SEM33-01 Room:102A Time:May 26 09:00-09:15

Electromagnetic waves radiated from the ground

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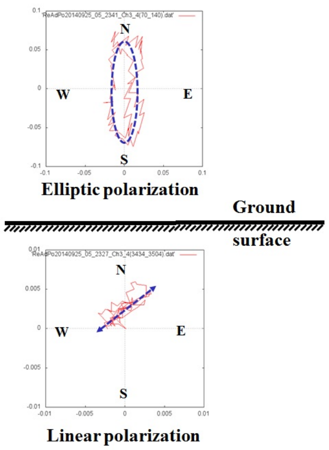
We have been observing electromagnetic (EM) pluses excited by earthquakes. Recently we have confirmed that the detected EM waves were co-seismic ones which were readily generated by piezo-electric effect in earth crusts by vibrations of seismic waves [1]. In order to inspect behaviors of the excited EM pulse, we prepared two sensor systems consisting of tri-axial magnetic search coils. One was inserted into a deep bore hole of 100 m in depth and another was installed on the ground. When an earthquake (M2.7) occurred at just below (at the depth of 11 km) the EM observation site, we simultaneously captured waveforms of an EM pulse in the borehole and on the ground. From the waveforms of magnetic north-south and east-west components detect by the both sensor systems, we obtained their wave polarizations in horizontal plane. Their results are shown in Figure 1. As shown in the figure, the wave above the ground shows elliptic polarization whereas that in the earth shows linear polarization. This means that the wave was propagating from the deep earth to the air region passing through the ground surface which is interface of two media with different refractive indices. We found that almost all of seismic waves can excite EM waves, and they were radiated out of the ground surface. This is a reason why co-seismic signals were often detected by MT method.

[1] Minoru Tsutsui, Behaviors of Electromagnetic Waves Directly Excited by Earthquakes, IEEE Geoscience and Remote Sensing Letters, Vol. 11, No. 11, pp. 1961-1965, 2014.
[2] M. Tsutsui, T. Nakatani, M. Kamitani and T. Nagao, Polarization and propagation property of electromagnetic pulses in the earth, in Proc. IGARSS, 2011, pp. 838-841.

Keywords: observation of electromagnetic pulses, polarization analysis, radiation from the ground



Japan Geoscience Union Meeting 2015
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SEM33-02 Room:102A Time:May 26 09:15-09:30

Three-dimensional forward calculation of magnetotelluric responses using a mesh-free particle method.

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Accurate forward calculation of electromagnetic induction in the earth is essential for quantitative modeling of subsurface resistivity structure. The expression of complicated topography and bathymetry in the three-dimensional (3D) model should be carefully handled for accurate numerical calculations, but frequently ignored, unfortunately. For example, a widely-used 3D inversion code of magnetotelluric (MT) data is based on the finite difference method (FDM), in which the 3D model consists of assembly of rectangular blocks. Therefore, a smooth relief on the ground can be expressed as stair-like hills and valleys. Previous studies indicated that such step-wise approximation of topography yields large calculation error of MT responses. The finite element method (FEM) can include the smooth topographic relief in the 3D model, while the selection of proper mesh configuration for FEM is a hard task for users.

In this research, I developed an new 3D MT forward calculation method with the MPS (Moving Particle Semi-implicit) method, one of the mesh-free calculation methods. The main purpose is the proper expression of topography / bathymetry in the 3D resistivity model. The MPS method is a particle method and is developed for the simulation of incompressible flow by Koshizuka and Oka (1996), and has been applied for the one and two-dimensional MT problems. I use the MPS method for the 3D simulation of electromagnetic induction in this study. In the forward calculation, electric and magnetic fields can be defined at each particle in a calculation model. Then, MT responses are calculated on an arbitrary point in the 3D model (on the surface, on the seafloor, and even in the earth). The results of MT forward calculation indicate enough accuracy, implying capability to application to the inversion procedure of MT responses with complicated topography.

Keywords: particle method, magnetotellurics, forward calculation, numerical calculation, mesh-free

SEM33-03 Room:102A Time:May 26 09:30-09:45

Accuracy evaluation of MT response calculated with Particle Method

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MT(magnetotelluric) method ,one of the electro-magnetic(EM) sounding methods, is considered as a technique in practice for the exploration of hydrocarbon resources.Conventionally, the finite difference method and the finite element method are often used as a numerical calculation of the electromagnetic field below the surface for the forward and inverse problem of the MT method (e.g.,Baba and Seama,2002; Minami and Toh, 2012).

