A trial of automatic structure analysis for magnetic survey in case of sharp boundaries of magnetization

*Shin'ya Sakanaka[1]

1. Graduate school of International Resource Sciences, Akita University

Utilizing the modern computing technology, highly complex structure can be automatically analyzed by inverse technique in geophysical exploration. Usually a number of blocks are assigned in the structure model numerically constructed and finally the parameters like as magnetization, density, and conductivity are determined for respective blocks. If the number of the blocks is larger than the number of observed data, that is so-called the under-determined problem. To solve the under-determined problem in inversion analysis, we have to include additional condition like as smoothness. The smoothness is one of promising condition in order to solve the under-determined problem and widely used. The resulted structure model with smoothness is a reasonable model in various cases. However, a structure model with non-smoothness is sometimes necessary in specific problem. We have an opportunity to conduct a magnetic survey at the site above the dacite intrusive rocks. This is one of stereotypes of structure with non-smoothness boundary. We want to have the technique to automatically analyze this kind of structure with sharp boundaries. Here we try to show one of effective algorithm to seek the numerical model with sharp boundaries. The algorithm is a kind of grid searches but effectively saving the amount of calculation. Firstly the structure model with two parameters alone, i.e. with two kinds of the values of the magnetization. Next the structure model with three parameters and more. So far, the algorithm is able to apply to the magnetization in magnetic survey or density in gravity survey. But this kind of algorithm is expected to apply to the problems with conductivity in the future.

Keywords: magnetic survey, grid search, Inversion

Development of aeromagnetic survey system using multicopter.

*Mitsuru Utsugi[1], Takeshi Hashimoto[2], Atsuyoshi Jomori[3]

1. Aso Volcanological Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University, 2. Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University., 3. NeoScience Inc.

Aso Volcanological Laboratory of Kyoto Univ. and Neoscience Inc. has developed an aeromagnetic survey system using multicopter. This system consists DJI S1000 multicopter and Bartington Mag566 fluxgate magnetic sensor and it can be measured magnetic 3-component data at very high sampling in the specified area fully automatically. Using this system, it is expected that we can acquire the magnetic field data on the active area of the volcano even while eruption is occurring.
To test our survey system, we conducted an aeromagnetic survey on Komezuka volcano, located in the northwestern part of the post-caldera central cones of Aso volcano, central Kyushu Island, Japan, on Aug., 2016. Komezuka is a basaltic monogenetic volcano comprising a scoria cone. On this volcano, Hasimoto et al. (2007) measured dense magnetic total field anomaly by ground-based observation. Applying magnetic upward continuation to this data, we can estimate the magnetic anomaly on the arbitrary point above the Komezuka volcano. Comparing this estimated anomaly and observed data acquired by our survey system, we verified the accuracy of our survey system and in our presentation, we will report this result.

Keywords: aeromagnetic survey, multicopter

Attempt at three-dimensional modelling of temporal change in resistivity structure beneath Aso volcano through the magmatic eruption in November, 2014

*Takuto Minami[1], Mitsuru Utsugi[2]

1. Ocean Hemisphere Research Institute, Earthquake Research Institute,The University of Tokyo, 2. Aso Volcanological Laboratory, Kyoto University

In Aso volcano in the center of Kyushu island, Japan, a magnetic eruption occurred on November 25th, 2014, for the first time since the last magmatic event in 1993. Since the magmatic eruption in 2014, phreatic/phreatomagmatic eruptions have occurred several times in Aso volcano recently. To monitor the activity of Aso volcano, a group in Kyoto University have been operating an electromagnetic monitoring system, ACTIVE (Array of Controlled Transient Electromagnetics for Imaging Volcano Edifice; Utada et al, 2007), around the active first crater of Aso volcano. ACTIVE system in Aso volcano consists of one transmitter that transmits electric currents into the ground through two electrodes, and several induction-coil receivers that observe only the vertical component of the magnetic field. In ACTIVE observation results before and after the magmatic eruption on November 25th, 2014, we found obvious temporal changes in the response function, the amplitude ratio of the received magnetic field to the transmitted electric current (nT/A). At the western rim of the first crater, larger amplitudes of the response function were observed over frequencies ranging 10 to 100 Hz after the magmatic eruption. Some movement of underground water/magma may be responsible for the temporal changes.
In order to interpret the ACTIVE data obtained before and after the magmatic eruption including topographic effects appropriately, we developed a three-dimensional forward code, by adopting a vector finite element method (FEM). In our forward modelling, the induction equation in terms of the vector potential, A, is solved with the gauge potential of phi=0 (Hano, 1991). We adopted unstructured tetrahedral mesh to represent arbitrary resistivity structure and complicated topography of volcanos. We demonstrated accuracy of our forward code in comparison to an analytical solution of Ward and Hohmann (1988), in a situation where a horizontal electric dipole is located just on one-dimensional layered structure. Currently, we are trying to apply an existing background conductivity structure obtained by AMT surveys to the background structure in our modelling, to investigate the cause of the temporal changes in the ACTIVE responses. In our presentation, we plan to show our results of forward modelling to interpret the temporal changes observed by ACTIVE system before and after the magmatic eruption in November, 2014.

