Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SEM33-P01 Room:Convention Hall Time:May 26 18:15-19:30

Wide-band Magnetotellurics Survey on Kuju volcanic Group, Kyushu iland

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Kuju volcano is one of the active volcano, in Kushu island, located at the prefectural border of Oita and Kumamoto. On this volcano active fumarolic activity can be seen around Mt. Hossho which is one of the volcanic cones that construct Kuju volcano.

On Mt. Hossho, phreatic eruption was occurred in 1995, and new crater chains

were created by this activity (Imura&Kamata,1996).About Kuju volcano, many studies using seismological tomographic method were conducted, and Yoshikawa et al.,(2004) pointed out that a magma reservoir exists beneath the southern part of Kuju volcano.

On this study, we conducted wideband MT (Magneto-Telluric) method for inferring the state of magma supply system in this mountain ranges in September and October 2014.

Five component EM fields were measured at 11site by three MTU-5A (Phoenix Geophysics Inc.) and at 23 site by seven ADU (Metoronics Inc.),and only 2component E fields at 33 site which are in the mountains, by ten ELOG. Observed time series data are converted to wideband section by Fourier transform and calculate impedance. In our presentation, we will show the details about our observations and also show the preliminary results of data analysis.

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AMT resistivity soundings across the Kamogawa-teichi fault zone, Boso Peninsula

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We conducted resistivity soundings across the Kamogawa-teichi fault zone, Boso Peninsula, using the audio-frequency-magnetotelluric (AMT) method, in order to obtain a subsurface structure to discuss the existence and past activities of the fault zone. The observed apparent resistivity and impedance phase were inverted to a resistivity section. The preliminary estimated resistivity section is consistent with the geological age, which is categorized to three groups; Miura Group: $<3\ \Omega$m, Hota Group: $\sim 10\ \Omega$m and Mineoka Group: $>30\ \Omega$m. In general, an active fault is identified as a conductive zone due to saturated water into a fractured zone. However, no significant conductor is found beneath the estimated faults and resistivity boundaries. This implies that there are no fluids relating to fault activities in this area. We suggest possibilities that this "fault zone" has never experienced any fault activities or that it has spent a long time since the last active term, which cannot be resolved only by this survey.

Keywords: resitivity, active fault, Kamogawa teichi fault zone, magnetotellurics

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Resistivity structure of the Sotobo area in Boso Peninsula, Central Japan

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Boso peninsula is located in a tectonically complicated area where the Pacific plate, the Philippine Sea plate and the North-American plate converge. The Philippine Sea plate is subducting along the Sagami trough, where megathrust earthquakes have repeatedly occurred. Near the megathrust earthquake source region, slow slop events (SSEs) have occurred at least five times within 20 years and the recurrence interval has decreased [Ozawa et al., 2014]. The studies of SSEs have been advanced actively. For example, it was indicated that SSE is a major driving process for earthquake swarms [Hirose et al., 2014]. On the other hand, Obara [2007] argued that SSE may be related to fluid liberated from down-going slab by dehydration process. But the details of the subsurface structure where it occurred have not still understood well.

A magnetotelluric (MT) survey was carried out between November and December in 2014 to investigate the structure relating to SSE and subduction of the Philippine Sea plate under the continental plate. Time series of the MT data were recorded using the MTU-5 system manufactured by Phoenix Geophysics Co. Large artificial electromagnetic noise was observed in this area during operation time of DC trains. Reduction of the serious noise will be essential to investigate deeper depth. In this preliminary stage, we analyzed only data for two hours per a day that was obtained from 2 to 4 a.m. to avoid the DC train noise. However the lower frequency bands (0.1 - 0.001 Hz) data still have not well identified due to local noise. We used the data at the frequency band of 320 to 1 Hz and applied the remote reference method referring the other site observed in same time. We acquired apparent resistivity and phase on each site based on the above process, and we also computed the phase tensor and induction vectors. The phase tensor was nearly circle at each frequency, and the induction vectors have not point to the specific direction in the frequency range. Finally we inverted the apparent resistivity and phase data and drew out a MT model.