However,using the finite difference method has a difficulty of including complicated shape in the model like the topography and underground heterogeneous structure.

For overcoming the weak point, the particle method attracts attention of MT users recently.The particle method is one of the techniques to make a model discretization with particles not aligned along lattice or mesh. It is easy for particle method to include any complicated shapes in the model.However, early researches have not discussed the calculation conditions and setting of the parameter which is thought to contribute.For example, the influence radius , one of the parameters in the particle method is important to be adjusted for keeping high accuracy of calculations beforehand in the particle method.

In this study,we performed examination about the better setting of the influence radius to achieve the high accuracy when we use the particle method for the analysis of the electromagnetic field in the MT method.

In our numerical results, the trend is obvious that the calculation error at high frequency was small enough if the influential radius was small.We also found that a relation between the degree of the electric field attenuation and the influential radius which can adjust the calculation error to be smaller.Influence radius and weight in particle method should be optimize.

Keywords: MT, Particle Method

SEM33-04 Room:102A Time:May 26 09:45-10:00

3-D forward calculation and inversion of magnetotelluric data using the meshes including the actual topography

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The author developed a 3-D MT inversion code using unstructured tetrahedral elements and a tool to make computational meshes including the actual topography from digital terrain data.

It is important to consider topographic effects in interpreting observed data of magnetotelluric (MT) method. Without ignoring these effects, it is, therefore, possible to misinterpret subsurface structures because the observed data from MT surveys can be strongly affected by the topography around the survey area. The most straightforward way to take account of these effects is to incorporate the topography explicitly in the computational grid used in forward calculation and inversion, and this method can be applicable to a wider range of surveys.

Among space discretization methods, the finite element method using the unstructured tetrahedral element is considered to be one of the most effective method to include topography in computational grids, because it can represent topography precisely without using too many elements, and a number of robust meshing algorithms have been proposed such as Delaunay triangulation method and the advancing front method.

The forward part of the developed inversion code uses the edge-based tetrahedral element to calculate the electromagnetic field on the earth's surface. The inversion code can use the impedance tensor, the vertical magnetic transfer function and the phase tensor as observational data, and it estimates the subsurface resistivity values by updating them using Gauss-Newton method.

To make 3-D computational mesh of model, the tetrahedral mesh generator TETGEN (Si 2007) was used. This program constructs a tetrahedral mesh by the constrained Delaunay triangulation method from an inputted piecewise linear complex (PLC). Thus, in order to make a 3-D mesh containing topography, the author developed the program which makes the PLC including the topography. First, this program makes the 2-D mesh including land-sea boundaries by the 2-D constrained Delaunay triangulation method from the data of coast lines. Next, the altitude of the water depth of each node of the mesh is interpolated from topographic data by the inverse distance weighting method, and then outputs the 3-D PLC containing the topography.

With the aid of the inversion code and the meshing tool, the author will perform forward calculation and inversion using the mesh including actual topography to evaluate the topographic effects precisely and interpret subsurface resistivity structures accurately.

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SEM33-05 Room:102A Time:May 26 10:00-10:15

3D Electrical Resistivity Imaging beneath Kyushu by Geomagnetic Transfer Functions and Network-MT Response Functions

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The Kyushu Island in the Southwest Japan Arc has many Quaternary active volcanoes, which exist along the volcanic front of N30^{o}E-S30^{o}W, in relation to the subduction of the Philippine Sea Plate (PSP). The volcanoes are located in northern and southern regions of the island, and no volcano is located in the central region between the two volcanic regions of the island. We have performed three-dimensional (3-D) inversion analyses to obtain a lithospheric-scale electrical resistivity structure (model) beneath the entire Kyushu Island by using a data set of Network-Magnetotelluric (MT) response functions [*Hata et al.*, 2015]. One of two major findings from a distribution of conductive anomalies in the model is that the volcanoes in the northern and southern volcanic regions have two different origins bordering the non-volcanic region at deep depths. Secondly, the degrees of magmatism and the relative contributions of slab-derived fluids to the magmatism vary spatially in the one non-volcanic and two volcanic regions.

