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Self-Potential Studies in Volcanic Areas (2) **— Usu, Hokkaido Komaga-take and Me-akan —**

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Abstract

Recent eruptions occurred in 1977 at Mt. Usu and in 1929 and 1942 at Mt. Hokkaido Komaga-take while Mt. Me-akan has no experience of essential eruption during the historic time except small phreatic eruptions. We made a comparative study of self-potential (SP) fields in these volcanoes. The large SP anomalies, in both spatial extent and magnitude, were observed over the summit crater of Usu and Hokkaido Komaga-take. These anomalies are commonly distributed along a fault or a fissure where is high ground temperature zone. These evidences indicate that the anomalies are mainly caused by electrokinetic effect due to upwelling of the hot ground water. On the contrary, we found a positive SP anomaly relating to geothermal activity at only limited area of the summit of Me-akan. Possibly the hydrothermal circulation of large size has not developed within the edifice of Me-akan. From these results, we may draw a hypothetic relation between the spatial extent of the SP anomalies and the period of dormancy of the volcanoes: the shorter the period of dormancy, the larger the spatial extent.

1. Introduction

In many cases, positive self-potential (SP) anomalies are observed on the high ground temperature zones of volcanoes. The cause of the anomalies is not

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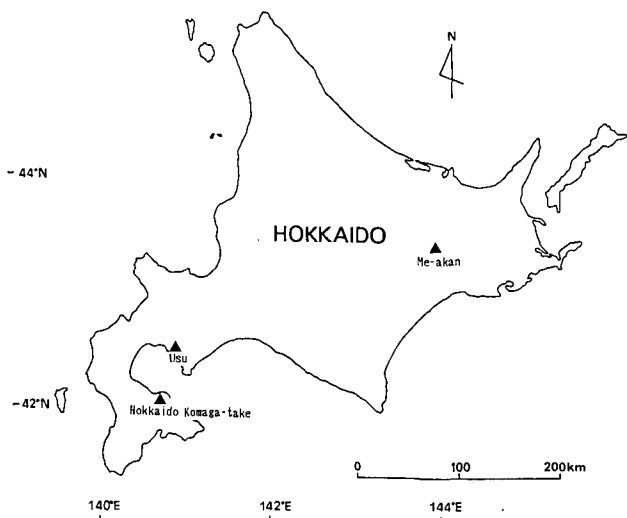


Fig. 1. Location map of Usu, Hokkaido Komaga-take and Me-akan volcanoes.

fully understood. However, recent advance of experimental and theoretical studies reveals that rather small anomalies ($\lesssim 100$ mV) could be generated by diffusion or thermoelectric effect and large ones, sometimes above several hundred mV, could be attributed to electrokinetic (or streaming) effect due to hydrothermal circulation within a porous media (Nourbehecht, 1963; Fitterman, 1979; Ishido and Mizutani, 1981; Sill, 1983; Morgan et al., 1989). Therefore, comparative study of the SP anomalies in the active and the dormant volcanoes provides valuable insight into the dynamic aspects of the geothermal systems.

Here, we will report the results of the field investigations in Usu, Hokkaido Komaga-take and Me-akan volcanoes following our previous work in Usu volcano (Nishida and Tomiya, 1987). Locations of these volcanoes are shown in Fig. 1. The equipments for measurements were composed of a pair of non-polarizing copper-copper sulfite electrodes and a high impedance voltmeter.

2. Self-potential mapping

2.1 *Usu volcano*

Usu volcano is a stratovolcano located in the southwestern part of Hokkaido, Japan. The edifice is composed of basaltic somma volcano and crater fill including dacite lava domes. Through the dacitic activities since August, 1977,

a big normal fault developed on the summit crater : Usu-shinzan fault (Katsui et al., 1985).

SP surveys were conducted on August, 1983 and 1985 as already reported by Nishida and Tomiya (1987). A positive anomaly developed over the mountain, 350~400 mV in magnitude, was most significant feature of the surveys. We made the third survey on August, 1987 in order to investigate temporal variation of the SP field.

