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SELF-POTENTIAL AND AUDIO-MAGNETOTELLURIC SURVEY IN WHITE ISLAND VOLCANO

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SUMMARY - A Self-potential survey and a audio-magnetotelluric survey were carried out in White Island volcano, New Zealand. SP anomalies of positive polarity are present over the active geothermal features where upflow must take place. Negative SP anomaly overlies the centre of the eastern subcrater and the north-eastern half of the central subcrater, where subsurface downflow could exist. The SP distributions observed in 1993 and 1996 are almost similar, except for the area close to the 1978/90 Crater Complex due to a change in volcanic activity. We assume there is a volcano-hydrothermal system beneath the Main Crater floor, which supplies upflow to thermal features along the edge of the subcraters. The audio-magnetotelluric data suggests altered clay layers at the surface and very conductive layer comparable to sea-water resistivity in the eastern subcrater. This layer suggests sea water invasion to the shallow depth or very conductive hydrothermal water in the volcano-hydrothermal system.

1. INTRODUCTION

White island volcano is one of the most active volcanoes in the world. This andesitic-dacitic composite volcano is located at the north-eastern end of the Taupo Volcanic Zone in New Zealand.

The most characteristic topographic feature of the volcano is the Main Crater, which is approximately **0.5 km x 1.25 km enlonged in ESE-WNW direction.** The Main Crater is subdivided into three subcraters - eastern, central and western subcraters and the historical eruptive activities have been taken place within the western and the west half of the central subcrater (Houghton and Nairn, 1989). There has been a crater lake over the active vents in this area fkom 1993 whose surface was at about 68.2 metre bellow sea level in 1993 fiom an aerial photograph analysis (Yasuda et al., in press).

In the Main Crater floor, there are many high-temperature fumaroles and acid springs. Chemical analysis of these fumaroles and *spring* discharges has shown that a large volcano-hydrothermal *system* underlies beneath the Main Crater floor and this *system* is isolated from *sea* water around the island (Giggenbach, 1987). This volcano-geothermal *system* has existed for at least 10,000 years based upon a study on trace metal enrichment in marine sediments (Giggenbach and Glasby, 1977). The abundance of groundwater within volcano-hydrothermal *system* is the most important external control on the style and mechanism of eruptions at the volcano (Houghton and Nairn, 1989).

To get additional data to understand this volcano-hydrothermal *system,* we have carried out self-potential surveys and audio-magnetotelluric measurements in this volcano.

2. MEASUREMENTS

2.1 Self-Potential survey

Self-potential(SP) *surveys* have been carried out in many geothermal and volcanic areas (e.g. Corwin and Hoove, 1979; Ishido *et* al., 1989; Ishido et al., 1994; Lénat, 1995) and in most cases, SP anomalies of positive polarity were found over high temperature upflow zones. The most likely cause of these positive anomalies are believed to be the *streaming* (electrokinetic) potential generated by hydrothermal circulation (Ishido *et* al., 1989).

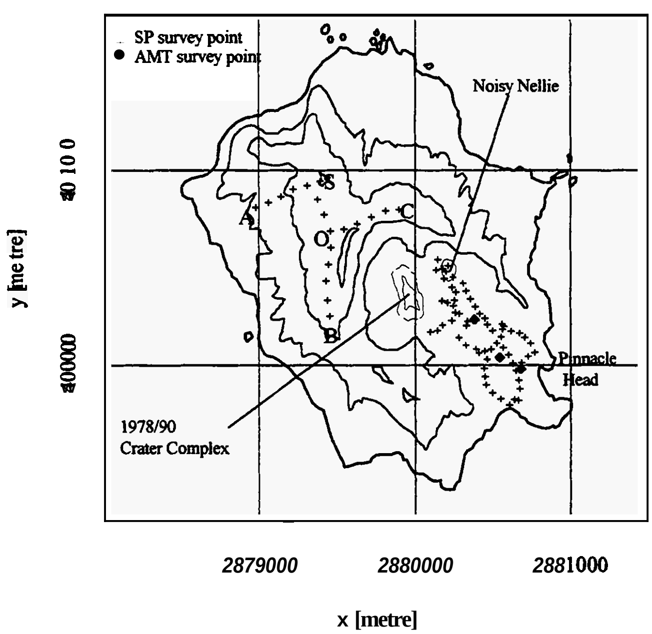

Figure 1 - Location map of the survey points
New Zealand Map Grid Projection
elevation contour interval=100 m

