The shallow structure imaging of integrated geophysical surveying of GPR and ERT at Oyunuma in the Goshougake geothermal area, northeast of Japan

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The Goshougake geothermal area is surrounded in active volcanoes of Akita Yakeyama volcanoes and Hachimantai volcanoes. In this area, we can observe active geothermal phenomena, such as hot springs, high temperature water marshes including Oyunuma, and mud volcanoes. In this field, a part of sidewalk was broken by mud volcanic eruption, and has closed to walk since autumn 2016. The event inspires our motivation to research the shallow structure at the field by geophysical method.
The previous studies with geophysical methods were applied to the area including the Goshougake geothermal area. The gravitational survey, magnetic survey, electrical survey, and seismic survey in the north Hachimantai area were carried out by Yora and Ito (1974). Airborne electromagnetic survey, MT survey, and electrical survey were carried out by Uchida and Mitsuhata (1995). The research target of these studies focused on the wide area and the studies imaging shallow structure have never reported at Oyunuma in the in the Goshougake geothermal area. Our research purpose is revealing the shallow structures at Oyunuma in the Goshougake geothermal area by the integrated geophysical surveying of GPR (Ground Penetrating Radar) and ERT (Electrical Resistivity Tomography).
In GPR survey, a line of 172 m long was arranged on the southeast of Oyunuma. We used 4 different antennas of 100 MHz, 270 MHz, 400 MHz, and 900 MHz with the GPR equipment SIR-3000 made by GSSI (Geophysical Survey System, Inc.) and adopted the profile measurement with keeping interval of transmitter and receiver antennas. In ERT, a line of 188 m long was arranged along the GPR survey line. We used the equipment SYSCAL Pro made by IRIS Instruments and adopted the array system of the dipole-dipole method. The number of electrode is 48 and the intervals of the electrodes were 4 m.
A series of the GPR analysis, that is, time-zero correction, background removal, bandpass filter (BPF), autocorrelation, predictive deconvolution, velocity analysis, and depth conversion were applied to the obtained data. Clear reflections appeared at two way time of 75-100 ns in the time sections derived by BPF in the records of 4 kinds of antennas. Especially, clear reflections appeared in the reflection record of 270 MHz antenna. We picked up 4 blocks (sections) with remarkably clear reflections in the GPR survey line and carried out detailed analyses on each classified block.
The reflection records obtained in GPR survey are presented in the time sections. In order to convert them in the depth sections, it is necessary to know the exact EM (electromagnetic) wave velocity. We developed an original computer program for the EM velocity analysis which can be applicable for GPR profiling using Visual Studio 2015 C#. Based on calculation using the program, we can draw the contour chart of velocity spectrum which evaluates the most appropriate mean velocity by the semblance values. The semblance value is the ratio of the energy of stacked waves included in a time window to the total input energy of the waves in the same window (Honda, 2014). The exact mean EM velocity in ground medium is estimated to be 0.093-0.147 m/ns for each block. When multiple reflectors appear in reflection records, appropriate velocities are obtained by the predictive deconvolution processing. The original program also calculates the autocorrelation function which is the parameter used in the predictive deconvolution processing. Using the EM velocity by the velocity analysis, we can convert GPR data to the depth sections and the clear reflections revealed in the depth of 4-5 m from the surface of the sidewalk.
The 2D resistivity inversion by the finite difference method is used in the analysis of ERT. The part of the

continuity of an extreme low resistivity zone to the ground surface matches the location of the outcrop of the vents of sulfur gas. Consequently, the zone of the extreme low resistivity is suggested to be a layer of the pass of thermal water.
Comparing the results of GPR and ERT in the depth sections, the clear reflections in the blocks (from block1 to block 4) in GPR sections are located at the area steeply changing from the low resistivity to the high resistivity in ERT section. We can conclude that the some features of the shallow structure in Goshougake geothermal area obtained by the geophysical methods provide the key to elucidate the mechanism and the prediction of the eruption of mud volcanoes.

Keywords: GPR, Velocity spectrum, Resistivity