Figure 2 shows topographic map and survey stations. Figure 3 shows temporal variation of the SP field on the summit crater and the southern flank. The potential values are presented here as the relative ones in mV to a common station away from the summit crater (double circles in Fig. 3). Inspection of Fig. 3 exhibits that the major positive anomaly greater than 2 km in spatial extent is distributed along the Usu-shinzan fault where is the high ground temperature zone. It is also characteristic that although the magnitude of the anomaly has gradually decreased with time, the wavelength of the anomaly

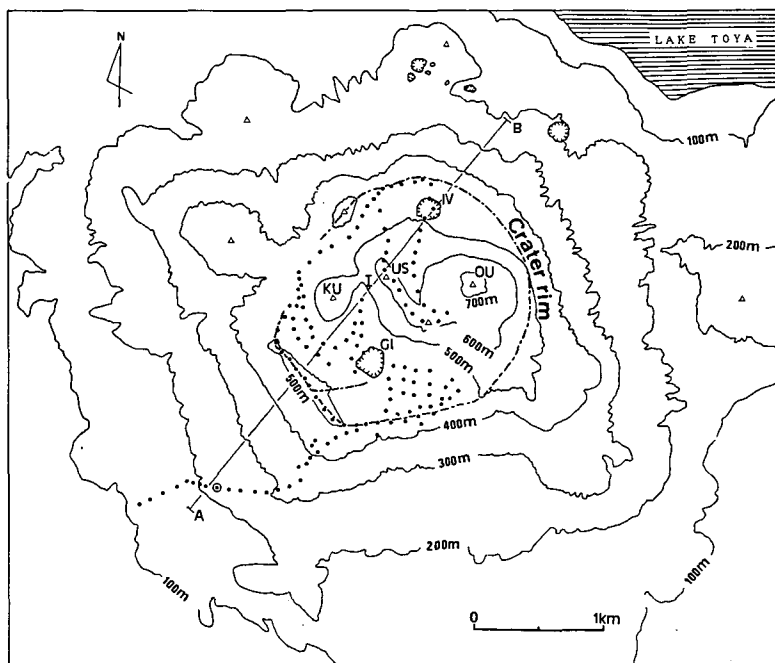


Fig. 2. Topographic map of Usu volcano and survey stations in 1987. The stations in 1983 and 1985 were shown by Nishida and Tomiya (1987). US: Usu-shinzan cryptodome, OU: Oo-usu lava dome, KU: Ko-usu lava dome, I: I-crater, Gi: Gin-numa crater, IV: No. 4 crater.

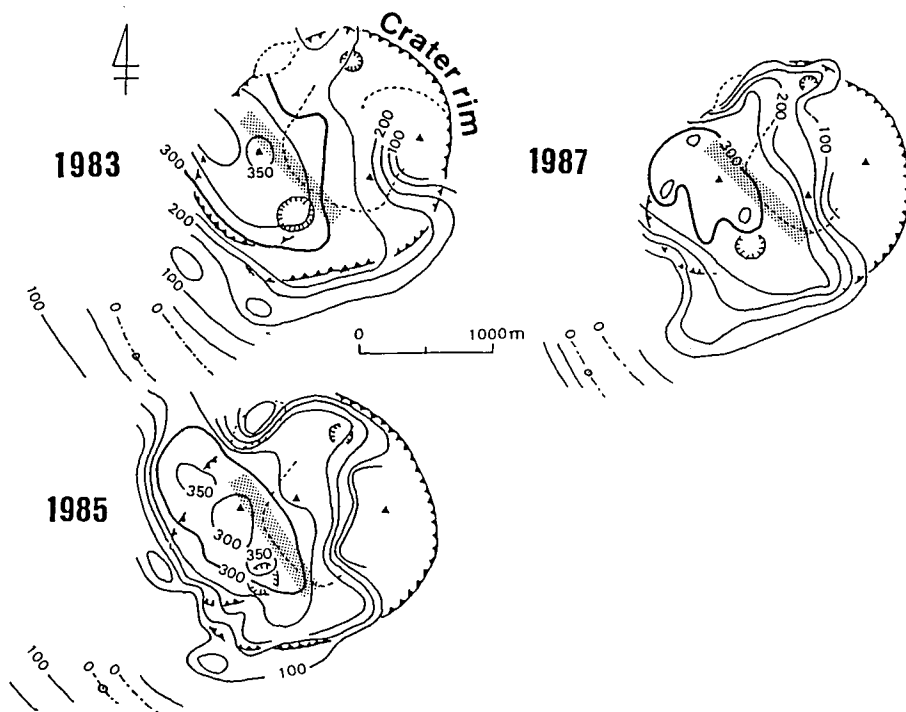


Fig. 3. Contour map of self-potential distribution on Usu volcano. Contour interval is 50 mV. Shaded parts indicate the Usu-shinzan fault.

appear to be stable ; that is, the effective depth to the source does no noticeably change.