The fluid flow through a porous medium can carry electric charge along the flow path by the interaction of the moving pore fluid with the electrical double layer at the pore surface (electrokinetic coupling; see e.g. Ishido and Mizutani, 1981). In case of source-free fluid flow, sources of conduction current (required for the appearance of electric potential on the ground surface) will appear wherever there are guradient of crosscoupling coefficient parallel to the direction of fluid flow (flow perpendicular to boundaries) (Sill, 1983; Ishido, 1989). The crosscoupling coefficient (zeta-potential) decreases in magnitude with decreasing temperature in the upflow region, resulting in positive-charge accumulation (positive sources of conduction current) along the upflow path.

Conduction current sources are induced at groundwater table for terrain-related SP. The electric potential generated by terrain-related fluid flow decreases as the ground surface elevation increases (usually 0.1mV/m to 10mV/m) (Ishido, 1989). In Izu-Oshima island, terrain-related SP of 1mV/m has been observed between zero and 400 m in elevation. However, SP tends to increase with increasing elevation above 400 m; a positive anomaly of about 3 km spatial extent is present centred at the summit crater (see e.g. Ishido et al., 1994). Ishido (1996) used numerical simulation technique (Ishido and Pritchett, 1996) to study these features of SP in Izu-Oshima volcano. Primary cause of the positive anomaly was shown to be the disappearance of terrain-related downflow of ground water due to heating of the volcanic vent and its neighbour. Positive current sources produced by the upflow itself are minor in this case.

In February, 1996, we have carried out SP profile surveys in the Main Crater floor and also in the outer slope of the Main Crater. We planned to measure SP almost whole area in the Main Crater floor. We also conducted a SP profile survey in the outer slope of the volcano to get topography effect on SP and wider SP profile. The locations of these profile survey points are shown in Figure 1.

We used one pair of silver-silver chloride non-polarizing electrodes (Ishido et al., 1992) for these profile surveys. We set an electrode at a base point and move the other electrode around the base point to measure potential difference at each observation point. The mean interval of the observation points is about 50 metres in the Main Crater floor and 100 metres in the outer slope. When we moved the electrode at a base point to another base point, we set three very close observation points which were measured from the both base points to minimze error due to short wavelength noise. In the Main Crater floor, the survey lines were set to cover almost whole area and to make some loops to check the

