Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SEM22-01 Room:301A Time:May 25 09:00-09:15

Transient response of the conducting Earth: Comparison of the observed and theoretical step response

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Transient response of the Earth in time domain is very useful to delineate electrical properties of our planet down to the lower mantle depths. Among many possible configurations of the external geomagnetic field, abrupt change in the dipole filed of external origin ($q_1{}^0$) is of particular interest here because it can be actually created by variations of the magnetospheric ring current and is of significant strength in the sense that it is clearly observable. The step response, $F_1{}^0$, of the conducting Earth for the dipole field, therefore, was examined in this study for a time range from a few hundred seconds through longer than 100 hours using vector geomagnetic time-series at the time of intense geomagnetic storms such as the Halloween storm event in 2003 observed simultaneously by ground geomagnetic observatories worldwide.

In general, the so-called impulse response of a physical system is given by time derivative of its step response. A well-known example of those responses is that the first derivative of the Heaviside's step function is equal to the Dirac's delta function. Time-series of observable quantity can be expressed by a convolution of the source and the impulse response from the time origin to an instant in concern. Thus, temporal variation of the poloidal geomagnetic field, $p_n{}^m(t)$, at the Earth's surface is also given by a convolution of source variation, $q_n{}^m(t)$, and the Earth's impulse response that conveys the electrical property of our planet. Here, n and m are the degree and the order of the spherical harmonic geomagnetic field, respectively. The convolution, however, can be evaluated more easily in frequency domain rather than time domain making use of FFT. The time derivative is also replaced by i x omega in frequency domain, where omega is the angular frequency of the electromagnetic (EM) variation in concern. Temporal variation of the Earth's step response, $F_n{}^m(t)$, is then derived by inverse Fourier transform back into time domain.

In the present study, $F_1{}^0(t)$ was estimated using hourly or one-minute values of $g_1{}^0$ and $q_1{}^0$ coefficients obtained by spherical harmonic analyses of geomagnetic storms and using the relation: $p_1{}^0(t) = g_1{}^0(t) + q_1{}^0(t)/2$. The curve of $F_1{}^0(t)$ is basically an increasing function of time, which implies that the electrical conductivity of the Earth is also increasing with depth. However, $F_1{}^0(t)$ flattened significantly for the time range between some dozen minutes and hours indicating that there may exist a region of enhanced electrical conductivity at mantle transition zone depths. Preliminary model studies using Hamano's (2002) three-dimensional (3-D) time domain EM induction scheme yielded an estimate for the probable depth range of the enhanced electrical anomaly that was very localized around the 410km seismic discontinuity. If the localized depth estimate is true, the transient response of the conducting Earth has possibly captured the thin water filter atop the 410km discontinuity proposed by Bercovici and Karato (2003).

In this presentation, we will further examine the probable depth range for the electrical conductivity anomaly by comparing the observed step response with the theoretical step response of spherically symmetric and/or fully heterogeneous earths. A direct conversion method of the observed step response into the electrical conductivity profile based on an iterative uniform sphere approximation will be applied and compared with the model calculation as well. The effect of Sq noise on the observed step response will also be examined and argued.

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SEM22-02 Room:301A Time:May 25 09:15-09:30

A reference electrical conductivity model of continental upper mantle estimated from the MT data in central Australia