MT images have showed basically three layer structure. Top layer, having 10 Ω-m, is extending to the several hundred meter depth and underlying the very low resistivity layer ($>$1 ohm-m). According to the drilling data, these two layers are interpreted as Shimosa and Kazusa Group respectively. The bottom of Kazusa group in the west area seems to be deeper than that of the east area of the survey area and has showed basin like structure. The resistive layer is distributed at several kilo-meters depths in the northeast area. This layer was interpreted as pre-Tertiary bed rocks. As shown here, we imaged subsurface structure of the Sotobo area at depths of several kilo-meters in this stage using noise free frequency band data. However we would like to delineate image the deeper area than the result of this survey to elucidate the structure of SSE or the relation of the two plates, so we need to remove noises from obtained data and observe wider area in the next stage.

Keywords: Magnetotelluric, Resistivity structure, Boso Peninsula, Kazusa Group

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Broad-band telluric and magnetotelluric measurements in Oita prefecture, Kyushu, Japan

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Recent development of 3-D magnetotelluric (MT) inversion codes (e.g., Siripunvaraporn et al., 2009; Kelbert et al., 2014) allows us to deduce the 3-D resistivity structure. However, it is still hard to obtain MT data at many sites. In particular, measurements of broad-band MT data is not easy to be conducted; because the apparatus is expensive, heavy, and has high electric power consumption (12~18W). These factors sometimes hamper to obtain large MT dataset, though a sufficient number of sites are crucial for a reliable 3-D resistivity structure.

For MT impedance calculations, it is not necessary to record the magnetic field in all sites. Alternatively, the MT impedance can also be calculated by using the magnetic field of other sites. Indeed, such kind of impedances has been used to deduce the high-resolution resistivity structure (e.g., Unsworth et al., 1997). In an extreme case, it is possible to deduce the 3-D resistivity structure with single magnetic field site (e.g., Hata et al., 2015). Considering that omitting of magnetic field measurements leads to reduce the effort in the field, we developed a new telluric measurement apparatus with low power consumption (1.8W). In the presentation, we will show the result of the field test that is performed by using the new telluric apparatus and the MT apparatus. The broad-band (200~0.001 Hz) MT impedances obtained in the Oita prefecture, Kyushu, Japan, will also be shown.

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Modification of resistivity structure beneath the Biwako fault, the southeastern part of the Yamasaki fault system

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Introduction

The Yamasaki fault zone (YFZ) consists of the Nagisen Fault, the main part of the YFZ, and the Kusadani Fault. The main part of the YFZ is further divided into a northwestern (NW) group (the Ohara, Hijima, Yasutomi, and Kuresakatouge Faults) and a southeastern (SE) group (the Biwako and Miki Faults) based on their latest faulting events and mean left-lateral slip rates; AD 868 and 1.0 m/kyr for the NW group vs. AD400 - 600 and 0.8 m/kyr for the SE group (Okada, 1987; Earthquake Research Committee, 2013).

The audio-frequency magnetotelluric (AMT) method is a powerful tool for investigating the structure of active faults in the upper few km of the Earth crust. In particular, this method is more sensitive to the structure of a strike-slip fault, where vertical to high-angle fault planes and fracture zones are expected, than seismic reflection or refraction surveys.

Observation

An AMT surveys were made at 81 stations along 7 survey lines across the faults of the NW group, while the survey was made at only 8 stations along 1 survey line across the faults of the SE group. It is important to make clear the subsurface structure of the SE group to know the whole nature of the YFZ and difference between the NE and SE groups of the main part of the YFZ.

We focused on the Biwako faults of the SE group in this study. The Biwako fault is a vertical dipping, left-lateral strike-slip fault system along a general strike of N50W.

An AMT survey was undertaken in June 2014 at nine stations along the transect across the Biwako fault. This transect passed the site of trench excavation survey (Earthquake Research Committee, 2013). To apply remote reference method, the remote station of the magnetic field was set ~15km north from the northeastern end of the transect. Two horizontal components of electrical field and three components of magnetic field were measured.

Analysis

After calculated MT response functions based on the remote reference method (Gamble *et al*., 1978), we adopted the phase tensor analysis (Caldwell *et al*., 2004) to estimate dimensionality of the resistivity structure beneath the study area and to determine the direction of the regional strike, if the structure is two-dimensional. The two-dimensional resistivity model was constructed using the code of Ogawa and Uchida (1996) from the MT responses of both TE and TM modes.