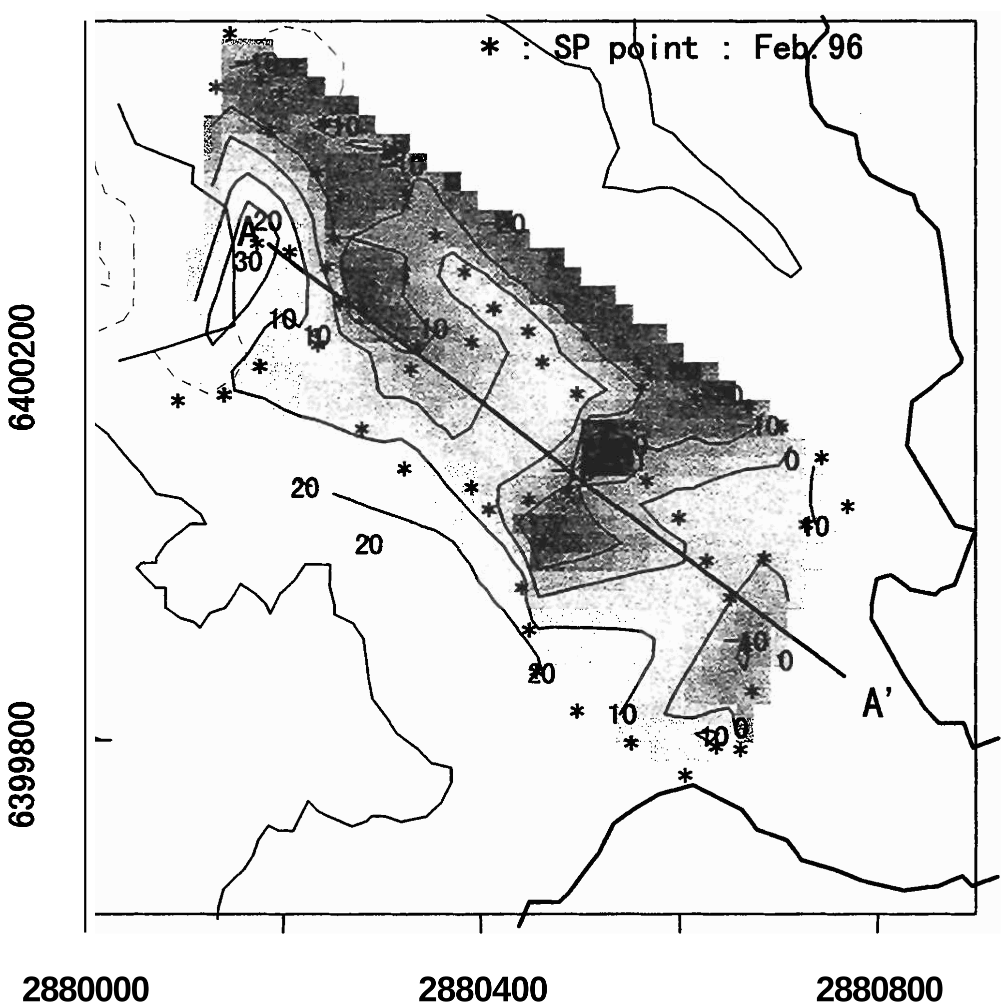

Figure 2 - Self-potential distribution in Feb.1996
New Zealand Map Grid projection

closure error. The maximum closure error was 2 mV.

To locate those survey points, we basically used differential GPS surveys using InfoNAV service of DOSLI (Department of Survey and Land Information, New Zealand). We had to interpolated the location of some survey points in the Main Crater floor from other well-located points and elevations from **Yasuda** et al.(1996)'s topography map due to steep crater wall and an unhealthy satellite during the survey period.

2.2 Audio-magnetotelluric measurements

To reveal detailed resistivity structure in relation to the underlying geothermal system, we also carried out three tensor audio-magnetotelluric (AMT) measurements in the Main Crater floor. In White Island, there were only few resistivity surveys : Schlumberger DC resistivity soundings (Bibby, personal comm.) and AMT soundings at few sites (Ingham, 1992).

The closest site to the active vents is approximately 200 m southeast of Noisy Nellie and the other two sites are aligned in NE-SW direction toward Wilson Bay as shown in Figure 1.

We used real-time tensor AMT system manufactured by Phoenix Geophysics, Canada. Each measurement took 2-3 hours to cover the fiequency range between 10 kHz and 1 Hz. Although the so-called dead-band signals (2 kHz-500 Hz) turned out to be too weak to analyse, other fiequency data were of good quality.

3. RESULTS

3.1 Self-Potential survey

The SP distribution in the Main Crater floor is plotted in Figure 2. The potential at a survey point near the shore of

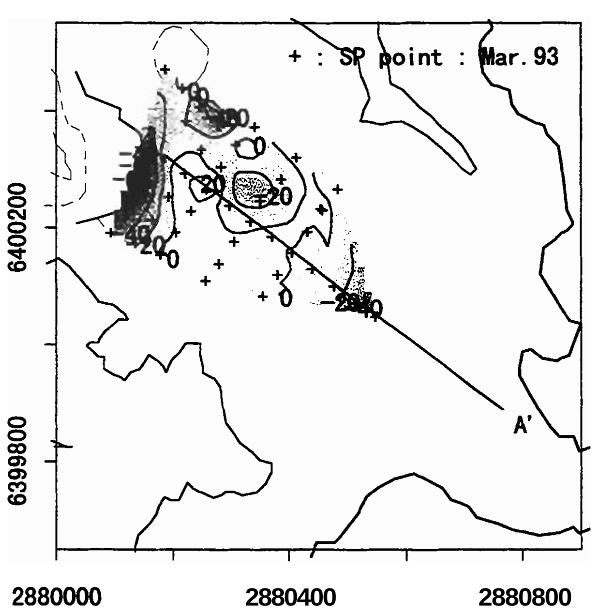

Figure 4 - Self-Potential distribution in Mar. 1993
[New Zealand Map Grid Projection]