A shallow depth resolution of the lithospheric-scale resistivity model, however, was too low to examine small-scale resistivity structures of the crust because of the period range between 480 and 40,960 s of the Network-MT data. Thus we have started to perform 3-D inversion analyses by using a data set of geomagnetic transfer functions whose period range is from 20 to 960 s to obtain a resistivity structure model, in which we can examine smaller-scale structures. The geomagnetic transfer functions were determined at 167 sites in the Kyushu district. Original raw data sets for the geomagnetic transfer functions were measured at the entire Kyushu island and several islands off the western coast of Kyushu from 1980's to 1990's [e.g., *Handa et al.*, 1992; *Shimoizumi et al.*, 1997; *Munekane et al.*, 1997]. In this presentation, we will show a new electrical resistivity model, which is obtained through a two-stage inversion process as follows. We determine a resistivity structure mainly at a shallow depth by applying 3-D inversion analyses for the geomagnetic transfer functions of 20-960 s first and then determine a lithospheric-scale resistivity structure by applying 3-D inversion analyses for the Network-MT response functions of 480-40,960 s, which is based on values of the previous resistivity model determined by using the geomagnetic transfer functions. In the two-stage inversion process, we use two types of DASOCC inversion code [*Siripunvaraporn et al.*, 2004; *Uyeshima et al.*, 2008; *Siripunvaraporn and Egbert*, 2009].

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SEM33-06 Room:102A Time:May 26 10:15-10:30

Temporal Resistivity Change of Crustal Resistivity Structure Before and After the 2011 Tohoku Earthquake

SAITO, Zenshiro[1*] ; OGAWA, Yasuo[2] ; HASE, Hideaki[2] ; KANDA, Wataru[2] ; HONKURA, Yoshimori[2] ; SEKI, Kaori[1] ; SAKANAKA, Shin'ya[3] ; ASAMORI, Koichi[4]

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The NE Japan was under the EW compression and localized strain distributions were observed along the Ou backbone ranges, which were responsible for generating the large inland earthquakes. The coseismic displacement of the 2011 off the Pacific Coast of Tohoku Earthquake (M9) released EW compressional strain and generated EW extension over the region. This earthquake had a great influence crustal dynamics in NE Japan. In particular, the seismicity around the Naruko area has sharply decreased. The GPS displacement show extension deficit (Ohzono et al, 2012), i.e. the Ou backbone rage shows less EW extension compared to the surroundings, because of the anomalous viscosity under the Ou backbone range. InSAR detected the subsidence of the geothermal regions around the Naruko area (Takada and Fukushima,a 2013). These suggest existence and migration of crustal fluids after the M9 earthquake.

MT is suitable to detect the fluid migration in the crust, as the resistivity is sensitive to the existence an connectivity of fluids, although they are minor components in the fluid bearing rocks. The previous profile MT dataset over Naruko volcano were obtained in 2003 (Asamori et al., 2010) and we tried to repeat MT measurements at the same places in 2013. Altough we tried to measure at the same spots, the locations are not exactly the same. In particular, we worry about the difference in the near surface local structures of the 2003 and 2013 sites. To overcome this difficulty, we used phase tensor (Caldwell et al, 2004) as response functions, which are insensitive to galvanic distortions of the near-surface local structure. To evaluate the temporal changes, it is important to show the errors of the phase tensors. For this, we used boot-strap method with 1000 realizations. We compiled the difference of α, β, ϕmax, ϕmin with error bars for all the period range. We found some consistent differences in the phase tensor parameters.

Keywords: resistivity, temporal variation, magnetotellurics, phase tensor, fluid

SEM33-07 Room:102A Time:May 26 11:00-11:15

Electrical conductivity imaging of "Normal Oceanic Mantle"

BABA, Kiyoshi[1*] ; TADA, Noriko[2] ; MATSUNO, Tetsuo[1] ; LIANG, Pengfei[1] ; ZHANG, Luolei[3] ; SHIMIZU, Hisayoshi[1] ; UTADA, Hisashi[1]

[1]Earthquake Research Institute, The University of Tokyo, [2]Japan Agency for Marine-Earth Science and Technology, [3]Tongji University

