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MONITORING OF GEYSER ACTIVITY IN WHAKAREWAREWA, NEW ZEALAND

Yuji Nishi[1], Tuneo Ishido[1], Mituhiko Sugihara[1], Toshiyuki Tosha[1], Nobuo Matsushima[1] and Bradley J. Scott[2]
[1]Geological Survey of Japan, 1-1-3 Higashi, Tsukuba, Ibaraki 305-8567, Japan
[2] Wairakei Research Centre, State Highway 1, Wairakei Private Bag 2000, Taupo New Zealand

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ABSTRACT

We carried out monitoring of self-potential (SP) and gravity in Whakarewarewa geothermal field, New Zealand. Seven electrodes were set around the major geysers, Prince of Wales Feathers, Pohutu, Waikorohihi and Mahanga. One SCINTREX CG-3M gravity meter was set near Te Horu cauldron, the water level of which was monitored using a capillary-tube type pressure gauge. We observed remarkable SP changes well correlated with the eruptions of Pohutu Geyser and the water level change of Te Horu. At one electrode near the geyser vent, SP increased suddenly by about 50 mV immediately before the each eruptions, decreased rapidly by 20-40 mV corresponding to the each ends of eruption and returned gradually to the original level. Although the electrokinetic effects is thought to be responsible for a part of observed signals, the mechanism of the SP changes is not fully understood at present.

1. INTRODUCTION

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., 1997; Lénat , 1995). In most cases, SP anomalies of positive polarity were found over high temperature upflow zones. The most likely cause of these positive anomalies is believed to be the streaming (electrokinetic) potential generated by hydrothermal circulation (Ishido et al., 1989). Therefore, we often use the SP method to investigate subsurface hydrology at active geothermal fields.

Geysering is one of the most fascinating geothermal features, which we can easily recognise. However, its subsurface structure and processes have not been well understood due to its complexities. In order to get better understanding of the subsurface processes taking place in the Whakarewarewa geothermal field, we applied the SP method to this area along with a continuous gravity recording.

Whakarewarewa is an active geothermal field near the southern boundary of Rotorua city, New Zealand and includes geysers, boiling springs, mud pools, and siliceous terraces. The major geysers, Prince of Wales Feathers, Pohutu, Waikorohihi and Mahanga, are located on Geyser Flat, 2,500 m^2 siliceous apron (sinter) standing about 7.5 metres above Puarenga Stream, along Te Puia fault. (Fig.1 : see Lloyd, 1975 for an outline of these geysers).

We carried out the first SP measurements around these geysers in 1996 and detected SP variations relating the geyser activity (Matsushima et al., 1996). The electric potential differences between four observation points near the geyser vents and a reference point were measured. At the nearest point to the vent of Pohutu, we found immediate self-potential increase by about 20mV after the eruptions of Pohutu.

In February 1997, we made the second SP observation together with continuous monitoring of gravity and water level of Te Horu cauldron. In the measurements, we tried to get longer-term, higher-sampling and higher-resolution data. This paper describes an outline of the measurements and major results we obtained.

2. FIELD MEASUREMENTS

Seven electrodes were set to monitor SP around the geyser vents (locations of seven electrodes and a reference (base) electrode are shown in Fig.1). We used silver-silver chloride non-polarizing electrodes (Ishido et al., 1992) and set them with a sponge sheet saturated with water from the geysers to get better electrical contact with the hard siliceous terrace. The electric potential differences between each electrode near the vents and the base electrode were recorded at 5 Hz sampling with a HIOKI 8845 DAT data recorder.

Change in Te Horu water level was recorded using a capillary-tube type pressure measurement system (Fig. 2). A chamber filled with air was located below the lowest water level, and the air pressure, which was equilibrated with the water pressure, was introduced to the ground surface via small diameter (~1 mm) stainless-steel tube and measured by a pressure sensor. This system could detect rapid water-level rises due to the drainage from Pohutu eruptions.

In addition to visual observation of the geyser activity, we measured the temperatures at the outflow paths by thermocouples. For Waikorohihi and Mahanga, thermocouple sensors were set in the outlet stream from each geyser, which enable us to identify clearly the onset and termination of each eruption of these geysers. For Pohutu and Prince of Wales Feathers, the sensors were set at small hollows near the vents. When the geysers were splashing, the hollows were filled with warm splashing water, whose temperatures were lower than Waikorohihi and Mahanga due to rapid cooling by splashing. When the geysers were at full column eruption, no water supply to the hollows caused lower temperatures. So, for these geysers, the temperature observation did not give so clear identification of eruptions as the Waikorohihi and Mahanga case.