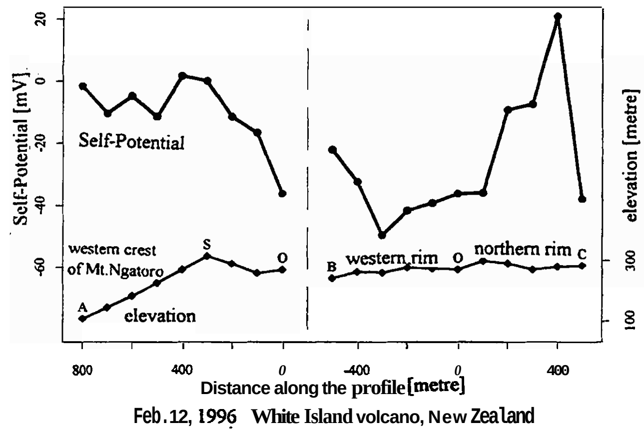

Figure 3 - Self-Potential profile in the outer slope

Crater Bay is set to zero. The SP profile along the survey line in the outer slope is shown in Figure 3, whose potential is relative to a survey point at Ngatoro Peak. These results from profiling surveys show that SP anomalies of positive polarity are present over fumarole areas both in the Main Crater floor and in the outer slope. In the Main Crater floor, positive SP anomalies are found around Donald Mound near the active vents, hot-spring area in the south-western edge of the eastern subcrater, and near Pinnacle Head (eastern edge of the eastern subcrater). Negative SP anomalies overlie about the centre of the eastern subcrater and the north-eastern half of the central subcrater.

In March 1993, Nishi et al.(1995) carried out the first SP survey in White Island volcano. They arranged the survey points almost as 50-metre-interval grid points near the 1978/90 Crater Complex. No survey points measured in 1993 were re-occupied by the present survey, since there was no clear benchmark left after the 1993 survey. To compare the results, we chose ten pairs of 1993 and 1996 survey points which are close to each other and adjusted the reference potential between two surveys. The result of 1993 SP survey after reference correction is shown in Figure 4 and the SP profiles along line A-A' in Figures 2 and 4 are shown in Figure 5. The SP distributions observed in 1993 and 1996 are almost similar, except for the area close to the edge of the 1978/90 Crater Complex, where a large negative anomaly was recorded in 1993, but positive

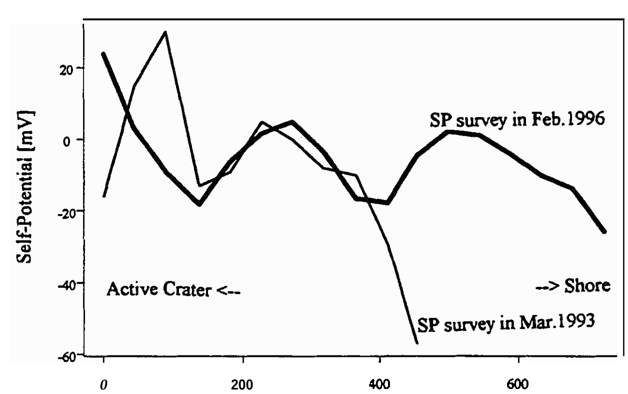

Figure 5 - Self-potential profiles in Mar.1993 and Feb. 1996 along the profile line A-A' in Figures 2 and 4