2.2 Hokkaido Komaga-take volcano

Hokkaido Komaga-take volcano, situated in southwestern Hokkaido, is made up of layers of andesite lava, tuff, pumice flow deposits and dry avalanche deposits. The summit of a typical cone-shaped volcano was broken by a violent explosion several thousand years ago. The explosion was accompanied by a rock avalanche to the east direction ; accordingly, a horseshoe-shaped crater was formed (Fig. 4). Its eastern opening was burried by subsequent eruptions to form the present topography. During the historic time, eruptions of great amount of pumice and ash occurred in 1640, 1765, 1856 and 1929 at some vents inside the crater of the volcano (Ishikawa, 1962). Recent moderate phreatic eruption (1942) formed a long fissure of 1.8 km in horizontal length. The fissure extended towards the NW-SE direction on the summit crater (Fig.

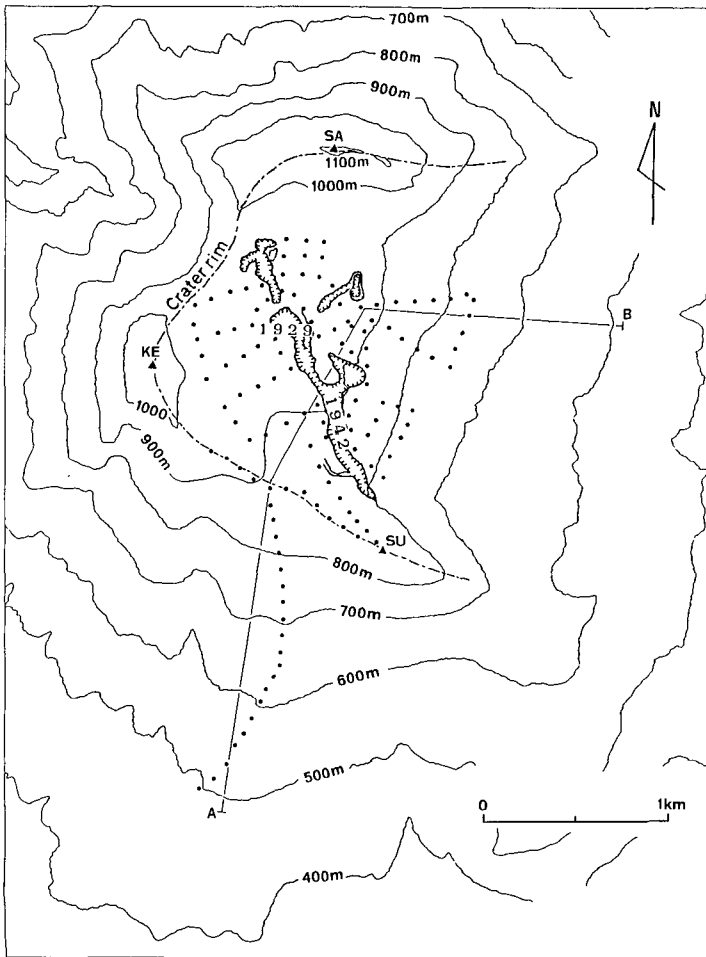


Fig. 4. Topographic map of Hokkaido Komaga-take volcano and survey stations in 1987 and 1988. SA: Sawara-dake, KE: Kengamine, SU: Sumidamori. The 1929 vent and the 1942 fissure are also shown.

4).

