir releases steam and hot water to the overlying conduit causing minor eruptions, and heating the water in the conduit. When the conduit becomes warm enough, the water in the conduit is able to boil, leading to a steam-dominated eruption that empties the conduit. The conduit is then recharged by the shallow, colder aquifer, and the eruption cycle begins anew. El Cobreloa provides insight into how small eruptions prepare the geyser system for large eruptions.

Keywords: geyser, El Tatio, geothermal systems, eruption

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Time variation in the chemical composition of fumarolic gases at Hakone volcano, Japan

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Introduction

Mt Hakone having the caldera structure is an active volcano located on the western end of Kanagawa prefecture. At the central region of caldera, several volcanic cones are located. On the flank of cones, geothermal areas have been developed. The magmatic activity, which formed the cones, started 50 Ka (Kuno, 1972). The activity is estimated to have continued until 3 Ka (Kobayashi et al., 1997). At the last eruption, the western flank collapsed at one of the central cones, resulting in the formation of dammed Lake Ashi (Ooki and Hakamada, 1975).

At Mt Hakone, volcanic earthquakes have been observed frequently, although no historical eruption is known. Especially in 2001, the occurrence of volcanic earthquake was intense. The seismic activity was accompanied with an inflation of body at the central cones. The inflation was interpreted to be brought by a pressure source at 7 km of depth (Daita et al., 2009).

Sampling of fumarolic gas

We sampled fumarolic gas at two sites since May 2013 at Owakudani geothermal area developed on the central cones. One of the sites is located 200m far from the Owakudani car parking in the direction of southeast. At the site we had sampled fumarolic gas in previous study. We call the fumarole as the regular fumarole. Another fumarole is located 500m far from Owakudani car parking in the direction of north. The fumarole has been generated recently. Before the generation, the area was forest. Now many large stout trees were killed by the geothermal effect. We call the fumarole as the new fumarole. Both of the fumarolic gases were sampled in the evacuated Giggenbach bottle containing 20 ml of 5M KOH solution.

Result

The main component of the regular and new fumarole was water vapor (H2O). The molar percentage of H2O was about 98% for the both fumaroles. Both of the gas contain CO2 gas as the major component next to H2O, the percentage was about 1 to 2%. The regular fumarolic gas contained H2S as much as 0.2 to 0.4%. The H2S concentration in the new fumarolic gas was only 0.036 to 0.050%, about 1/10 to the regular fumarolic gas.

The CO2/H2S molar ratio indicated a time variation, a monotonic decrease since May 2013 to Oct 2013. Daita (2013) reported a similar trend based on the observation with detecting tubes. Daita (2013) found an abrupt increase in the CO2/H2S molar ratio on Jan 2013. The increased ratio had been kept until April then decreased gradually toward Oct 2013. According to the seismic observation by Hot Springs Research Institute of Kanagawa Prefecture, volcanic earthquakes occurred frequently in Jan and Feb 2013. We suppose the change in the CO2/H2S ratio has been synchronized with the occurrence of volcanic earthquakes.

Keywords: Fumarolic gas, CO2, Volcanic activity, Hydrothermal system

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Geochemical characteristics and changes of thermal waters around Tokachidake volcano, Japan

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Tokachidake volcano, located in central Hokkaido, caused three magmatic eruptions (AD 1926, 1962 and 1988-89) in the 20^{th} century. The seismic and thermal activities at the summit crater area have increased since AD 2010. We have continuously investigated thermal waters around the volcano since AD 1986 in order to understand the volcanic activity. Around the AD 1988-89 eruption, the chemical compositions and temperature of the thermal waters had obviously changed (Murayama et al., 1991). Therefore, we need to reveal the origin and changes of the thermal waters in order to forecast the future volcanic activity.

The thermal waters are discharged in the Nukkakushi crater (Ansei crater) and at its lower reaches, which is located at about 2 km southwest from the summit craters. Each thermal water is acidic with pH $<$3.2. At the time of AD 1986, all thermal waters were rich in sulfate ion but were scarce in chloride ion. In addition, anion content of the thermal waters decreases in proportion to the distance from the Nukkakushi crater. Therefore, the thermal waters derived from the Nukkakushi crater area flow, while mixing with groundwater, and are discharged at the lower reaches.