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To investigate the one-dimensional reference electrical conductivity profile beneath continents, we conducted a magnetotelluric (MT) observation with long dipole span near Alice Springs, central Australia. We utilized geomagnetic data acquired at the Alice Springs geomagnetic observatory operated by Geoscience Australia. Using the BIRRP processing code (Chave and Thomson, 2004), we estimated the MT response functions for periods from 100 to 10 to 5 sec. The phase tensor analysis revealed that the shallower uppermantle (up to several thousand seconds in period) is two-dimensional, while the deeper upper mantle is three-dimensional. We focused the two-dimensional part, from which we can extract one-dimensional model. The pioneering work demonstrated by Agarwal et al.(1993) suggests that we should use Berdichevsky average, determinant or TE-mode response to model one-dimensional conductivity structure in two-dimensional environments. From the view point of galvanic distortion in regional two-dimensional structures supposed that Groom-Bailey decomposition would be performed, Berdichevsky average response involves phase mixing as well as static shift, while determinant and TE-mode responses involve only static shift. Adopting Faraday's law, we can correct static shift of TE-mode using geomagnetic transfer function (Ledo et al.,2002), while such a procedure for correcting static shift of determinant responses has not yet been developed. Following the procedure of Ledo et al.(2002), we estimated TE-mode responses with static-shift free. We inverted the TE-mode MT responses into a one-dimensional conductivity profile using Occam inversion (Constable et al.,1987), and plan to compare the one-dimensional structure with electrical conductivity profiles predicted from compositional models of the earth's upper mantle by calculating phase diagrams in the CFMAS (CaO-FeO-MgO-Al2O3-SiO2) system.

SEM22-03 Room:301A Time:May 25 09:30-09:45

The three-dimensional conductivity structure of the stagnant slab: preliminary result

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We performed a three-year-long seafloor electromagnetic (EM) survey in the Philippine Sea, including the western edge of the Pacific Ocean, to image electrical features of a deep mantle slab and the surrounding mantle in three-dimensions (3-D). The project iterated one-year-long deployment of ocean bottom electromagnetometers (OBEMs), involving a total of 37 instruments installed at 18 sites. The data obtained have been analyzed in the order of their recovery based on a magnetotelluric (MT) method.

In this study, we attempt to obtain a 3-D electrical conductivity model from the observed data. The seafloor topography is known to significantly affect the EM response functions obtained by OBEMs. We assume that the distorted EM fields are separated into long-wavelength (more than a few tens of km) and short-wavelength (less than a few tens of km) components, and propose their separate treatment: The long-wavelength parts are incorporated into a newly developed 3-D inversion code (Tada et al., submitted), and effects of the short-wavelength topographies are corrected with other 3-D forward code (e.g. FS3D; Baba and Seama, 2002).

From a preliminary 3-D electrical conductivity model, we find three significant features so far. (1) The conductivity of the Pacific Plate is much lower than that of the Philippine Sea Plate in the top of the upper mantle. (2) The difference of conductivity between the Pacific Plate and the Philippine Sea Plate becomes small at the depth of 200km. (3) The conductivity beneath the central Mariana Trough is lower than that of surrounding area at the depth of somewhere between 100 and 200 km. We will explain more detail about the 3-D result and discuss it in the presentation.

Keywords: Stagnant slab, 3-D conductivity structure, Marine MT method, Inversion

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SEM22-04 Room:301A Time:May 25 09:45-10:00

3D Magnetotelluric imaging of the Marmara Sea and westward extension of the North Anatolian Fault

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Turkey is seismically very active country that has hosted large destructive earthquakes throughout the history. The sources of these devastating events are two main fault zones which are the North and East Anatolian Fault Zones. The last two demonstrative earthquakes on the North Anatolian Fault Zone (NAFZ) occurred at the eastern edge of the Marmara Sea, confirming migration of big events from east to west on this transform fault. In view of there is a seismic gap in the Marmara Sea and seismic energy accumulation increases day bay day at its eastern edge, occurrence of the next destructive earthquake in the Marmara is inevitable. Seismic, geodetic and other studies showed complexity of the structure suggesting various estimates about the extension of the NAFZ through the Marmara Sea. In this study, we benefit from the high depth resolution of the Magnetotelluric (MT) method to resolve the electrical resistivity structure beneath the Marmara Sea and disclose its relation with the geologic structure. In order to investigate extension of the NAFZ beneath the Marmara Sea we deployed long period ocean bottom electromagnetic data at 16 sites which form 4 profiles perpendicular to the possible traces of the NAFZ. Variation of the geoelectric strikes from east to west shows different oriented faults in the Marmara Sea and points out necessity of 3D modeling in this region. The highly conductive anomaly in electrical resistivity models extends from crustal depths to the lithosphere and merges with the melted mantle material at the eastern part of the Marmara Sea. This conductive anomaly is surrounded by relatively resistive anomalies which imply continuation of the fault structure from land to the Marmara Sea. Our results clear the location of the highly conductive and resistive anomalies that has crucial implications in two aspects; conductive anomaly may trigger the micro-seismic activity and resistive anomalies may act as asperity zones where stress accumulation results in large earthquakes.