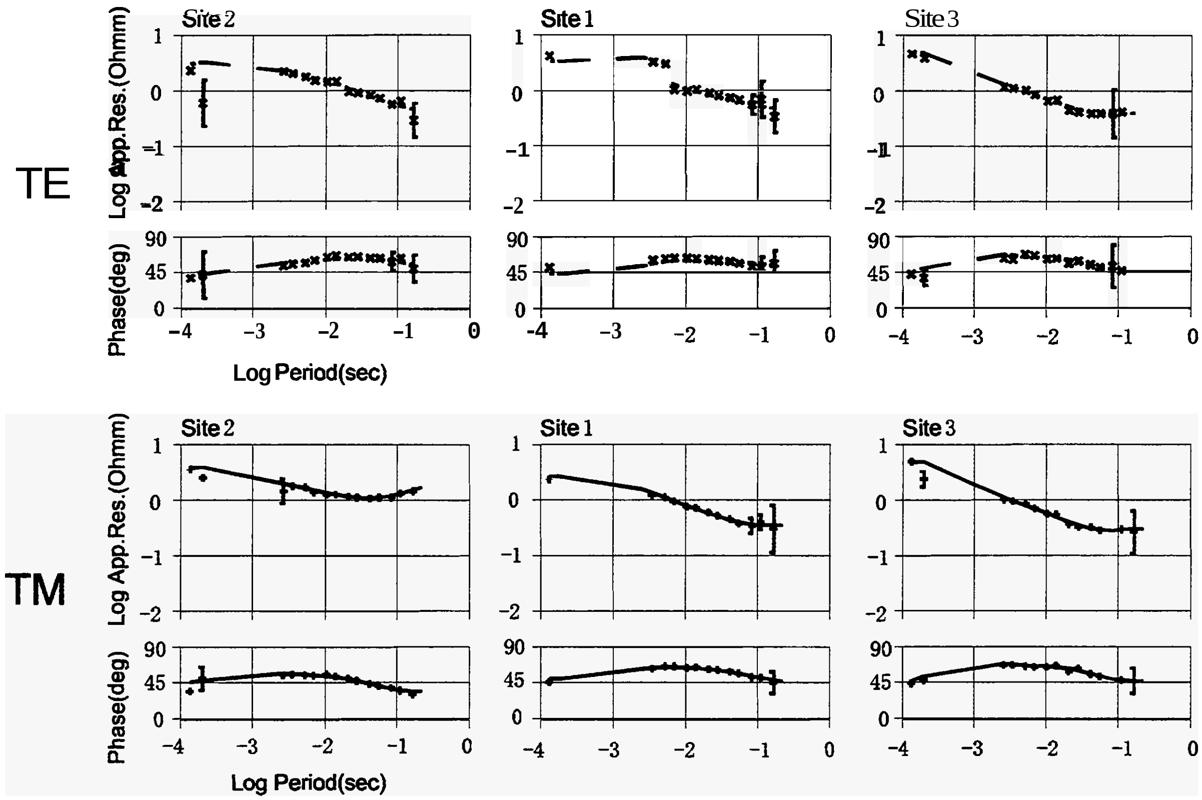

Figure 6 - Audio-magnetotelluric sounding curve after tensor decomposition in N22°E rotated frame

anomaly is present in 19%.

3.2 Audio-megnetotelluric measurements

We interpreted the audio-magenetotelluric survey data in view of a regional two-dimensional model overlain by three-dimensional local galvanic scatterers. First of all, we searched for survey-consistent (i.e., site-independent and period-independent) strike directions. We used an extended version of Groom-Bailey (1989) decomposition., where strike is site-independent and period-independent and twist and shear are site-dependent and period independent (McNeice, 1994, McNeice and Jones, in preparation). Since we focus on the deeper structures, we used impedance data in the frequency band between 100 Hz and 1 Hz in order to find the strike direction. The best fitting strike direction was N22°E.

Then., by fixing the strike direction as N22°E, we again decomposed the data of all the sites with period-independent twist and shear. We define TE and TM mode data where telluric field is along and perpendicular to the strike direction., respectively. The decomposed TE and TM responses are shown in Figure 6. Even after the decomposition., the static shift still have to be solved in the two-dimensional inversion as described below.

Two-dimensional inversions were carried out using the code of Ogawa and Uchida (1996). The static shifts for both TE and TM modes at all the sites are treated as part of model parameters in addition to the rectangular blocked resistivity. The misfit norm of the model was minimized under the dual constraints that model roughness norm and static shift norm are both minimized (Ogawa and Uchida, 1996; Ogawa, 1996). The tradeoff parameters between these norms were determined so that the Bayesian likelihood is maximized, in other words, ABIC (Akaike Bayesian Information Criterion) is minimized (Akaike, 1980; Uchida, 1993).

The starting model was a uniform earth of 10 Ωm resistivity. We set the error floor of 10% in the apparent resistivity data and an equivalent in phase data. After the twentieth iteration., the rms converged to 0.91. The modeled apparent resistivity (including static shifts) and phase are plotted in Figure 6 by the lines. TM and TE model responses are represented by solid and broken lines, respectively.