Horizontal flow zone between up-welling and down-welling of the mantle convection, which occupies large portion of the ocean floor, is thought to represent "normal" mantle that is away from tectonic activities. The research group of Normal Oceanic Mantle Project consists of researchers in Earthquake Research Institute (ERI), The University of Tokyo, and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) have investigated normal oceanic mantle by means of marine geophysical observations to elucidate two fundamental questions of the Earth Science; 1) What is the physical condition for the lithosphere-asthenosphere boundary (LAB)? 2) Is the mantle transition zone (MTZ) a major water reservoir of the Earth? We set the target field to two areas, which are northwest (Area A) and southeast (Area B) of Shatsky Rise in the northwestern Pacific, and have carried out seafloor electromagnetic (EM) surveys using ocean bottom electromagnetometers (OBEMs) and electric field observation systems (EFOSs) since 2010. Total 36 OBEMs were deployed at 17 sites in Area A and 8 sites in Area B through this project.

We have reported preliminary analysis of part of the data and 1-D electrical conductivity structure models for Area A and Area B, before. We have conducted new trial for the seafloor measurement in 2012-2014, that the sampling intervals were switched between 10 and 60 seconds by timer during the observation (60 seconds were conventionally used). This procedure expects that we can obtain the MT impedance for the periods shorter than conventional approach and we can consume the battery more efficiently. We used BIRRP (Chave and Thomson, 2004) for the MT response estimation. We could not obtain good MT responses for the period shorter than several hundred second by the conventional application of BIRRP. However, BIRRP yielded better result with the option of two-stage processing. We obtained good MT responses down to about 50 seconds for 9 sites in Area A and 1 site in Area B. Also, We found that the MT responses obtained by 60 second sampling data produce downward bias in the apparent resistivity for the period shorter than about 400 seconds. Then, we used the MT responses obtained by 10 second data for the periods shorter than 400 seconds, and those obtained by 60 second data for longer periods for the following analysis.

We have averaged MT responses for Area A and Area B, respectively, and then estimated 1-D conductivity structure correcting the effect for the land-ocean distribution and seafloor topography. For Area A, the conductivity of the upper most lithosphere (crust) was constrained much better than the previous analysis. This must be because of the extension of the periods in the new MT response. For Area B, 10 second data were available for only one site so that we analyzed the MT responses obtained from 60 second data for the periods down to 480 seconds to produce the average response. As the result, new 1-D model does not show a strange curve at 50-100 km depths and high conductivity peak at about 170 km depth, which were seen in the old model. These features are thought to be fakes due to smoothness constraint of the inversion and downward biased apparent resistivity at periods shorter than 400 seconds. The thickness of highly resistive layer, which is thought to be cool lithospheric mantle, is similar with the previous results. It tends to be thinner for Area A compared with Area B and significantly thinner than Area C (off the Bonin Trench).

The crustal age for the Areas A, B, and C are about 130, 140, and 147 Ma, respectively. Based on plate cooling with age, the age difference cannot produce significant difference in the thermal structure. Consequently, the difference in the electrical conductivity of the upper mantle for the three areas cannot be explained by the simple cooling process of homogeneous mantle.

Keywords: oceanic upper mantle, northwestern Pacific, ocean bottom electromagnetometer, magnetotellurics, electrical conductivity structure

SEM33-08 Room:102A Time:May 26 11:15-11:30

Electromagnetic investigation into the mantle transition zone in the Normal Oceanic Mantle project

MATSUNO, Tetsuo[1*] ; UTADA, Hisashi[1] ; BABA, Kiyoshi[1] ; SHIMIZU, Hisayoshi[1] ; TADA, Noriko[2]

[1]Earthquake Research Institute, University of Tokyo, [2]Japan Agency for Marine-Earth Science and Technology

We report a preliminary analysis of marine electromagnetic field data that were obtained under the Normal Oceanic Mantle project for elucidating an electrical conductivity structure of the mantle transition zone in the northwest Pacific. A primary aim of this study is to answer one of fundamental questions in the solid earth science “Is the mantle transition zone a major water reservoir of the Earth?” from observations for the electrical conductivity structure with our new and latest instruments. To elucidate the electrical conductivity structure of the mantle transition zone, periods of electromagnetic response functions should be long as more than 10^5 s (approximately 1 day) due to the response sensitivity to plausible electrical conductivities of the mantle [Fukao et al., 2004]. The electric field observation system (EFOS) has achieved better signal-to-noise ratio at the target long period range than the ocean bottom electromagnetometer (OBEM) in measurement of voltage difference variation with its long electrodes separation of almost 2 km [Utada et al., 2013]. In addition to utilizing the EFOS, multi-year observations with EFOSs and OBEMs were conducted (up to 2 years for EFOS and up to 4 years for OBEM) to obtain data for estimation of electromagnetic response functions at the long period range with high accuracy.