Keywords: Ocean Bottom Electromagnetics (OBEM), North Anatolian Fault Zone (NAFZ), Magnetotellurics (MT), Marmara Sea, Resistivity / Conductivity, Fluid-controlled seismicity

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SEM22-05 Room:301A Time:May 25 10:00-10:15

Thick sedimentary layers above the seismic basement in the Chuetsu area, Central Japan, inferred from MT and AMT surveys

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We conducted MT and AMT electromagnetic surveys in the Chuetsu area, Central Japan, where Neogene sedimentary layers were thickly deposited and the serious damage caused by long-period earthquake ground motion happens frequently. For the Niigata sedimentary basin including this area, the 3-D subsurface structure models were constructed using mainly geological data and seismic data. The purpose of the electromagnetic surveys is to investigate the deep resistivity structure from the surface to the seismic basement in this area and to verify the subsurface structure models with different approach from the conventional method. The MT and AMT data were collected at 34 and 91 sites, respectively, which were located along a NW-SE profile traversing the regional geologic strike. Since the cultural noise levels are considerably high in this area, it is difficult to acquire the high quality MT data. Using the far remote reference method, we performed long-term measurements at many sites simultaneously with a maximum of 16 pieces of equipment so that MT data could be acquired when strong natural signals occurred. In data processing, we selected the periods with the strong signals and edited the data of the high S/N ratio in them to raise the quality of data. As a result, MT parameters which can be used for quantitative analysis of resistivity structure were obtained. Two-dimensional analysis was applied along the profile. The precise resistivity section up to a depth of about 1.5 km was obtained from the AMT data and the deep resistivity section up to a depth of about 15 km from the MT data. We interpreted the resistivity sections using geological data and well data, and compared them with the past subsurface structure model. The resistivity structures from MT and AMT data are consistent with the resistivity log of nearby a 3100 m-deep well. The high-resistivity basement is good agreement with the seismic basement obtained from the seismic survey. Very conductive layers correspond to the Neogene sedimentary layers of Nishiyama, Shiiya, Upper Teradomari and Lower Teradomari formations. They are shallow and thin at anticlines, and deep and thick at synclines. The zone of lowest resistivity corresponds to the Upper or Lower Teradomari layer. Resistive layers at or near surface correspond to the volcanic rocks or the Uonuma formations of mainly Pleistocene age, which are not altered. From the detailed resistivity section, the location and scale of anticline and syncline structures can be estimated.

This research is funded and supported by Japan Nuclear Energy Safety Organization (JNES).

Keywords: MT, AMT, resistivity structure, Neogene sedimentary layer, seismic basement, subsurface structure model

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SEM22-06 Room:301A Time:May 25 10:15-10:30

A proposal and a feasibility study of highly sensitive geo-electromagnetic field measurements using SQUID magnetometers

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A superconducting quantum interference device (SQUID) magnetometer is well known as a highly sensitive magnetic sensor, which has a wide frequency range from DC to 10 kHz or higher with the noise level of 10^{-15} T/rtHz. This sensitivity is around 1000 times higher compared to conventional magnetic sensors such as a fluxgate magnetometer and a proton magnetometer. Is not a highly sensitive measurement using SQUID magnetometers available for geo-electromagnetic research?