Interpretation

The optimum model obtained is characterized by the clear resistivity boundaries correspond to the surface traces of west and east segments of the Biwako fault and by low resistivity zone dominated on the north side of the fault. We interpreted that the dominant low resistive zone on the north side of the fault is caused by aqueous fluid in wide damaged zone which is developed in the tensile region between the western and eastern segments. The clear resistivity boundary near the fault is caused by a fault core which can be a barrier to water flow across a fault plane. It is still unclear how the conductive region at the south side of this survey line generated.

Keywords: Biwako fault, Yamasaki fault system, active fault, resistivity structure, Magnetotelluric method

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A report on the fundamental investigations of an electrical resitivity structure beneath Chugoku and Shikoku regions

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In order to contribute to a reduction in damage caused by earthquakes and volcanic eruptions, heterogeneities of crustal and upper mantle structure should be clarified based on fundamental investigations of electrical resistivity sructure in Chugoku and Shikoku regions, southwestern Japan arc. In this presentation, a preliminary report on fundamental surveys, using data acquired in 2014 incorporated in the existing data, will be shown.

Our research group has shown that there is a clear relationship between resistivity and seismicity in the Sanin and Shikoku regions. In the eastern part of San-in region, it was found that a conductive area exists in the deep crust part under the seismic region, which is a resistive area, along with the seismic activity area stretching nearly in the east and west direction. However, recent observation result conflicts with the model advocated by the group including the author that has studied electrical resistivity in Sanin region (ex, Ozaki et al., 2013). That is, there is a possibility that the deep low resistivity area beneath the Sanin region does not exist in series. Assuming that inland earthquakes occur because of local stress concentration caused by heterogeneity beneath a seismic activity band (Iio, 2009), the heterogeneity in this area should be clarified hereafter. Wideband MT obsevations were carried out at 5 sites in the western extension area of Shikano and Yoshioka faults, from late Sep to early Oct 2014. The area is located between the 1943 Tottori earthquake (M7.2) and 1983 Misasa earthquake (M6.2) source regions. Natural geomagnetic and electric field variations were measured using Phoenix MTU5 systems. Apparent resistivity and phase data were used for model analysis assuming an EW strike direction. A preliminary two-dimensional model shows almost a similar resistivity structure, as a whole, to those obtained by the existing studies in this region. However, the location of the deep crustal conductor is slightly shifted to the south.

On the other hand, in the Shikoku region, investigations were carried out mainly in the outer zone, and the result suggested that a remarkable conductive area should exist in the upper crust and that the conductive area in the central and western part should have a clear relation with the non-seismic area. These studies suggest that high conductivity(low resitivity) is possibly caused by the existence of deep crustal fluids, which probably play an important role in the inland earthquake occurrence mechanism of these regions. However, the existence of the plate is not thoroughly identified in the geological inner zone of the southwestern Japan Arc. Therefore, in order to grasp a whole tectonic setting, from the fore to the back arc side in the southwestern Arc, quantitative discussions based on the wideband MT survey covering whole these regions should be required (Shiozaki et al.,2014). In order to elucidate the regional characteristics of the large scale resistivity structure, fundamental wideband MT observations have been conducted at 5 sites in the observations gap area in the east and central region of Shikoku from late Nov to mid-Dec 2014. Preliminary results show that the derived apparent resistivity and the phase curves have a common feature for all 5 sites.

We would like to express sincere gratitude for the Nittetsu Mining Consultants Co. Ltd. kindly let us use their continuous geomagnetic records as remote references. This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under its Observation and Research Program for Prediction of Earthquakes and Volcanic Eruptions, and also supported by a Tottori Prefecture Environmental Academic Research Promotion Project issued in Fiscal year 2014. Last of all, we would like to express our thanks to T.Uto, H.Hataoka, S.Yamamoto, Y.Ikezoe, M.Fukunari, A.Hamada, Y.Tsuyoshi and S.Yoshida of Tottori University for their help during data acquisition.