A SP survey was conducted on October, 1987 and a supplemental one was made on June, 1988. Figure 5 shows the compiled anomaly map. Dot-dashed contours represent the reference value while solid and dashed contours represent the positive and the negative anomalies, respectively. It is characteristic that a positive anomaly, about 400 mV in magnitude and more than 1 km in spatial extent, develops on the summit crater. This major anomaly approximately

rock fragments owing to the small phreatic explosions in 1955. No juvenile materials were thrown out. Small pits and fissures were formed on the crater bottom. From one of these pits, similar phreatic explosions occurred repeatedly in 1956 (Katsui, 1962).

We made a SP survey on August, 1988. Figure 6 shows the topographic map, the survey stations and the contour map of the SP anomalies. Although the area surveyed was unfortunately limited because of difficulty of access, we may be able to delineate the general tendency of the SP anomalies on Me-akan. We found a positive anomaly around the Ponmachineshiri crater. Magnitude and spatial extent of the anomaly, however, are much smaller than those of Usu and Hokkaido Komaga-take.

A positive anomaly, as high as 240 mV, was observed at about 1 km southwest of the Ponmachineshiri crater where no surface manifestations such as

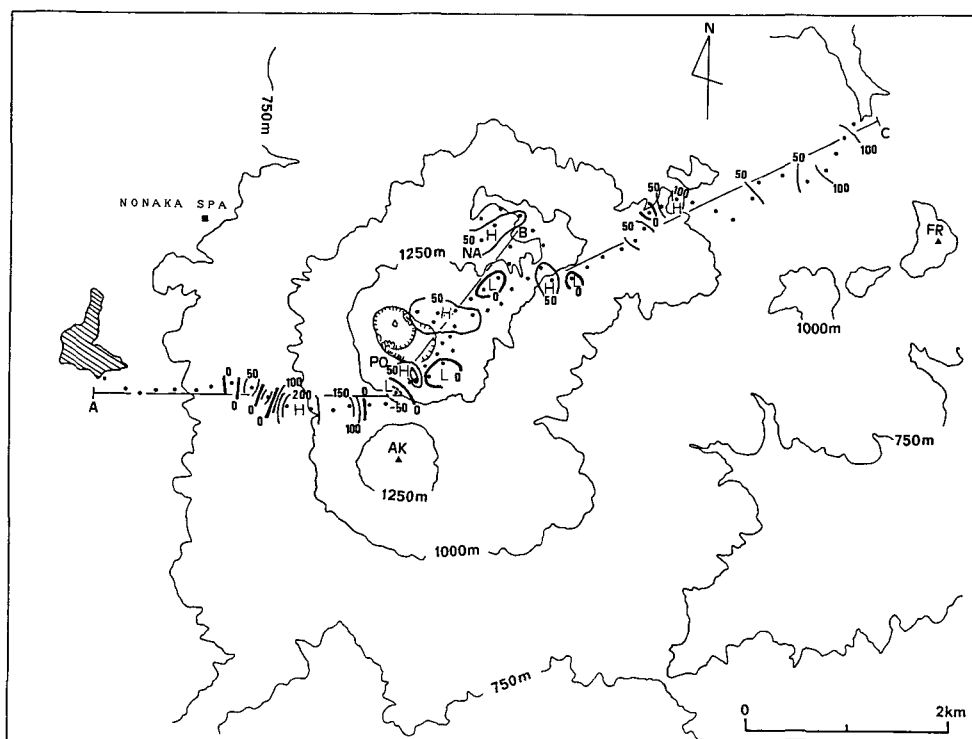


Fig. 6. Topographic map of Me-akan volcano, survey stations in 1988 and contour map of self-potential distribution. Contour interval is 50 mV. PO: Ponmachineshiri crater, NA: Nakamachineshiri crater, AK: Mt. Akan-fuji.

fumarolic activity and anomalous ground temperature are present.