4. DISCUSSION

As the Main Crater floor is covered by volcanic ash erupted from White Island (Houghton and Nairn, 1991), the surface conditions at the survey points look almost same. There are not so large elevation changes (up to 40 metres) in the Main Crater floor and a correlation plot between elevation and SP shows no significant terrain-related effect. So, the main causes of the positive and negative SP anomalies are thought to be electrokinetic coupling associated with upflow and downflow of the hydrothermal convection beneath the area

SP anomalies of positive polarity are present over the active geothermal features where upflow must take place. The positive SP anomalies are well correlated to the thermal anomalies derived fiom airborne thermal infrared mapping by Mongillo and Wood (1995). Negative SP anomaly overlies the centre of the eastem subcrater, where the two small craters identified by Mongillo and Wood (1995) overlap, where vertical permeable channels for meteoric water downflow could be developed. In the north-eastem half of the central subcrater, where another negative SP anomaly is present, the growth of galleys and enlargement of Donald Duck crater occurred from 1993 to 1996. Subsurface downflow was probably associated with these changes in topography, since drain of steam and fluid was estimated to occur corresponding to the subsidence of the Princess Crater and the Sag in 1992 (Mongillo and Wood, 1995).

The change in SP around Donald Mound from 1993 to 1996 reflects a change in volcanic activity. In 1993, at the end of an active period, drain of steam and fluid took place just near the crater wall of the 1978190 Crater Complex to the crater lake lying 100 metres below, and this caused subsurface downflow to generate the negative SP anomaly. In 1996, this region has been heated up to stop the downflow and d a c e *boiling* hot-springs have appeared due to the re-activated volcano. Repeated levelling surveys showed remarkable uplift near this active region (Otway, personal comm., 1996); this supports the upflow model from the present results.

The magnitudes of the SP anomalies detected in our survey are small compared to those observed at other active volcanoes such as Izu-Oshima (Ishido et al., 1994). In particular, there is almost no terrain-related SP along the profile on the western crest of Mt.Ngatoro against the elevation change of about 180 metres as shown in Figure 3. The survey line was set on the older cone of White island (Houghton and Naim, 1989), where the surface is covered by thick ash with stiff crest. Probable explanations are : almost all of the rainfall will run down to the sea on the surface due to very small permeability of the surface of the older cone and there is almost no saturated ground wafer in this summit area.

Preliminary interpretation of the audio-magnetotelluric data showed the following features. (1) All the AMT sites show low resistivity (approx. 10 Ωm) from the highest frequencies, which suggests altered clay layers at the surface. (2) The two SE sites are then underlain by more conductive layer (approx. 0.3 Ωm), comparable to sea-water resistivity. (3)On the other hand, at the AMT site 2 (the NW site), showed resistive regime (approx. 1.3 Ωm) at 20-160 m depths. This is required by the increasing TM apparent resistivity toward longer period at the NW site.

Surface thermal features, thermal infra-red mapping, and our SP survey suggest there are upflow zones along the edge of the eastern subcrater. Since shallow volcano-tectonic earthquakes in White Island were located mainly beneath the eastern subcrater in 1992 seismic observation, Nishi et al.(in press) suggest the volcano-hydrothermal system beneath the eastern subcrater whose bottom could be 1 km depth. So, it is natural to assume the volcano-hydrothermal system is existing beneath Main Crater floor including the eastern subcrater and this system supplies upflow to these thermal anomalies along the edge of the eastern and central subcraters. The very conductive layer observed at the AMT sites 1 and 2 suggests shallow sea water invasion (and shallow sealing structure) beneath these sites or very conductive hydrothermal water in the volcano-hydrothermal system.

5. CONCLUSIONS

A Self-potential survey and a magneto-telluric survey were carried out in White Island volcano, New Zealand. SP anomalies of positive polarity are present over the active geothermal features both in the Main Crater floor and in the outer slope. These anomalies are well correlated thermal infra-red mapping result and subsurface upflow must take place h e a t h these anomalies. Negative SP anomaly overlies the centre of the eastern subcrater and the north-eastern half of the central subcrater, where subsurface downflow could exist. The SP distributions observed in 1993 and 1996 are almost similar, except for the area close to the edge of the 1978/90 Crater Complex, which reflects a change in volcanic activity.

The audio-magnetotelluric data showed low resistivity fiom the highest frequencies, which suggests altered clay layers at the surface. The two AMT sites in the eastern subcrater showed very conductive layer comparable to sea-water resistivity, while the AMT site 2 (the NW site), more resistive regime at 20-160 m depths.

We assume the volcano-hydrothermal system is existing beneath the Main Crater floor and this system supplies subsurface upflow to thermal anomalies along the edge of the eastern and central subcrater. The very conductive layer observed by AMT implies sea water invasion to the shallow depth of the eastern subcrater or very conductive hydrothermal water in the volcano-hydrothermal system.

6. ACKNOWLEDGEMENTS

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