Keywords: Aso, volcano, electromagnetic, monitoring, resistivity

3-D electrical resistivity model beneath Aso caldera for clarifying magmatism in the lower crust

*Maki Hata[1], Nobuo Matsushima[1], Shinichi Takakura[1], Mitsuru Utsugi[2], Takeshi Hashimoto[3]

1. Advanced Industrial Science and Technology, 2. Aso Volcanological Laboratory, Institute for Geothermal Sciences, Graduate School of Science, Kyoto University, 3. Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University

Aso caldera, with a diameter of up to 25 km, is situated on the island of Kyushu in the Southwest Japan Arc. The caldera was formed during 270–90 ka by four huge eruptions that produced hundreds of cubic kilometers of pyroclastic deposits. A number of post-caldera cones/volcanoes exist at the central part of the caldera and Naka-dake, one of the cones, has cyclically erupted since the sixth century. In the past few years, Naka-dake experienced a magmatic eruption in November 2014, a phreatomagmatic eruption in September 2015, and an explosive eruption with spewing volcanic ash 11,000 m into the air in October 2016.

The crustal structure beneath Aso caldera has been studied previously by electromagnetic and seismic surveys. Seismic tomography of the crust has identified low-velocity anomalies beneath the caldera that may correspond to magma chambers [e.g., Sudo and Kong, 2001; Abe et al., 2010]. Sudo and Kong [2001] reported a spherical low-velocity anomaly centered at 6 km depth that flattens at 10 km depth to the west of Naka-dake. Abe et al. [2010] reported a large, low S wave velocity layer at a depth of about 17 km, corresponding to the Conrad discontinuity in and around Aso caldera. Hata et al. [2016] revealed a possible magma pathway in the form of a significant series of electrical conductive anomalies in the upper crust, extending north from Naka-dake at depths of >10 km. However, the space resolution of a magnetotelluric (MT) survey was insufficient to examine the lower crustal structre in the electrical resistivity/conductivity model for a deep-seated magma reservoir associated with the post-caldera magmatism beneath Aso caldera.

We had carried out a MT survey of about 40 sites mainly at the outer part of the caldera from Nov. to Dec. 2016 in addition to the previously obtained about 50 sites in the caldera from Nov. to Dec. 2015. By using the period range between 0.005 and 2,380 s of MT data for about 100 sites in total, we try to perform three-dimensional (3-D) inversion analyses in order to obtain a crustal-scale electrical resistivity structure (model). In the inversion process, we use a parallelized DASOCC inversion code [e.g., Siripunvaraporn and Egbert, 2009]. In this presentation, we will show the new crustal-scale resistivity model beneath Aso caldera.

Predicting 3-D resistivity structure from magnetotelluric data in the southern geothermal area of Hokkaido, Japan

*Midori Hayakawa[1], Toru Mogi[2]

1. Hokkaido University, Graduate school of science, 2. Hokkaido University, Faculty of Engineering

Geothermal gradient is high in Oshima Peninsula located in the southern part of Hokkaido. Especially in "Yakumo-Nigorikawa geothermal zone" located in the central part of the Peninsula, where recent volcanic activity is not seen, the geothermal gradient is the highest. Many geothermal features and hot springs are found in this zone, and many geothermal studies have been performed in various ways. We carried out new Magnetotelluric survey in Yakumo area at 20 stations, and reported 2-D resistivity structure used 2D inversion code (Ogawa and Uchida, 1996) last year. We tried to construct 3D resistivity structure using ModEM (Egbert and Kelbert, 2012) based on same site data. However, resistivity structures are different from 2D resistivity structure. To investigate validity of 3D resistivity structure, we checked reproducibility of a rectangular structure. The result showed that; when we distributed observation points equal short spacing regularly, we got good reproducibility, but inverted structure did not fit the original shape. We concluded, based on the test inversion, that we need to use short spacing equality distribution of data points to get good inversion result. The site distribution is not equal array and space distribution in Yakumo area survey, and we could not get correct 3D structure.