There were some works on the measurements of geomagnetic fields using SQUID magnetometers in Japan. It was a challenging experiment that Kitamura first demonstrated observation of geomagnetic fields using a bulk-type SQUID magnetometer in 1978. Unfortunately, the SQUID at that time did not have enough performance for field measurements. Then, he pointed out what to improve for a SQUID system if it was applied for geo-electromagnetism. Later, some groups demonstrated measurements of ULF electromagnetic signals using portable HTS-SQUID magnetometers operating in liquid nitrogen on the purpose of detection of electromagnetic phenomenon associated with volcanism and earthquakes.(Kamata 2000, Kasai 2001, Nomura 2002, Machitani 2003) However, those measurements were sometimes affected by an ambient noise or unexpected malfunction in the system. In addition, their experiment period was not so long enough that the availability of using SQUIDs has not been presented for geo-electromagnetic measurements yet. On the other hand, LSBB in France reported that magneto-ionosphere responses in the order of 100 pT-1 nT to P-wave emissions for earthquakes were detected with a SQUID system located underground.(Waystand 2009)

We have been developing MEG (magnetoencephalography) systems with low temperature SQUIDs operating in liquid helium, which are now in practical use and available for clinical diagnosis of brain diseases and for research on brain functions. Based on the techniques we developed, we again propose a SQUID system as a new tool for stationary and highly sensitive measurements in geo-electromagnetic research. In this session, we introduce a prototype SQUID system for this purpose. The system has the frequency bandwidth of DC-500Hz and the noise level is 15 fT/rtHz at 100 Hz and 2 pT/rtHz at 0.01 Hz. The dynamic range of the detectable field is set to be 300 nTpp. The data is acquired with a 16-bit logger with the maximum sampling frequency of 1 kHz. The time is calibrated with a GPS signal. First, we plan to place this system 1 m below ground and demonstrate a continuous measurement of magnetic fields for a month or longer to seek for what is necessary for the next improvement.

We are not experts in geo-science. We look forward to some discussions and appreciate not only useful advice but also severe opinions on our idea from the point of view of experts in this session.

The part of this work is supported by SEI Group CSR Foundation.

Keywords: SQUID, geo-electromagnetic fields, highly sensitive measurements, superconductivity

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SEM22-07 Room:301A Time:May 25 10:45-11:00

Geomagnetic variation associated with seismogenic ionospheric disturbance

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We investigate geomagnetic variation associated with the seismogenic and tsunamigenic ionospheric disturbance excited by the M9.0 Tohoku earthquake. In the south part within 600 km from the epicenter, the clear acoustic and gravity waves excited by the tsunami. This may occur due to the E-region dynamo originated from the acoustic and gravity waves. On the other hand, we observe the geomagnetic variation associated with the seismogenic and tsunamigenic variation in the north part. So far, the physical mechanism is still unclear.

Keywords: Earthquake, Geomagnetic variation, Ionospheric disturbance

SEM22-08 Room:301A Time:May 25 11:00-11:15

Characteristics of vertical electric fields derived from borehole measurements in association with an earthquake

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We have shown many examples of electric fields associated with natural and artificial earthquakes, but they are all horizontal components and no information has been derived for the vertical component. In theoretical arguments, the vertical electric field should vanish at the surface of the Earth and hence surface measurements are unlikely to be significant. We therefore attempted to measure vertical electric fields using a borehole casing pipe as an electrode with a surface coil surrounding the borehole at the Earth's surface. In fact, Takahashi and Fujinawa established such a measurement system for two boreholes in the Boso peninsula and we used this system for our measurements. At one site, the borehole length is 803 m and at the other site it is 106 m. Both sites are equipped with electrodes at the surface for measurements of two horizontal components of electric field. The electrode span ranges from 9 m to 36 m. Both sites are located in electrically noisy environments and precise measurements of electric field turned out to be almost impossible. Nonetheless, fairly clear signals could be observed for the main ground motion of an earthquake of magnitude 7.0 which occurred in the vicinity of Torishima on January 1, 2012. In the deep borehole case, the magnitude of vertical electric field is half of that of horizontal electric field, whereas in the shallow case the vertical electric field is one order of magnitude smaller than the horizontal electric field. This is quite understandable in view of the expectation that the vertical electric field should be smaller and smaller towards the surface of the Earth. This result indicates that seismic dynamo effect signals can be detected by borehole measurements. The theory of seismic dynamo effect predicts that the resonance between the seismic velocity and ions motion in groundwater at depth should occur at the cyclotron frequency corresponding to the total magnetic field. This should be verified through the transfer function of electric field to seismic velocity. We finally point out that clearer electric-field signals would be observed if measurements are made at the bottom of deep borehole and the detection of seismic wave there in terms of electric field would become possible well before the arrival of seismic wave at the surface of the Earth.