Three EFOSs were deployed in September 2012 and were recovered in September 2014. One EFOS recorded excellent data for full two years, and the other two EFOSs recorded good data for one year in total. The sampling rate of the EFOSs was 1 s, and clock drift of each EFOS, which was less than 120 s, was corrected for the subsequent data analysis. MT response functions were estimated by using the processed EFOS electric field data and OBEM magnetic field data obtained at the same site, and GDS response functions were estimated by using OBEM magnetic field data (Baba et al. in the same session will present details on OBEM data). These response functions were estimated mainly at the period range of 10^5 - 10^6 s. MT responses were estimated at 3 sites in Area A (northwest of the Shatsky Rise), and GDS responses were estimated at 15 sites in Area A and at 7 sites in Area B (southeast of the Shatsky Rise).

The estimated response functions were compared with predictions from a known semi-global 1-D electrical conductivity model of the north Pacific with land-ocean conductance distribution in a surface layer [Shimizu et al., 2010]. The comparison done so far suggests that the mantle transition zone may be more resistive than the reference 1-D model and a north-south variation in electrical conductivity of the mantle transition zone may be none or weak under Area A. A further data analysis is ongoing, and the result of the analysis and an interpretation of the result on the thermal and geochemical state of the mantle transition zone will be presented.

Keywords: mantle transition zone, electrical conductivity structure, northwestern Pacific

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SEM33-09 Room:102A Time:May 26 11:30-11:45

Development of geomagnetic total force models by applying Natural Orthogonal Component (NOC) method

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Geospatial Information Authority of Japan (GSI) has conducted nationwide continuous geomagnetic field vector observations since 1997. By utilizing these continuous data, we developed 2 types of geomagnetic total force models by applying Natural Orthogonal Component (NOC) method. One model is constructed from continuous total force observation data of proton and overhauser magnetometers. The other model is constructed from continuous 3-component geomagnetic vector observation data of fluxgate magnetometers. We call the models ”scalar model” and ”vector model” respectively. We developed the scalar model from total force observation data of 17 observatories operated by the GSI, Japan Meteorological Agency (JMA) and Earthquake Research Institute (ERI) and additional 2 observation stations operated by the ERI. We evaluated accuracy of the model by Leave-One-Out Cross-Validation (LOOCV), and the model reproduces total magnetic forces at the observatories and stations with the consistency of a standard deviation of 2.6nT. On the other hand, the vector model is developed from vector observation data of 17 observatories operated by the GSI, the JMA and the ERI. The model reproduces total magnetic forces at the observatories with the consistency of a standard deviation of 3.7nT. In order to remove a long wavelength trend of total geomagnetic force from total force observation data time series around a large volcano, we reproduced time series of total magnetic forces around Mt. Fuji and removed them from total force observation data at four observation stations around Mt. Fuji. The detrending revealed that detrended time series of one of the stations, Fujishi, contain clear seasonal variation with amplitude of 2nT. Time series of another station, Fuji-no-miya, also contain a clear step down which might be caused by piezomagnetic effect with an earthquake in the eastern part of Shizuoka Prefecture on March 15, 2011.

Keywords: Principle Component Analysis, Geomagnetic total force model, Natural Orthogonal Component, Geomagnetic charts

SEM33-10 Room:102A Time:May 26 11:45-12:00

A method of representing standard secular variations around such as Japan

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Geomagnetic reference field models are mathematical or numerical expression of the geomagnetic field or its secular variation at a specific point (and a time). Geomagnetic reference field models aiming at representing only a specific region is sometimes called regional geomagnetic reference field models. Determining procedure of geomagnetic field models from a discrete set of data is regarded as an interpolation. Also, it is regarded as a high-cut filtering when the model is expressed by a combination of analytical functions. Many procedures have been used to determine geomagnetic field models. A classical method is using polynomial functions. In Japan, Tazima et al. (1976) reported. Sumitomo, 19xx. Ji et al. (2006) published an example of around Japan by using Spherical Cap Harmonic Analysis (SCHA). Recently, revised SCHA (R-SCH) was proposed and applied to several regions in the globe (Thebault et al., 2006).