To monitor the gravity change near Te Horu cauldron, we used a Scintrex CG-3M , microprocessor-based automated gravimeter. This gravimeter allows us to get continuous recording of gravity change using its cycling data acquisition mode.

At Whakarewarewa, we started the observation described above on 20 February 1997. From 21 to 22 February, we obtained continuous recordings of SP variation, Te Horu water level and thermocouples for about 24 hours. Unfortunately, we could not get continuous gravity data during this period.

3. RESULTS

Figures 3 to 5 show recorded SP variations, water-level change and geyser activity during the regular eruption period. Fig. 3 shows the SP variations of the electrodes near Pohutu and Prince of Wales Feathers (PWF) (An enlarged part is shown in Fig. 4). The top and bottom traces are the output from the thermocouple near Pohutu and change in Te Horu water level, respectively. In the middle of the figures, the SP recordings of electrodes No.1 thorough 5 are plotted. The periods of the geyser eruption indicated from the thermocouple data are shaded. The SP changes and Te Horu water level were monitored in real-time in the field with visual observation of the geyser activities.

SP of electrode No.4, which was set at the nearest point to the vent of Pohutu, increased suddenly by about 50 mV several tens of second prior to the onset of each eruptions, decreased rapidly by 20-40mV corresponding to the end of each eruptions and returned gradually toward the original level. This change in SP was the largest one among all electrodes.

Electrodes No 1 and 2, which were set ~7 m and ~3 m away from the vent of Pohutu respectively, showed smaller (about 10 mV) and gradual increase at the onset of each eruptions (see Fig. 3). Electrode No. 3, which was set ~9 m from Pohutu, also showed increase, but its magnitude was very small (less than 3 mV). Although electrode No. 5 was set close to electrode No. 4 (80 cm), only this one showed decrease by about 5 mV corresponding to the rapid SP increase at electrode No. 4. Wetting of the electrodes is not responsible for the observed SP changes for electrodes No. 1 through 5, since the main features were repeated whether or not the ejected water from Pohutu reached to the electrodes.

Fig. 5 shows the geyser activities of Waikorohihi and Mahanga and SP variations of electrodes No. 6 and 7 near Waikorohihi and Mahanga. The top and bottom traces are the outputs from the thermocouples near Waikorohihi and Mahanga and relative water level change of Te Horu, respectively. In the middle of the figure, SP recordings of electrodes No.6 and 7 are plotted. The periods of Pohutu eruption are shaded in this figure.

The eruption cycle of Waikorohihi was about one hour with 20 to 30 minutes of eruption. Mahanga had a very short eruption cycle, about one minute, and relatively long quiet periods, which seem to correspond to the Pohutu eruptions. Electrode No. 6 near the vent of Mahanga showed increases in SP during the active period of Mahanga. Although electrode No. 7 showed a clear correlation with the Waikorohihi activity, this seems to be due to wetting of the electrode; SP began to increase when the ejected water spread out on the terrace and reached to the electrode, and returned to the original level corresponding to the disappearance of the ejected water after the eruptions.

The change in Te Horu water level had a good correlation with the eruptions of Pohutu as Weir et al. (1992) observed. However, the details of the correlation were different. In our observation, the most regular period is described as follows: When the water level turned from decline to rise, the water rose gradually to a certain level without geyser eruption. When the water level almost reached a peak in a cycle, an eruption started (here, a ‘cycle’ means the cycle of Te Horu water-level change, whose period is several tens of minutes in Fig.3 and Fig.4). While the geyser was erupting, the ejected water from Pohutu flowed into Te Horu, which caused a rapid rise and a successive drop of the water level. When an eruption stopped, the water level was lower than the level at the onset of the eruption. If the water level remained relatively high at the end of the eruption, the next eruption started after a short break. In most cases, this short cycle of eruption and break was repeated several times. During these eruptions, the water level dropped gradually. After this repetition, if the water level was lower than the critical level there was a relatively long rest time before the next eruption(s) and the water level turned from decline to rise, which is the beginning of the next cycle. These cycles were observed more regularly in the later half of our observation period. The former half of the period was probably disturbed by heavy rainfalls on 20 February.

Fig. 6 shows the temporal variation of the gravity measured on the bank of Te Horu cauldron. Unfortunately, we could not record geyser activity during this observation. Only Te Horu water level was measured with gravity. The geyser activity was different from that in the SP monitoring period as mentioned above, probably due to heavy rainfall.