3. Discussions

Interest is recently focused on an electrokinetic effect as a cause of positive SP anomaly having large magnitude. Because this effect relates to upward movement of pore fluids, the use of SP method is suitable to delineate the hydrothermal process of volcanic regions. The SP field also relates to other subsurface conditions: electrical resistivity, geothermal gradient, and so on. Therefore, we made very low frequency (17.4 kHz) magnetotelluric soundings

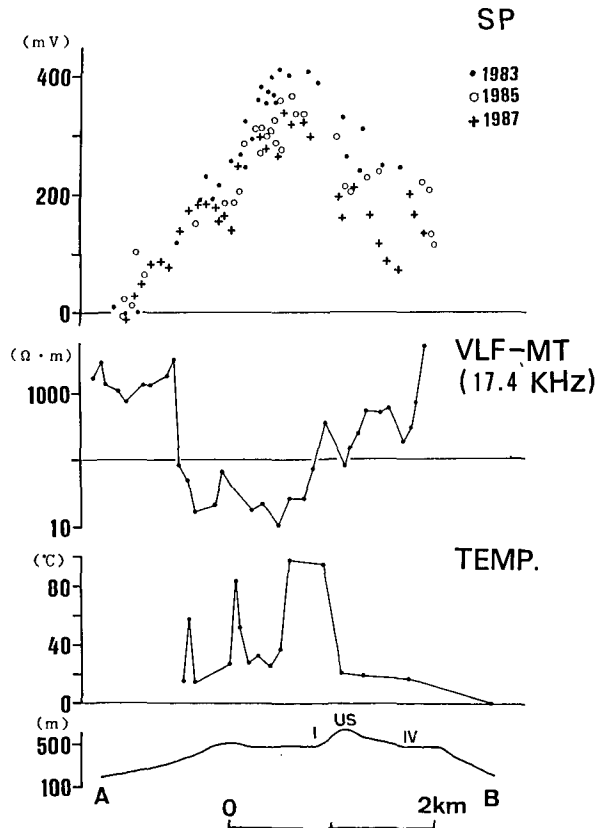


Fig. 7. Temporal variation of self-potential anomaly, apparent resistivity (VLF magnetotellurics) and ground temperature along the profile A-B in Fig. 2 with topographic profile of Usu volcano. I: I-crater, IV: No. 4 crater, US: Usu-shinzan cryptodome.

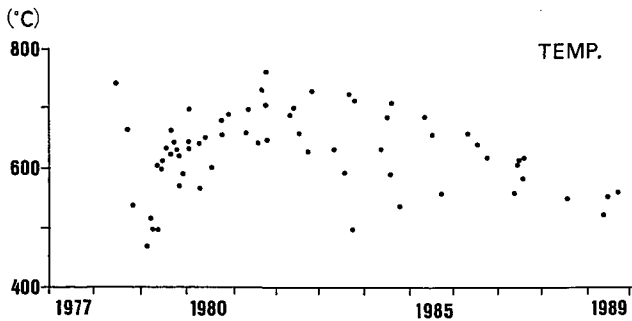


Fig. 8. Temporal variation of volcanic gas temperature at I-crater of Usu volcano (Usu Volcano Observatory, unpublished).

(VLF-MT) in three volcanoes concerned for interpretational support of the SP anomalies. We also conducted ground temperature measurements at a depth of 1 m in Usu and Me-akan. In Hokkaido Komaga-take, we refer to the ground temperature observed by Sapporo District Meteorological Observatory (1987). Figures 7, 9 and 10 show these data along each traverse in Figs. 3, 5, 6 with the SP anomalies. Detailed examination of these figures reveals the individual aspect of the SP anomalies on each volcano, although the positive anomalies commonly correlate with the low resistive and the high ground temperature zones.

The high potential anomaly is mostly distributed over the whole area of the summit crater of Usu (Fig. 7). To interpret the anomaly, we refer to other geophysical data. The low resistive crater fill (a few to a few ten Ωm) suggests the existence of abundant ground water. The high ground temperature areas are distributed on the summit crater. These evidences enable us to infer that upwelling of the ground water takes place within the edifice. In addition, the highly permeable Usu-shinzan fault may activate further increase of the upwelling of the ground water. Therefore, the potential anomaly of Usu is interpreted by the electrokinetic effect as already concluded in the previous paper (Nishida and Tomiya, 1987).

The SP profiles in Fig. 7 show an appreciable decrease of 50~100 mV for four years. The decrease of the magnitude probably relates to the recent decrease of the thermal energy release from the Usu edifice (Matsushima, 1988) and the decrease of volcanic gas temperature shown in Fig. 8 (Usu Volcano Observatory, unpublished). Because the thermal energy release decreases in proportion to the flow rate of the hydrothermal circulation; hence, the electrokinetic potentials.