Keywords: Magnetotelluric method, 3-D inversion, ModEM

Wideband MT survey in Aridagawa non-volcanic earthquake swarm region, Wakayama Prefecture

*Makoto Tamura[1], Makoto Uyeshima[2], Tsutomu Ogawa[2], Yasushi Yamauchi[3], Takehiro Inagaki[4], Atsushi Kato[5]

1. Geological Survey of Hokkaido, Hokkaido Research Organization, 2. Earthquake Research Institute, The Univercity of Tokyo, 3. TEPCO., Power Grid, 4. KEPCO, 5. J-Power

An active non-volcanic earthquake swarm has been observed at the north western Wakayama area. Kato et al. (2010) performed high-resolution tomographic imaging of seismic velocities and proposed that these swarms are triggered by circulating fluids and fluid pressure fluctuations driven by the thermal anomaly of the solidified diorite magma. In 2009, Uyeshima et al.(2010) performed MT survey in the Aridagawa area, southern margin of swarm activity, and detected conductive anomaly structure that presume the existence of connected interstitial water. But the details of the relationship between the swarm activity area and resistivity structure have not still understood well.
In 2015, we performed wideband MT survey at another profile across the Aridagawa area. Five component electromagnetic fields were measured at 5 sites by ADU-07 (Metronix Geophisics). We obtained continuous 1024Hz data, which were saved in the CF-memory once per an hour. After the survey, we made 32Hz and 1Hz data by downsampling. To avoid leakage current noise from the DC train (the Kisei main line), in analyzing the 1024 Hz data, we used only midnight data that was obtained from JST 2 to 5 a.m..
MT responses of a frequency band of 384-0.039Hz were estimated using remote reference method and the robust processing code BIRRP (Chave and Thomson, 2004). From the GB decomposition analysis (Chave and Smith, 1994, Toh and Uyeshima, 1997) and geological features, we considered that the optimum regional strike is in the EW direction. We tried to obtain a 2-D resistivity structure along N-S profile with the aid of the REBOCC 2-D inversion code (Siripunvaraporn and Egbert, 2000). In this presentation, we show the results of 2-D inversion and the relationship with the swarm activity.

Keywords: Wideband MT survey, Aridagawa region, Wakayama Pref., non-volcanic earthquake swarm region

A research report on the fundamental investigations of an electrical resistivity structure beneath Chugoku and Shikoku regions, southwestern Japan(2016)

*Ichiro Shiozaki[1], Tomofumi Uto[1], Shinji Yamamoto[2], Yasuo Ikezoe[2], Hiroshi Hataoka[2], Tatsuya Noguchi[1], Satoru Kawaguchi[1], Yuya Fukumoto[2], Ryokei Yoshimura[3], Hideki Murakami[4], Naoto Oshiman[3], Yoshihisa Iio[3]

1. Graduate School of Engineering, Tottori University, 2. Faculty of Engineering, Tottori University, 3. Disaster Prevention Research Institute, Kyoto University, 4. Research and Education Faculty, Kochi University

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 structure in Chugoku and Shikoku regions, southwestern Japan arc. In this presentation, a research report on fundamental surveys for the following two topics, using data acquired in 2016 incorporated in the existing data, will be shown.
(1) 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. Harmonious research results has been shown from geodetic GNSS(GPS) data analysis by Nishimura (2015) who implies that relationship between strain concentration zone in Sanin region and the occurrence of the 1943 Tottori earthquake, the 1983 Tottori Chubu earthquake, and the 2000 western Tottori earthquake. 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.
In this background, a Magnitude (M) 6.6 Earthquake in the Central Tottori Prefecture on October 21, 2016 occurred. Before this earthquake, there were earthquakes frequently occurred since October 2015 in the area about 10 km east of the area where the 2016 earthquake occurred, and the east side is the western extension of the Kano and Yoshioka faults, the 1943 Tottori earthquake fault. In order to elucidate the heterogeneous structure of the lower crust beneath the seisimic region, we set up several survey lines across the central focal region of the Chubu region to carry out wideband MT observation. According to the result of one-dimensional analysis of Bostic inversion based on determinant impedance by integrating existing MT data, it was shown that the low resistivity region exists continuously in the form of a band around the depth of 10 km in the region.
(2) In the Shikoku region, in order to elucidate the regional characteristics of the large scale resistivity structure, fundamental wideband MT observations have been conducted at 8 sites in the observations gap area around the central part of Shikoku region.
By integrating the existing MT data, we tried model analysis using the program code of Ogawa and Uchida (1996) assuming that the midwestern part of Shikoku region has a two-dimensional structure of N75E strike direction harmonious with the geological structure. The preliminary resistivity model shows interesting features; the north-dip resistivity structure matching with the hypocentral distribution found at the upper crustal depth in the northern part of the Median Tectonic Line, etc.
Acknowledgments: 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 2016 Tottori Prefecture Environmental academic research promotion promotion project. 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. We used joint research equipment of Kyoto University Disaster Prevention Research Institute for observation of this research. Reference magnetic field record is free data Last of all, we would like to express our thanks to T.Higa of Kyoto University and T.Yamamoto, M.Fukunari, Y.Yoshida and F.Okabe of Tottori University for their help during data acquisition.