4. DISCUSSION

4.1 Correlation between SP variation and geyser activity

The SP variations at electrodes No. 1, 2 and 3 can be explained by an electrokinetic process, which is proposed to interpret our first observations (Matsushima et al., 1996). At the onset of geyser eruption, boiling begins at the top of hot water column in the geyser vent. Then a substantial two-phase flow occurs in the upper part of subsurface channel(s) and the two-phase region extends downward with time. This two-phase flow carries positive charge in the flow direction by electrokinetic coupling, since the zeta-potential is thought to be negative (Ishido and Mizutani, 1981) for the liquids ejected from the geysers at Whakarewarewa (Lloyd, 1975). This "drag" current produces negative and positive sources of "conduction" current at the start and end points of the two-phase flow, respectively. Since the positive source is located at shallower levels than the negative one, the change in potential on the ground surface becomes positive. While D is less than R (where D is the vertical distance between the positive and negative sources and R is the horizontal distance between the electrode and the geyser vent), change in SP at the electrode is negligible since the contribution of the negative source is comparable to that of the positive source. As D increases with time, the area of positive SP change expands outward.

The SP variation at electrode No.4 cannot be interpreted in the same way. The large variation is probably related to the local SP anomaly around electrode No. 4; SP at No. 4 is about -50 mV during the rest periods of Pohutu, which is in contrast to SP at electrodes No. 1, 2, 3 and 5 (0-15 mV). This large negative anomaly suggests that the point of No. 4 close to the vent of Pohutu is on a block which has negative potential compared to the surrounding blocks and does not have enough electrical contact with the surroundings. At the onset of eruption, rise in water level and/or two-phase mixtures in the subsurface channels will bring about fully electrical contact between this weakly isolated block and the surrounding blocks and make the potential approach to zero. Electrode No.5, located near to the point of No.4, showed sudden drop at the onset of each eruptions of Pohutu. This behaviour can be explained by an influence from this contact with the negatively charged block.

The electrokinetic mechanism explaining changes in SP at electrodes No. 1, 2 and 3 may also contribute to a part of the large change observed at electrode No. 4. Since the point of No. 4 is very close to the geyser vent, we also need to consider the effects of "spray electrification" (e.g. Matteson, 1971).

4.2 Correlation between the water level change of Te Horu and the geyser activity of Pohutu

Lloyd (1975) showed a subsurface model of Geyser Flat from observations of eruption correlation among the geysers and dye tracing experiments. Weir et al. (1992) constructed a simple model of heat and mass balance for Geyser Flat from their observations of geyser activity, Te Horu water level and wind speed and direction. They showed that the wind direction and Te Horu water level had important roles on the geyser activity, and there was a very good correlation between the Te Horu water level change and the geyser activities.

Our observation also showed a good correlation of Te Horu water level with the activity of Pohutu, which is slightly different from that by Weir et al. (1992). At the beginning of a water-level change cycle, the geyser system is heated up and a rise in the Te Horu water level occurs, which is associated with a subsurface overflow from Pohutu. When the water level in the cavern reaches a critical level, the system starts to release the energy as a geyser eruption. The eruption transports water and heat from the subsurface to the air, and cooled water flows into Te Horu, resulting in a rapid rise in the water level. As the energy stored in the subsurface decreases with time, the water in Te Horu begins to drain back into the system and the water level falls. The continued draining from Te Horu continues until the next eruption, which is triggered by the reduced water level (and therefore plugging pressure) in the cavern. After several frequent eruptions, insufficient mass remains for further eruptions, and the system remains quiescent while it recharges.

4.3 Gravity Change

At first, we tried to compensate for gravity changes with the Te Horu water-level change based upon the model by Weir et al. (1992). However, the corrected data has a particular signal whose amplitude is ~10 microGal. Although the dominant frequency of the gravity signal seems to be the same as the water-level change, the peaks of the detected signal do not coincide with the water level extremes. The gravity change should be interpreted by a combination of water-level change and mass re-distribution in the subsurface space. Since we set a single gravimeter at one point and did not observe the geyser activity during the monitoring period, we cannot interpret the relationship between the geyser activity and the gravity signal more quantitatively.

5. CONCLUSIONS

In February 1997, we carried out monitoring of SP and gravity near the geysers in Whakarewarewa. We observed remarkable SP changes well correlated with the eruptions of Pohutu and the change in Te Horu water level (which also had a good correlation with the eruptions of Pohutu). At one electrode near the geyser vent, SP increased suddenly by about 50 mV immediately before the each eruptions, decreased rapidly by 20-40 mV corresponding to the each ends of eruption and returned gradually to the original level. We also detected gravity signals of about 10 microGal, which is thought to reflect the mass re-distribution in the subsurface space.

