Three-dimensional resistivity structure around Beppu geothermal zone

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SUMMARY

To delineate fluid pathways and associated heat sources, we conducted broadband magnetotelluric (MT) surveys from 2014 to 2020 around Beppu geothermal field. The resultant resistivity structure shows two conductors situated beneath southwestern side of Garan volcano and beneath Beppu bay at depth of 3~8 km. The earthquake swarms in 2007 occurred within a resistive zone sandwiched by the two conductors. Other seismicity occurred at resistive zones. Therefore, we interpret the conductive zones as ductile zones with temperatures exceeding 400°C. There are two heat sources for Beppu hot springs: one is located beneath southwestern side of Garan volcano, another is located beneath Beppu Bay.

Keywords: Beppu, magnetotelluric, resistivity, hot spring, heat source, earthquake swarm

INTRODUCTION

Beppu geothermal field is located in the north-eastern area of Kyushu Island, Japan. There are many famous hot springs in Beppu city, and their primary heat source has been considered to be located beneath Garan volcano (Allis and Yusa, 1989 Geothermics), western part of Beppu city. At shallow level beneath Garan volcano, it is suggested that volcanic fluids are mixed with meteoric water and flows through the east-west trending faults bordering the northern and southern perimeters of the Beppu alluvial fan. Additionally, another heat source is inferred beneath Beppu Bay, as indicated by seismic swarm in 2007, during which hypocenters migrated from a depth of 10 km within Beppu Bay to a depth of 3 km southwest of Beppu city. This NNE to SSE migration is considered as indicative of the movement of volcanic fluids (Maeda et al., 2010 EPS).

Method

To delineate fluid pathways and associated heat sources, we conducted broadband magnetotelluric (MT) surveys from 2014 to 2020 around Beppu geothermal field (Fig. 1). Typical recording duration for one site was 10 days. We calculated MT response functions at 153 sites by Bounded Influence Remote Reference Processing (BIRRP) (Chave and Thomson, 2004 GJI) and estimated 3-D resistivity structure by femtic inversion code (Usui 2015 GJI, Usui et al., 2017 GJI, Usui et al., 2024 JGR).

Result

The resultant resistivity structure shows two conductors situated beneath southwestern side of Garan volcano and beneath Beppu bay at depth of 3~8 km. The earthquake swarms in 2007 occurred within a resistive zone sandwiched by the two conductors. Other seismicity occurred at resistive zones. Therefore, we interpret the conductive zones as ductile zones with temperatures exceeding 400°C. Notably, past eruption vents of Garan volcano, Tsurumi volcano, and Yufu volcano are positioned around the edge of the conductor beneath southwestern side of the Garan volcano, while the hot springs are situated along the traces of east-west trending fault lines. At an approximate depth of 20 km, the conductor beneath the southwestern side of Garan volcano branches into northern and southern regions, with deep low-frequency earthquakes observed at the edges of these two deep conductors.

Conclusions

Our conclusions are as follows

(1) There are two heat sources for Beppu hot springs: one is located beneath southwestern side of Garan volcano, another is located beneath Beppu Bay.
(2) Volcanic fluids are supplied continuously from Garan volcano, while intermittent supply occurs from Beppu Bay, coinciding with earthquake swarms.
(3) The edges of conductors may act as sub-vertical magmatic fluid pathways.
(4) East-west trending faults act as horizontal pathway for hot spring water at depths of a few kilometers.

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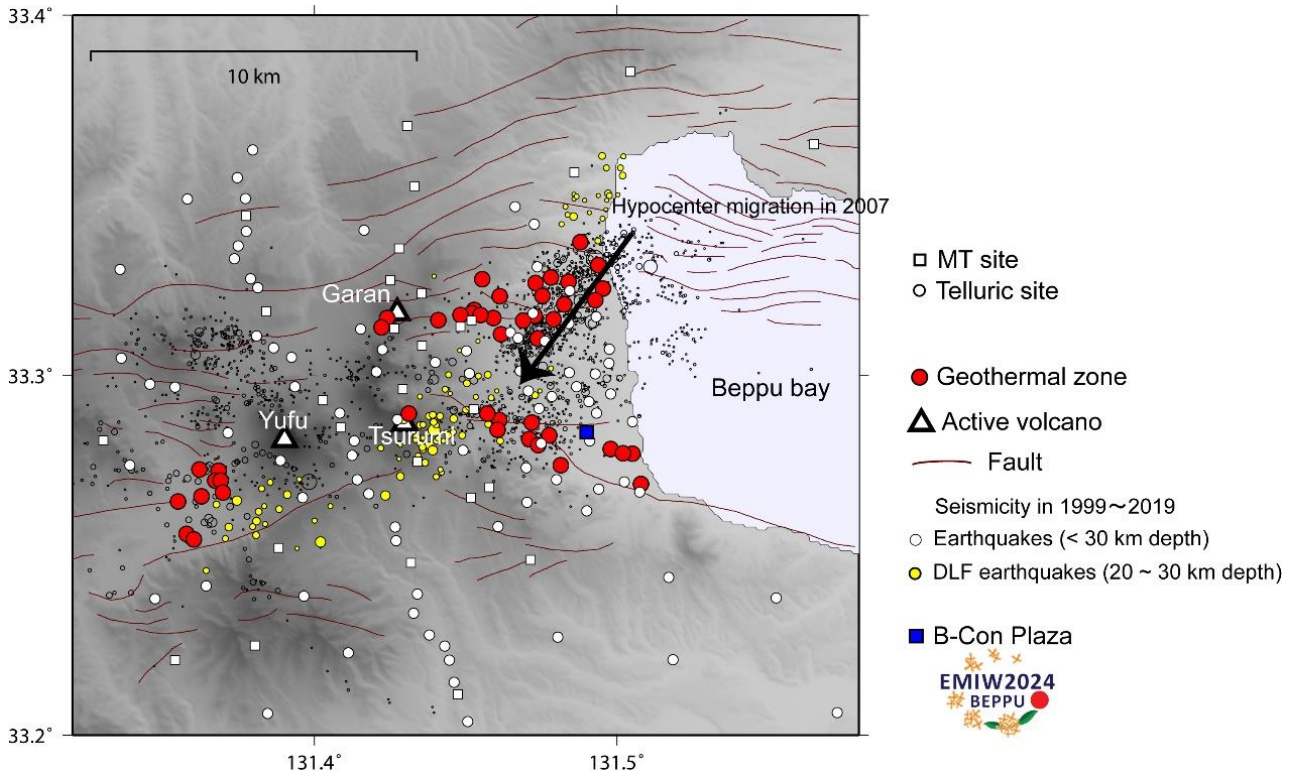

Figure 1. Observation map for broad-band MT surveys conducted in 2014~2020.