Keywords: Earthquake in the Central Tottori Prefecture on October 21, 2016, Shikoku region, electrical resistivity, fundamental investigation

Nation-wide spatial distribution of the ultra-long period magnetic transfer functions in the China Mainland

*Yiren Yuan[1,2,3], Makoto Uyeshima[1], Qinghua Huang[3], Qi Li[2]

1. Earthquake Research Institute, the University of Tokyo, 2. Institute of Geophysics, China Earthquake Administration, 3. Peking University

China mainland located in the south part of the Eurasian continent is an interesting area, where the Pacific plate is subducting from the east, and the Indian continent collides from the south. Recently, several seismic tomography researches revealed stagnant Pacific slab deep below the central to northern part of China. High crustal heat flow as well as the Neogene-Quaternary basaltic volcanic activities in the NE China area has been interpreted due to the subducting or stagnant Pacific slab and possible fluid supply from the slab. India-Eurasia collision also causes significant crustal uplift in the Tibet and clockwise rotation in the eastern part of the suture. Investigation of nation-wide very deep electrical conductivity structure beneath China mainland will enable us to have a better understanding of the dynamics of the continent and generation mechanism of the intra-continental earthquakes and volcanoes, since electrical conductivity is particularly sensitive to the presence of interconnected highly conductive phases, such as partial melts or aqueous fluids.

In this study, in order to elucidate the mantle electrical conductivity structure down to the transition zone beneath whole China mainland, we investigated the geomagnetic records obtained by the National Geomagnetic Center of China. We analyzed hourly geomagnetic data from 42 stations with absolute measurements for nearly 8 years (2008/01/01-2016/12/31). After we calculated the angle between azimuth of the geomagnetic pole and that of the geographic pole at respective stations with the aid of the IGRF models, we obtained the geomagnetic data rotated to the geomagnetic dipole field coordinates. The vertical component to the horizontal components transfer functions (GDS transfer functions) and inter station horizontal field transfer functions of periods up to 100days were estimated with the aid of the remote reference method with a robust estimation scheme. In the presentation, we will show the characteristics of the spatial distribution of both the GDS and the horizontal transfer functions. We will also show results from the OCCAM 1-D inversion with minimum and smooth structure constraints by using the GDS transfer functions.

Keywords: geomagnetic depth sounding, horizontal transfer function, china mainland, ultra long period, mantle electrical conductivity structure

Synthetic test for a 3-D global inversion of the electrical conductivity by using the Sq band

*Takao Koyama[1]

1. Earthquake Research Institute, University of Tokyo

The electrical conductivity is sensitive and enhanced due to the presence of fluids, high thermal anomaly, metals and so forth, and is one of the important physical parameter to elucidate the interior and dynamics of the Earth. The electromagnetic sounding is a suitable tool to reveal the electrical conductivity strucutre in the deep Earth, and has been widely used for over a hundred years. For shorter periods than 10000 sec, a plain wave approximation of the EM field may be valid and generally used in, say, magnetotelluric method. For longer periods than a few day, a simple P10 distribution approximates well the EM variations in global scale. An intermediate band, however, has complex distribtusions and careful consideration of a spatial distirbution of the EM variation must be necessary.
In this study, we test the 3D global inversion by using the syntetic data with higher modes of the spatial distirbution. In a forward modeling part, an integral equation method is used, as the boundary conditions are already satisfied in synthtic Green's functions and thus numerical grids are not necessary in the air. In an inversion part, a quasi-Newton method and an adjoint approach are adapted to reduce a number of forward calculations.
In this presentation we show the synthtic results and discuss the possibility to elucidate the electrical conductivity structure in the mantle, especially, mantle transition zone and around by using the Sq field data.