One of applications of geomagnetic reference field models is extracting the crustal geomagnetic field. Given that spatial scales of variations in the crustal geomagnetic field are considered to be smaller than those represented by geomagnetic reference field models, differences between observed values and predicted values by a model are regarded as the crustal field.

However, conventiomnal models are unsatisfactory, at least when our purpose is on extracting crustal field for several region such as Japan. Two horizontal components (i.e. B_X and B_Y) represented by polynomials do not always satisfy the irrotationality condition: $\partial B_X / \partial Y$ - $\partial B_Y / \partial X$=0, which should be satisfied in a region with no electric currents. Quantitative relationship between the order of polynomials and the precision of the model is also unsure. SCHA and R-SCHA are designed for a region with a shape of a sperical cap, which is considerably different from Japan islands. The difference in shape yields instability in determining model parameters. Indeed, results presented in Ji et al. (2006) demonstrate unnaturally large secular variations at marginal regions of their analysis.

In this presentation, the author propose a method of representing the regional reference field around Japan using conventional Spherical Harmonic (SH) Functions. To reduce a number of SH functions for representing the spatial distribution, the Principal Component Analysis is applied to SH functions after restricting the variables' range of position to Japan Islands. Obtained major components of the Principal Components are used as the basis functions for representing spatial distribution. This method have three advantages compared with conventional methods. First, the obtained field model automatically satisfies Laplace's equation. Second, we can stably determine corresponding model parameters because orthogonality of basis functions over the target region is assured. Third, truncation errors can be evaluated by assuming an experimental spectrum law of Gauss's coefficients.

Keywords: geomagnetic secular variation, regional geomagnetic field model, spatial distribution, Spherical Harmonic Functions, Principal Component Analysis

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SEM33-11 Room:102A Time:May 26 12:00-12:15

Total Magnetic Field Changes associated with the 2010-2011 seismo-volcanic crisis at Taal Volcano (Philippines)

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A mechanical model was presented which caused the 2010-2011 seismo-volcanic crisis of Taal Volcano, when the total evacuation of the inhabitants was conducted at the initial stage of the crisis in 2010. The model explains the observed magnetic changes as due to the piezomagnetic effect, in which a large hydrothermal reservoir repeated inflation and deflation. This implies that the hydrothermal reservoir plays the most important role in the activity of Taal Volcano.

Keywords: Taal Volcano, 2010-2011 seismo-volcanic crisis, Total Magnetic Field Change, Hydrothermal Reservoir, Curie Point Isotherm, Piezomagnetic Effect

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SEM33-12 Room:102A Time:May 26 12:15-12:30

A Comparison Evaluation of Geomagnetic Observation Signal Using HTS-SQUID Magnetometers at Iwaki Observation Site

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This study addresses a comparison evaluation of high-resolution geomagnetic field observation systems using HTS-SQUID (high-temperature-superconductor based super conducting quantum-interference-device) magnetometers.

Our research group reported successful observation of ”co-faulting” Earth’s magnetic field changes, whose sources are the earthquake piezomagnetic effects, in 2008 Iwate-Miyagi Nairiku earthquake of M7.2 (2011 Okubo et al.). Then, an important finding is that the geomagnetic variation signal accompanying fault movement is very small; therefore development of a high-sensitive magnetometer system is very significant.

To solve this problem, since March 2012 we have introduced long-term precise geomagnetic observations using high-temperature-superconductor based superconducting-quantum-interference-device (HTS-SQUID) magnetometer system Unit No.1 (mark I) at Iwaki observation site (IWK) in Fukushima, Japan. The observation clock has been synchronized by use of GPS signals. An high-resolution accelerometer is also installed at observation point.

Moreover, since October 2014, we have also introduced the new HTS- SQUID magnetometer system Unit No.2 (mark II). In this study, we make a comparison evaluation of the geomagnetic field observation systems, and then we estimate the performance of our HTS-SQUID magnetometer systems for geomagnetic observation.

Keywords: HTS-SQUID Magnetometer, Geomagnetic Observation, earthquake piezomagnetic effect

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.

SEM33-P02 Room:Convention Hall Time:May 26 18:15-19:30

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