Although a part of the SP changes can be explained by the proposed electrokinetic model, the mechanism is not fully understood at present. We must take into account subsurface complex structures and/or processes. However, the observed SP change has very clear correlation with the eruption of the geysers. We believe continuous SP measurement is another powerful geophysical tool to monitor and interpret geyser systems.

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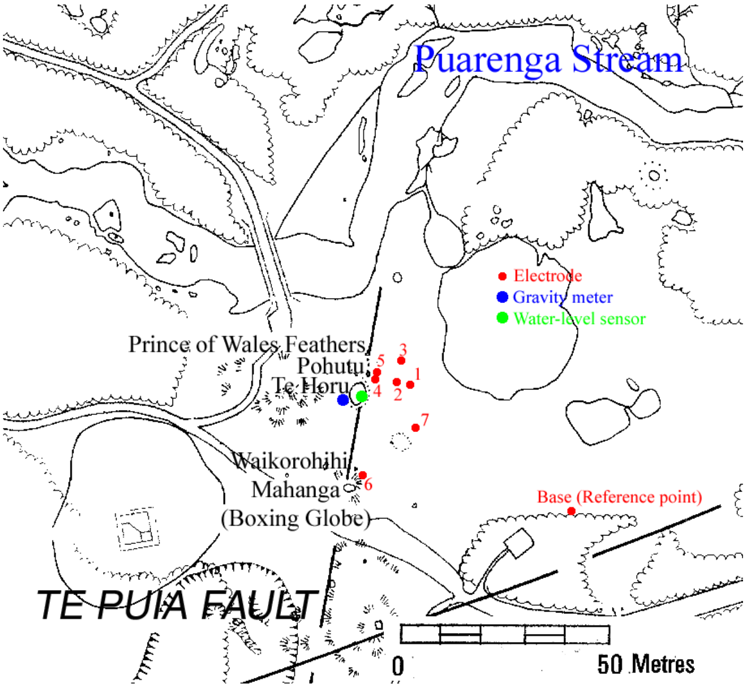

Figure1 Map showing the location of electrodes (red circles), a gravimeter (blue circle), and a water-level sensor near the geysers at Whakarewarewa.

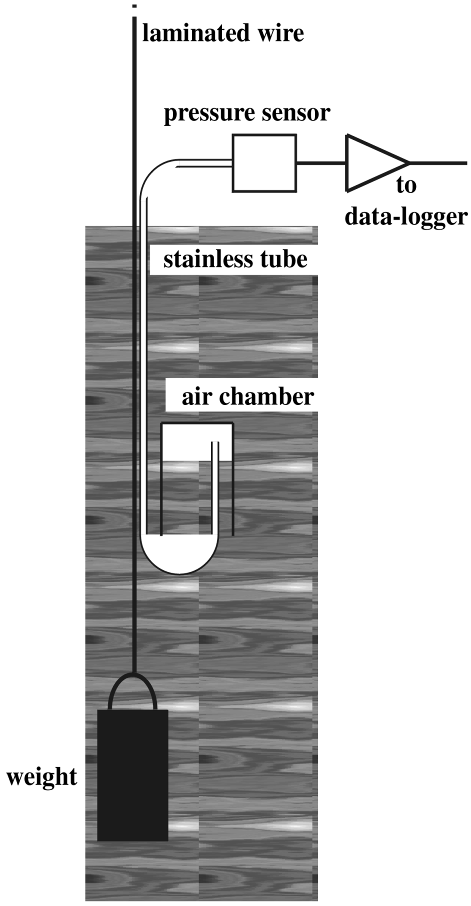

Figure2 Pressure measurement system to monitor the water-level change of Te Horu cauldron.

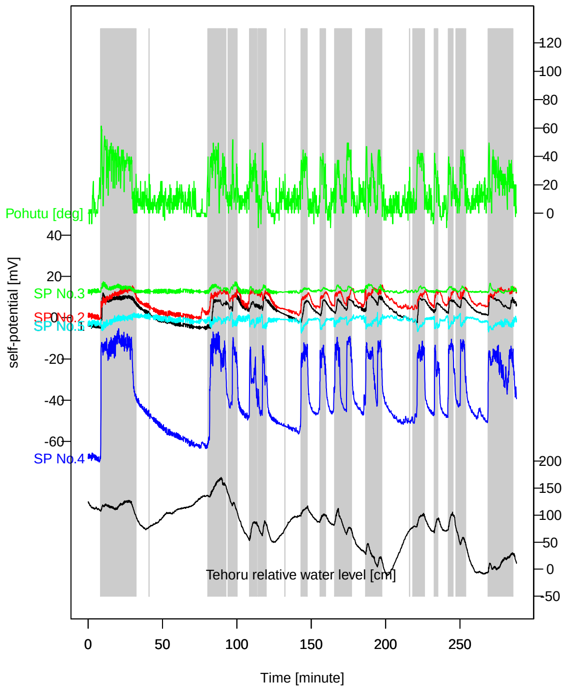

Figure 3 Temporal variations of geyser activity of Pohutu (upper), self-potential (SP) (middle) and the water level of Te Horu (lower).