Keywords: electrical resitivity, fundamental investigation, Chugoku and Shikoku region

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Dense AMT observations across the Japan Median Tectonic Line Izumi fault zone

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The Japan Median Tectonic Line Fault Zone (MTL) is a fault system that extends for about 360km and locates along the geological boundary between the Ryoke and the Sanbagawa belts. Izumi segment fault zone of the MTL consists of Gojodani and Shobudani faults, etc. Wideband Magnetotelluric (MT) soundings were carried out across these faults (Yoshimura *et al*., 2014). The obtained resistivity model was characterized by a contrast around the MTL. However, the shallow resistivity structure was not so clear.

In order to delineate fine subsurface structure around the fault, we carried out audio-frequency magnetotellurics (AMT) measurements at 38 sites along a 5km profile perpendicular to the Gojodani and Shobudani faults in November, 2014. MT responses of a frequency band of 10,400-0.35 Hz were obtained using remote reference processing (Gamble *et al*., 1979). As a result, relatively good quality MT responses were obtained at most sites.

In this presentation, we will show the final MT response functions at each site and report a preliminarily results of two-dimensional inversions.

Keywords: the Japan Median Tectonic Line Fault Zone, magnetotelluric, damage zone, shallow resistivity structure

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The 3-D magnetic imaging using the L-1 norm regularization, Part II.

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Recently some new methods for 3-D magnetic imaging were proposed (Li and Oldenburg,1996, Portniaguine and Zhdanov,2001, Pilkington,2013). Some of them have a goal to obtain the “sparse” model i.e. the simplest model that reproduce the observed data. This is because, most of the traditional way of inversion for the potential data provides distorted or unfocused images of real magnetic structures. In this study, we propose a new method introducing an L-1 norm penalized least square procedure and tried to obtain a simple, high-resolution and focused model.

Lasso (Tibshirani, 1996) is a linear regression and variable selection procedure based on the L1 penalized least square. L1 penalty has an effect of shrinkage the value of model parameters which have weak contributions to be zero. So, the Lasso does both continuous shrinkage and automatic variable selection simultaneously. On the other hand, Lasso has some drawbacks. One of them is, at most Lasso algorithm can select nonzero variables of same number of observed data. So, in the case of $p << n$ problem, i.e. when the number of unknown parameters (n) is larger than the number of observations (p), this algorithm cannot be adopted or overly shrinkage model will be obtained.

To overcome this limitation, Zou and Hastie (2005) proposed a new L-1 penalized method named ’elastic net’, and Hebiri and van de Geer (2011) proposed ’S-Lasso’. These methods are the compromise of the L-1 and L-2 or some quadratic regularization method. Using these methods, we can treat $p << n$ problems in the framework of L-1 penalized method.

In This study, we propose a new 3-D magnetic inversion method based on the Lasso-type regularization (i.e. generalized elastic net) and show the results of applying our method to the synthesized and real magnetic data.

Keywords: L1 regularization, magnetc inversion, aeromagnetic survey

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Geomagnetic three-component secular changes in eastern Hokkaido, NE Japan

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Based on the total field records, regional anomaly in the rate of geomagnetic secular changes have been observed in eastern Hokkaido, NE Japan (Oshima et al., 1994; Hashimoto et al., 2012). This area is under a compressive regime due to subduction of Pacific plate from east-southeast toward west-northwest (Ishikawa et al., 2001). Positive geomagnetic anomalies are also distributed in the southern coastal area, suggesting the existence of highly-magnetized rocks (Sugisaki et al., 2001). For these reasons, Nishida et al. (2004) suspected the piezomagnetic effect as the predominant cause of the rate of geomagnetic secular changes. We started three-component absolute measurements at eight continuous magnetic stations in 2009, aiming at revealing the mechanisms of the anomaly. The measurements have been performed twice or three times at each station by 2014. We report a brief overview of the absolute measurements up to 2014.

In the total field, the values at each station have been subtracted from values at the reference station Memambetsu Magnetic Observatory (MMB) of Japan Meteorological Agency to remove the variations of extra-terrestrial origins. We applied the same procedure also to declination, horizontal and vertical components. We then recognized that the rate of secular change in individual component also differs from site to site. Now, it is clear that the anomalous secular changes in the total field in this area were not brought by the so-called orientation effect. Trends of horizontal and vertical components were steeper near the southern coast as in the case of the total field. Declination seemed more complicated, presumably showing clockwise rotation in the northern area, while anti-clockwise in the south.