The high ground temperature zone of Hokkaido Komaga-take (Fig. 9) well correlates with a strikingly high potential anomaly over a long fissure, formed at the 1942 eruption. A geological investigation revealed Komaga-take volcanic products compose good confined aquifers (Sagayama, 1986). From these geophysical and geological setting similar to Usu, we can reasonably assume that the electrokinetic effect plays an important role in the cause of the SP anomaly on Hokkaido Komaga-take. When we make a comparison between Figs. 7 and 9, it is obvious the SP anomaly is small in spatial extent and the

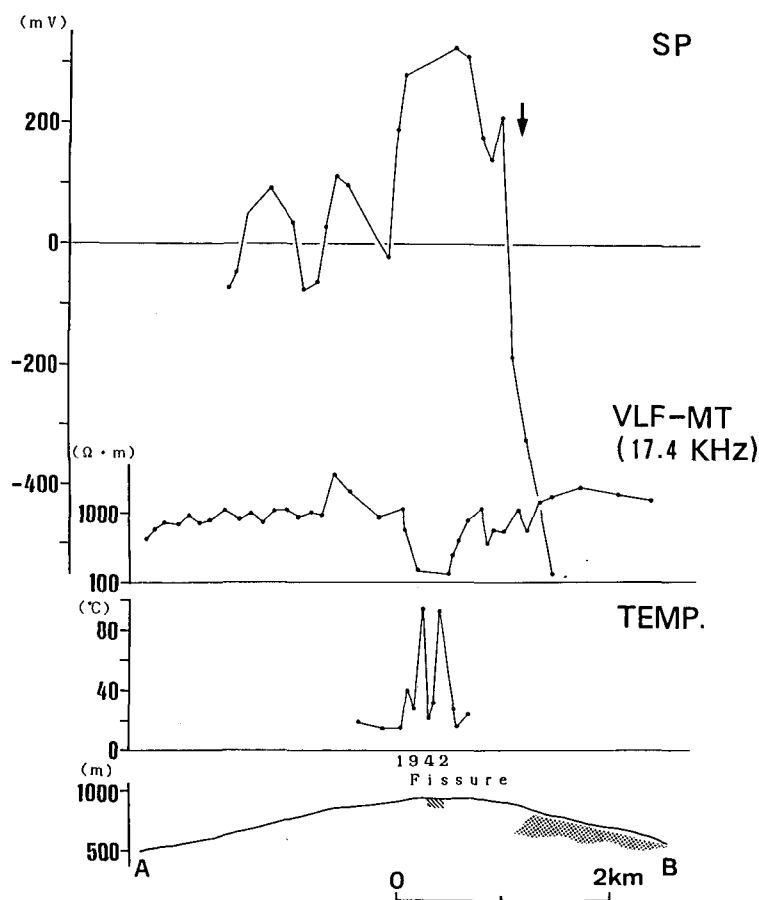


Fig. 9. Self-potential, apparent resistivity (VLF magnetotellurics) and ground temperature along the profile A-B in Fig. 4 with topographic profile of Hokkaido Komaga-take volcano. Temperature measurements were made by Sapporo District Meteorological Observatory (1987). Arrow, see text. The buried horseshoe-shaped crater rim is proposed at the eastern flank.

geothermal activity is weak in Hokkaido Komaga-take relative to those in Usu, suggesting the size of hydrothermal circulation within Hokkaido Komaga-take is smaller than that in the case of Usu. Kimura and Matsubayashi (1988) studied the hydrothermal circulation induced by a vertical and hot intrusive rock. They concluded that the size of circulation is correctly proportional to the temperature difference between the hot intrusion and the surroundings. Therefore, the difference in the spatial extent of the SP anomalies probably depends on the period of dormancy of the volcanic activity (Hokkaido Komaga-take: 50~60 years, Usu: ~10 years); that is, the size of circulation has been contracted during rather longer dormancy in Hokkaido Komaga-take.