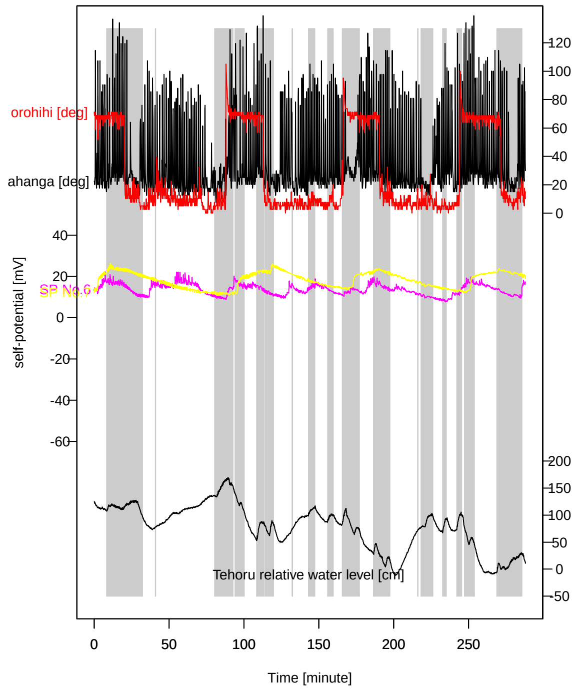

Figure 5 Temporal variations of geyser activity of Waikorohihi and Mahanga (upper), self-potential (SP) (middle) and the water level of Te Horu (lower) for the same interval of Figure 1.

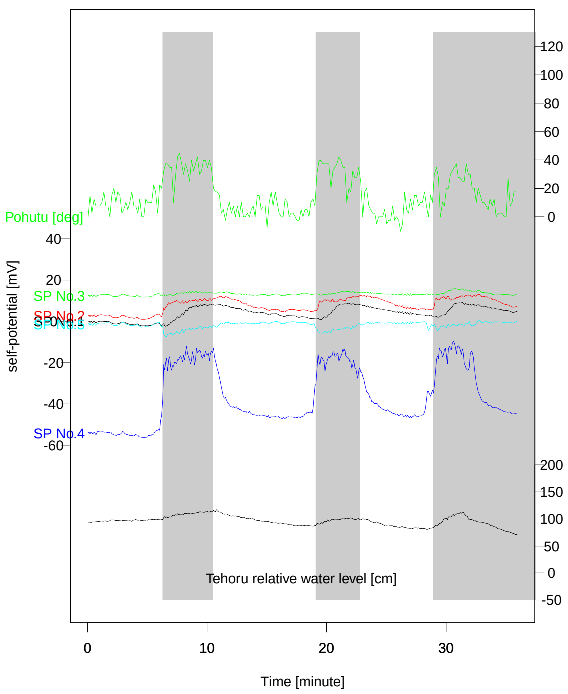

Figure 4 Temporal variations of geyser activity of Pohutu (upper), self-potential (SP) (middle) and the water level of Te Horu (lower) from 136.8 minute to 172.8 minute in Figure 3.

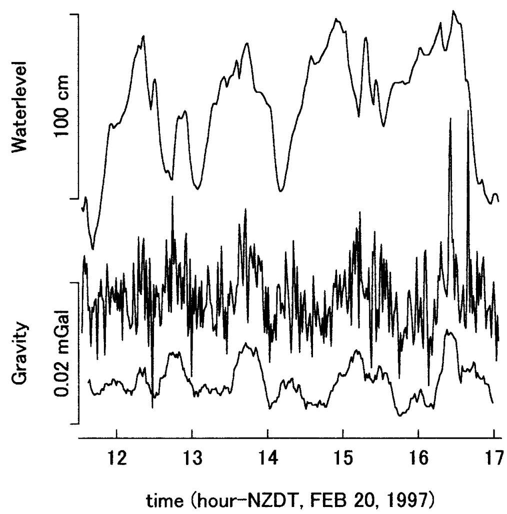

Figure 6 Temporal variation of gravity (unfiltered and low-pass filtered) and the water level of Te Horu.