At the Fukiage hot spring area (1,000 m a.s.l.), the concentration of chloride and sodium ions in the thermal waters had abruptly increased since AD 1986. The increase of these chemical concentrations had continued until AD 1992, and the concentration of them had decreased since then. Accompanied with the chemical change, the temperature of the thermal waters had also increased more than 20 ^{o}C around the AD 1988-89 eruption. Such increase of the chemical compositions and temperature of the thermal waters had occurred related to the increase of the volcanic activity. Thus, these increases can be explained by mixing of highly dense NaCl type thermal water into shallow aquifer, and its mixing ratio changed with the volcanic activity. The chemical and thermal changes of the thermal waters have not occurred at the Okina hot spring (1,060 m a.s.l.). This indicates that the input of highly dense NaCl type thermal water has occurred at the lower reaches of the Okina hot spring.

Based on our investigations, the thermal waters in this area are formed by mixing of three end-members, sulfate ion rich thermal water, dense NaCl type thermal water and groundwater. The effect of the dense NaCl type thermal water is recognized only at the Fukiage hot spring area, and the mixing ratio changes according to the volcanic activity. The concentration of chloride and sodium ions in the thermal waters has begun to increase again since AD 2012. However, the increase is obviously small compared with that before the AD 1988-89 eruption, and the oxygen and hydrogen isotopic compositions of these thermal waters have not shown obvious change yet. Observations of the thermal waters will provide useful information to forecast the future volcanic activity in Tokachidake volcano, and hence we will continue the observations.

Keywords: Tokachidake volcano, thermal water, chemical composition, eruption forecasting

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Case study of the behavior of isotope in several hot-spring field

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1. Introduction

The behavior of oxygen and hydrogen isotope in geothermal field suggests the origin of fluids and the water rock interaction in fluid path. And there are various origins of high temperature hot springs in Japan, for example, separation from magma, heating meteoric water in the underground.

In this paper, we show the several samples of the isotopic analysis in high temperature hot spring fields including hot spring binary test field and we discuss the diversity of origin of the hot springs.

2. Examples of several hot spring fields

(1) Hachijo Island

There is a geothermal power plant (3.3MW) in Hachijo Island. To clarify hydraulic system, we measured oxygen and the hydrogen isotope ratio of the hot spring fluid, underground water as spring and the fluid at geothermal power plant. The isotope ratio of spring is similar as rain in Hachijo Island and the value of d is about 20 and hydrogen isotope ratio of spring is about -35 ‰. The hot spring fluid in Hachijo Island has two patterns. One is the origin of meteoric water due to similar isotope ratio as spring water. And another is the origin of seawater due to similar isotope ratio as seawater. The isotope ratio of fluid of geothermal plant is higher oxygen ratio than spring and hot spring water and this suggest that the origin of the fluid of geothermal plant is mixture meteoric and magmatic water.

(2) Matsunoyama hot spring field

In Matsunoyama hot spring field, the test of binary power plant is carried out using Takanoyu #3 hot spring fluid with about 100 ℃ and 10,000 mg/l Cl. The hydrogen isotope ratio is about -25 ‰ and oxygen isotope ratio is about 0 ‰ higher than meteoric water. And the isotope ratio of Matsunoyama #4 well with 2,000mg/l shows the mixture of meteoric water and Takanoyu #3. The origin of Takanoyu#3 is fossil salt water with methane gas and geo-pressure structure.

(3) Minami-Izu hotspring field

There is high temperature hot spring with about 100 ℃ and 10,000 mg/l Cl in Minami-Izu hot spring field, too. In this field the temperature and Cl concentration decrease eastern area. The isotope ratios of the several hot springs and underground water exist on the meteoric line. This suggest the origin of hot spring is meteoric water and the reason of temperature and cl concentration decreasing is mixture with low temperature meteoric water.

Keywords: hot spring, geothermal, isotope, meteoric water, fossil salt water