Keywords: seismic dynamo effect, electric field, seismic wave, borehole

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Effects of permeability on Self Potential: numerical experiment and application to a real data

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The objective of this study is to elucidate effects of permeability on self potential (SP) and feasibility how the SP profile is useful to detect the subsurface permeability structure. SP is the electrical potential mainly generated by the groundwater flow. In general, the SP is affected by the permeability, electrical conductivity and coupling co-efficient. Although the distribution of permeability is an important parameter for the groundwater flow, the effects of permeability on SP have not been well discussed, especially in field data interpretation. In this study, we simulated the groundwater flow and SP to estimate the effects of permeability on SP.

First, we simulated the groundwater flow and SP under the rainfall condition to express natural groundwater flow and SP. Our simulation results show that the magnitude of SP is proportional to the difference of height of water table, and less correlation to the thickness of vadose zone. The dominant factors that decide the magnitude of SP were permeability and the mass of precipitation. Then, we simulated the groundwater flow and SP affected by the heterogeneity of permeability. Here, the groundwater flow is calculated under the condition with the fixed hydraulic head in this case. The anomalies of SP on the surface appear just above the lateral edge of anomalous permeability zones. These anomalies reflect on the groundwater flow around the heterogeneity of permeability. As a result, we found that the high permeable heterogeneity generated the larger anomalies than low permeable one.

Finally, we simulated the groundwater flow for interpretation of observed SP in the Saijo City. We could simulate the similar pattern of SP profile with two different models. One model has the uniform permeability and heterogeneity of electrical conductivity and coupling co-efficient. The other has the heterogeneity of permeability, electrical conductivity, coupling co-efficient. We compare the observed information of groundwater flow to simulated groundwater flow results. The area of recharge and discharge of model that the permeability is not uniform were similar to the observed area of recharge and discharge. From these results, the model with heterogeneity of permeability is better than the other in this area. We conclude that importance of permeability on interpretation of observed SP is indicated by these forward calculations. In the future, it could be possible to estimate the subsurface structure of permeability from both SP profile and the information of groundwater flow.

Keywords: Self Potential, Simulation, Permeability, Groundwater Flow

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SEM22-10 Room:301A Time:May 25 11:30-11:45

On temporal variation of SP spatial distribution on Miyakejima Island before and after the 2000 summit eruption

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We performed repeated SP surveys before and after the 2000 Miyake summit eruption. Before the eruption, stable W-shape anomaly was detected in 1991, 1995, 1996 (Sasai et al., 1997) and the stability was confirmed by long baseline electrical potential difference monitoring from 1997 to 2000 (Sasai et al., 2002). After the eruption, we performed repeated SP surveys in 2002 for the south-line, in 2005 and 2011 for both the south and north-lines. We detected enhancement of the electrical potential at altitudes from 300 to 600m, where minimal potential of -600 to -500 mV compared with the potential near the coast had been detected in the 1990-s surveys. The temporal variation of the spatial distribution of SP was still detected in 2011 compared with results in 2005. The potential enhancement probably indicates large-scale temporal variation of hydrothermal activity or that of subsurface resistivity structure.

Keywords: miyakejima, 2000 summit eruption, self potential, hydrothermal activity, resistivity