Keywords: Sq, electrical conductivity, inversion

Estimation of the seafloor electromagnetic responses in the mixed excitations band by using Sompi Spectral Analysis

*RUIBAI LI[1], Hisayoshi Shimizu[1], Kiyoshi Baba[1], Hisashi Utada[1]

1. Earthquake Research Institute, the University of Tokyo

Electromagnetic (EM) responses such as magnetotelluric (MT) impedance and geomagnetic depth sounding (GDS) response in the period range between several minutes to one day are used to study the electrical conductivity in the upper mantle. Spatially uniform and quasi-random magnetic field variations due to geomagnetic disturbances are considered as the source field in regional EM induction studies using the EM responses. However, the magnetic field variations in the period range from 10^4 to 10^5 seconds contain those with different spatial structure such as the solar quiet (Sq) daily variations and those induced by the ocean tide. Because of this, the period band is referred to as mixed excitation band (ME band). Careful treatment of EM field data is necessary to estimate responses in the ME band that reflect actual conductivity structure. For example, Baba eta al. (2010) estimated the EM responses using a method based on Fourier transform after removing line spectra of EM field variations at periods of Sq field variation and constituents of ocean tides. However, it has been shown that the estimated observed responses in the ME band still contain signatures of non-uniform and westward- propagating source field (Shimizu et al., 2011). Estimating EM responses free from these effects in the ME band is a challenge for the ocean bottom EM induction studies. In this study, we aim to have better estimates of EM responses in the ME band by selecting signals of the vertically propagating plane-wave source carefully. For this purpose, we employ the Sompi method (e.g., Kumazawa et al.,1990) that can identify existing wave elements (or namisos) in time series with a high frequency resolution. The Sompi method is applied for two horizontal magnetic field components at once (Asakawa eta al.,1988) to find complex frequency of namisos and then the amplitude and phase of three magnetic field and two horizontal electric field components are determined by assuming that they have common frequency of variation. Obtained line spectra for the EM fields are used to select suitable namisos for EM response estimation by a least square method. The criteria to select namisos are (1) selecting namisos in period ranges that are sufficiently away from those of Sq harmonics and ocean tides, (2) selecting namisos that do not show the westward propagating nature similar to the Sq field, and (3) selecting namisos with a quasi-linear polarization in the vertical plane. In this study, we applied criterion (1) at first. Then, the criteria (2) and (3) were applied to the namisos selected by criterion (1) separately. It was confirmed that responses estimated using (2) or (3) at periods shorter than 10^4 seconds are almost identical to those estimated by Baba et al., (2010) within the estimation error at periods shorter than 10^4 seconds. However, the abrupt change of EM responses at periods around 10^4 seconds in the previous work became smaller after applying criterion (2). On the other hand, the value of EM responses estimated using criterion (3) also reduced significantly at the shorter period of the ME band. Results of these two cases show that signatures of the Sq field variation in the EM responses are reduced at the shorter period part of the ME band up to $2x10^4$ seconds. However, we could not obtain statistically significant responses at longer periods because sufficient number of namisos was not available after the namiso selections. Using Sq field variation itself as the source field at the longer period in the ME band is another way to utilize EM field information to constrain the electrical conductivity of the mantle.

Asakawa, E., et al. (1988). *J. Geomagn. Geoelec.,* 40: 447-463.
Baba, K., et al. (2010). *Phys. Earth planet. Inter.,* 183: 44-62.
Kumazawa, M., et al. (1990). *Geophys. J. Int.,* 101: 613-630.
Shimizu, H., et al. (2011). *Geophys. J. Int.,* 186: 193-206.

Keywords: Sq, Electromagnetic response

Localized variations in the geomagnetic field and their relation with tectonic activities

*Ken'ichi Yamazaki[1]

1. Disaster Prevention Research Institute, Kyoto University

Localized variations in the geomagnetic field is believed to be related with tectonic activities.
I extract the local variations by means of the principal component analysis.
No obvious relation have been found between the extracted local variations in the geomagnetic field and tectonic activities.

Keywords: geomagnetic field, secular variation, localized anomalies, tectonic activities, principal component analysis