Current results are still preliminary because the number of absolute measurements is small yet. It is necessary to add further data in order to make the discussion more accurate. In addition, numerical modeling of piezomagnetic effect in three-component will contribute to constrain the mechanism of the anomaly.

Keywords: geomagnetic three-component absolute measurements, geomagnetic secular change, eastern Hokkaido

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Distribution of electromagnetic fields induced in Japan

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The electric field induced by a geomagnetic field variation can be enhanced in Japan by a large conductivity contrast between seawater and rocks (the coast line effect). We should know plausible geomagnetically induced currents there when unprecedentedly large geomagnetic disturbances occur. Distributions of the electromagnetic fields induced at the surface of a realistic earth are estimated as the first step.

The electromagnetic fields induced at the surface of a 3D earth under an inducing magnetic field in the magnetosphere are computed in the frequency domain by the finite difference code developed by Uyeshima and Schultz (2000). The periods used are 200, 800 and 3600 seconds. The grid size is 12.5km x 12.5km at latitudes between 25-50^{o}N and longitudes between 125-150^{o}E and is gradually increased at the outside the region.

A 3D distribution of the electrical conductivity inside the Earth is obtained down to 12.5 km deep by using the ETOPO1 bathymetry data and the sediment thickness data by Laske and Masters (1997). A radially symmetric conductivity distribution is used at depths lower than 12.5km. The conductivities of seawater and sediment are fixed as 3 and 0.1 S/m, respectively, while the rock conductivity is used either of 0.01 or 0.0001 S/m to demonstrate the effect of a conductive or resistive lithosphere.

The inducing dipole magnetic field is given at 10 Earth radii as a boundary condition. If it is an axial dipole, the source magnetic field variation is polarized mainly in the north-south direction in Japan. We rotate the dipole every 30 degrees against the equator plane to realize other polarizations.

We pick up the maximum amplitude of the induced electric field among all source field patterns at every surface grid point to construct the distribution map of the maximum possible induced electric field in Japan. The map shows that the electric field is enhanced along the coast lines and the electric field amplitude is larger for the resistive lithosphere than that for the conductive one. The amplitude reaches twice compared to that from a homogeneous earth model. In most surface grids, the electric field amplitude at a shorter period is larger than that at a longer period. The electric field is enhanced especially at Tsugaru-Toshima peninsulas, Toyama bay, Izu peninsula, and east coasts of Kyusyu Island where offshore sea depths quickly become deeper.

The geomagnetic field at the surface also shows heterogeneity because of induction. When the source magnetic field is an axial dipole, the east-west component is generally weak and the vertical components are can be large at coastal areas. The north-south component at Tohoku and Kyusyu is similar to that of a 1D homogeneous earth, while it is weaker at areas from Kanto to Chugoku.

Distributions of the impedance tensor are also obtained. The impedance tensor substantially varies over Japan suggesting that the influence of sea on the regional induction is immense. For instance, Hokkaido could be divided into several areas following the spatial pattern of the impedance tensor, which show some similarities to the impedance tensor at Doto obtained by Uyeshima et al (2001). Similarly, several districts over Japan are recognized from the viewpoint of the spatial pattern of the impedance tensor depending on the direction of the source magnetic field.

The comparison between the computed and observed impedance tensors at Kakioka, Kanoya and Memambetsu indicates that the computed tensors qualitatively reproduce the observed ones, but the amplitudes and frequency dependencies show discrepancies. A more realistic conductivity model is necessary, if a more precise estimate of the electromagnetic field induced at the surface.

Keywords: electromagnetic induction, geomagnetically induced currents, impedance tensor

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Estimating the distribution of electrical conductivity in the earth with the maximum-likelihood method

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We estimated radial electrical conductivity distribution in the Earth by solving an inversion problem with an objective function that allows errors in the model. In general, geophysical inverse problems are solved by the least squares method that minimizes the objective function consisting of linear combination of the data misfit and the regularization term. The predicted data is obtained by a forward calculation for the set of optimized model parameters. However, this method implicitly premises that the model has no error.