The cause of the high potential gradient, about 400 mV in 100 m, at the eastern flank of Hokkaido Komaga-take (Fig. 5 and an arrow in Fig. 9) is unknown, but it can be attributed to a lateral variation in electric resistivity of the medium. The SP field may be distorted by resistivity variations across a contact as shown in the case of Usu (Nishida and Tomiya, 1987). We observed

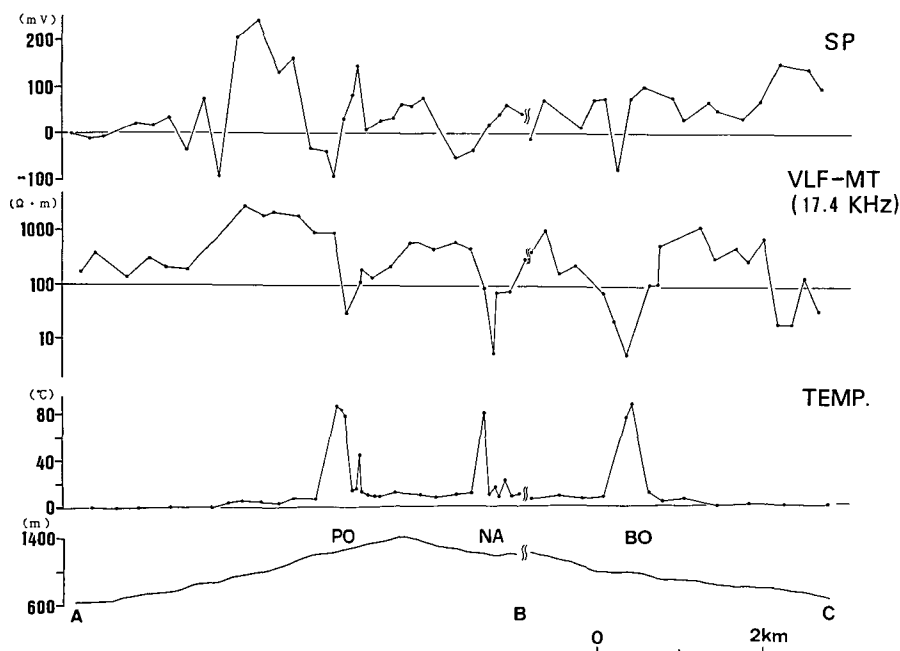


Fig. 10. Self-potential, apparent resistivity (VLF magnetotellurics) and ground temperature along the profile A-B-C in Fig. 6 with topographic profile of Me-akan volcano. BO: Kengamine geothermal area, PO: Ponmachineshiri crater, NA: Nakamachineshiri crater.

the high potential gradient near the place where the resistivity varies from about 1,000 Ωm to 2,000 Ωm . Therefore, the buried horseshoe-shaped crater rim (that is, the border of resistive somma volcano and less resistive crater fill) supposedly exists there at a depth shallower than the skin depth of VLF electromagnetic field ($<100\text{ m}$) as shown in Fig. 9.

Although a positive SP anomaly, 160 mV in magnitude, was observed at only limited area of Ponnmachineshiri crater, we could not find any remarkable anomalies at other geothermal areas of Me-akan such as Nakamachineshiri and Kengamine (Fig. 10), implying the hydrothermal circulation of large size has not developed within the edifice of Me-akan. This may relate to the fact that Me-akan has no experience of essential eruption during the historic time.

A noticeable SP anomaly amounting to 240 mV at about 1 km southwest of the Ponnmachineshiri crater does not correlate with ground temperature but correlate with resistivity. The anomaly of unknown origin may be amplified by highly resistive materials beneath the southwestern flank of Me-akan.

4. Concluding remarks

We observed the large positive potential anomalies, in both spatial extent and magnitude, over the summit crater of Usu and Hokkaido Komaga-take. These anomalies are commonly distributed along a fault or a fissure where is the high ground temperature zone. These evidences indicate that the anomalies are mainly caused by electrokinetic effect due to the upwelling of the hot ground water. On the contrary, we found a positive potential anomaly relating to geothermal activity at only limited area of the summit of Me-akan. The spatial extent of the anomaly closely relates to the size of hydrothermal circulation. And the development of the circulation depends on the volcanic activity of each volcano. Considering the dormant period of the three volcanoes concerned, the following result may be drawn: the shorter the period of dormancy, the larger the spatial extent of the SP anomaly.

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