We tried to solve an inversion problem without the premise. Solutions by the maximum-likelihood method are not necessarily equal to those by the least square method. Specifically, We applied this method to the vector geomagnetic observatory data all around the globe in November, 2003 and estimated the radial electrical conductivity profile. A heterogeneously conducting shell was placed at the top of the radially symmetric sphere. We worked with the data per minute at 69 observatories during the large geomagnetic storm and subtracted the vector average for 5 quietest days. We then separated the corrected time-series into internal and external origin. The separated internal magnetic field can be reproduced by our maximum-likelihood method using forward response of the radially symmetric conducting sphere to the separated external magnetic field.

It was revealed that the maximum-likelihood method led to the different solution from that by the least squares method and that the maximum-likelihood method gave us appropriate information on model choice. However, it was necessary to apply a priori information on the model parameters as much as possible (e.g., all electrical conductivities must be positive) and to add a regularization term to the objective function. We will also discuss the pertinent way of adding errors to the synthetic data and the effect of initial models on the final model.

Keywords: electrical conductivity, magnetic storm, inversion

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Direct simulation of resistivity on porous model obtained from high-resolution X-ray CT

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Resistivity imaging is widely used to estimate both the class ofgeo-materials (e.g., rock, sand, etc.) and the state variables of geo-materials (e.g., porosity, degree of saturation, etc.) on a cross-sectional plane (survey area) placed in the underground. For engineering use, the resistivity imaging of underground is adopted to observe the behavior of groundwater flow and to comprehend the changes of ground state caused by ground improvement. In order to increase the accuracy in the estimation of geological properties derived from resistivity imaging, we need to reveal the relationship between the resistivity and several physical parameters such as porosity, degree of saturation, and electrical conductivity of pore fluid. In other words, the resistivity has the dependency with those physical parameters.

Here, we have conducted a series of finite element simulations with above physical parameters to discuss the relationship between the resistivity of porous media and those physical parameters. The three-dimensional porous models are created by a series of sectional images obtained from the high-resolution X-ray CT. Although this method requires a precise micro-structure of porous media before the consideration, we can quantitatively estimate the resistivity of the porous model. This method also enables us to discuss the anisotropic properties on the resistivity by changing the direction of energization along the x, y, and z-axis.

Subsequently, the simulation results are compared with those obtained from experiments and with those derived from the empirical law, i.e., Archie's equation. According to the comparison, the simulation results are in good agreements with experimental results and indicate similar function form that proposed in Archie's equation being available for unsaturated state. Also, we have tried to extract the micro-scopic physical parameter such as the tortuosity. The tortuosity is one of the key parameters to characterize the transport properties of porous media, but it is difficult to measure the tortuosity through experiments.

Finally, we discuss the limitation of Archie's equation and infer that Archie's equation is applicable to geo-materials having a degree of saturation exceeding 40%.

Keywords: resistivity, porous media, finite element method, X-ray CT, Tortuosity

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Development of resistivity modeling code designed to high-density electrical prospecting for cylindrical rock samples

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Crustal electrical resistivity structures are obtained through geoelectromagnetic observations, and are used to interpret characteristics of subsurface crustal activities such as earthquake occurrence and volcanic activities (e.g., Ogawa et al., 2001; Yoshimura et al., 2009). Because electrical properties are very sensitive to the existence of fluid, geoelectromagnetic methods are used to detect crustal fluid.

Resistivity images are interpreted in relation between the porosity of rock and its connectivity with several mixing lows (e.g., Archie, 1942; Hashin and Shtrikman, 1962; Glover et al., 2000). In order to verify the applicability and scalability of such interpretations, we plan to carry out high-density electrical prospecting for rock samples whose other geophysical characteristics are well known.

As the first step of laboratory experiments, we have developed a numerical simulation code of DC method for cylindrically-shaped samples as a tool for feasibility studies. In our code, three dimensional finite-difference methods described in Dey and Morrison (1979) is modified for the cylindrical coordinate system.

For performance evaluation, the results of numerical experiment were compared with results of electrical prospecting to simulation sample (conductive plastic). As a result, we confirmed a cylindrical-shaped outer boundary is represented consistently by developed code. Also, we detected thin structure whose thickness is 1mm or less and estimated its resistivity by forward modeling.

In this presentation, we will report the results of comparison between numerical simulations and electrical prospecting to simulation sample.

Keywords: rock experiments, electrical resistivity, numerical simulations