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

TOH, Hiroaki[1*], HAMANO, Yozo[2]

[1]Graduate School of Science, Kyoto Univ., [2]IFREE, JAMSTEC

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

ICHIKI, Masahiro[1*], FUJI-TA, Kiyoshi[2], Liejun Wang[3], Jim Whatman[3], Adrian Hitchman[3]

[1]Graduate School of Science, Tohoku University, [2]Graduate School of Engineering, Osaka University, [3]Geoscience Australia

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

TADA, Noriko[1*], BABA, Kiyoshi[2], UTADA, Hisashi[2]

[1]JAMSTEC, [2]ERI, University of Tokyo

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

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

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

KAYA, Tulay[1*], OGAWA, Yasuo[1], TANK, Bulent[2], KASAYA, Takafumi[3], M. Kemal Tuncer[4], HONKURA, Yoshimori[1], OSHIMAN, Naoto[5], MATSUSHIMA, Masaki[1]

[1]Tokyo Institute of Technology, [2]Bogazici University, [3]JAMSTEC, [4]Istanbul University, [5]Kyoto University

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

Japan Geoscience Union Meeting 2012
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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

TAKAKURA, Shinichi[1*], YOSHIMI, Masayuki[1], HORIKAWA, Haruo[1], Minoru Teshima[2]

[1]AIST, [2]NMC

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

Japan Geoscience Union Meeting 2012
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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

KAWAI, Jun[1*], MIYAMOTO Masakazu[1], OYAMA Daisuke[1], KAWABATA Miki[1], ADACHI Yoshiaki[1], HIGUCHI Masanori[1], UEHARA Gen[1], OGATA Hisanao[1]

[1]Applied Electronics Laboratory, Kanazawa Institute of Technology

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

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

Geomagnetic variation associated with seismogenic ionospheric disturbance

MOCHIZUKI, Kaori[1*], KAMOGAWA, Masashi[1], KAKINAMI, Yoshihiro[2], ORIHARA, Yoshiaki[3], YUMOTO, Kiyohumi[4], MOGI, Toru[2], HATTORI, Katsumi[5]

[1]Dpt. of Phys., Tokyo Gakugei Univ., [2]Institute of Seismology and Volcanology, Hookaido University, [3]Earthquake Prediction Reserch Center, Tokai University, [4]Space Environment Research Center, Kyushu University, [5]Department of Earth Sciences, Graduate School of Science, Chiba University

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

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

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

HONKURA, Yoshimori[1*], MATSUMOTO, Takumi[2], MATSUSHIMA, Masaki[3], OGAWA, Yasuo[1]

[1]Volcanic Fluid Research Center, Tokyo Institute of Technology, [2]National Institute for Earth Science and Disaster Prevention, [3]Department of Earth and Planetary Sciences, Tokyo Institute of Technology

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

Japan Geoscience Union Meeting 2012
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SEM22-09 Room:301A Time:May 25 11:15-11:30

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

OZAKI, Yusuke[1*], MIKADA, Hitoshi[1], GOTO, Tada-nori[1], TAKEKAWA, Junichi[1], TSUJIMURA, Maki[2], Fatma HACHANI[2]

[1]Kyoto Univ. Grad. School of Eng., [2]Graduate School of Life and Environmenta

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

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

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

UYESHIMA, Makoto[1*], HASE, Hideaki[1], AIZAWA, Koki[1], KOYAMA, Takao[1], Yasunori Nishida[2], Research Group of Geo-electromagnetism on Miyakejima Volcanic Island[1]

[1]Earthquake Research Institute, The University of Tokyo, [2]Hokkaido University

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

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

SEM22-P01 Room:Convention Hall Time:May 25 15:30-16:45

Statistics of the Local Electric Currents in Porous Geo-Materials Obtained by Pore-Scale Computer Simulations

NAKASHIMA, Yoshito[1]*, NAKANO, Tsukasa[1]

[1]AIST (GSJ)

Computer simulations of steady-state electric currents in fluid-saturated porous sediment/rock were performed using pore-scale X-ray microtomographic images (Refs 1, 2). An example of the simulated local current magnitude is shown in the figure below (Berea sandstone image, 0.64mm x 0.64mm x 0.64mm, Solid voxels are dark blue. The direction of the macroscopically applied field gradient is indicated by a solid arrow). The main results are as follows. (i) The histogram of the magnitude of the local current flux vector obeys a unimodal log-normal distribution having a long positive tail. Simulations using model images were also performed to show that the flux broadening in large pores and the flux mixing at the pore network junctions are responsible for the log-normal shape. (ii) The simulation enabled us to directly visualize pore voxels with large and small fluxes, confirming the existence of transport pores and stagnant pores. Because of the unimodal nature, however, it was difficult to distinguish transport pores and stagnant pores using an objective threshold in the histogram. (iii) Another histogram of the flux vector component along the direction of the macroscopic potential gradient was analyzed. A negative tail was found in the histogram, indicating that local counter currents exist in the porous geo-materials. However, the population and intensity of the counter fluxes are too small and weak to contribute to the overall charge transport across the porous media system. A long positive tail representing a large-flux current pathway was also observed in the histogram. However, again, the population of the large-flux transport pores is small. As a result, the main conveyer of the electric charge is the stagnant pores (not the transport pores), which have small positive flux values but a large population. The present study was supported in part by JSPS KAKENHI (No. 23241012).

References:
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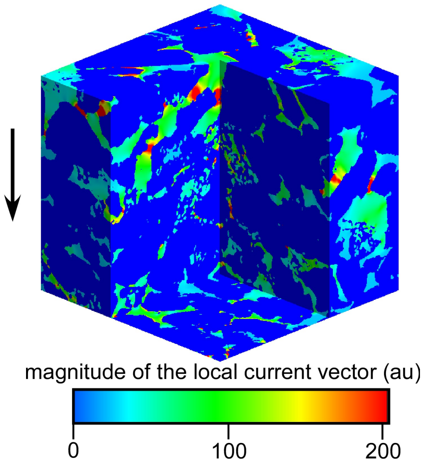
[2]Y. Nakashima and T. Nakano (2011) Journal of Applied Geophysics. http://dx.doi.org/10.1016/j.jappgeo.2011.06.021

Keywords: formation factor, Archie's law, electric conductivity, pore-scale simulation, diffusion, x-ray microtomography



SEM22-P02 Room:Convention Hall Time:May 25 15:30-16:45

Resistivity structure around the focal area of M6.4 earthquake beneath Mt. Fuji volcano

AIZAWA, Koki[1*], YAMAYA, Yusuke[1], UYESHIMA, Makoto[1], HASE, Hideaki[1]

[1]Earthquake Research Institute, Univ. of Tokyo

Broad-band magnetotelluric (MT) measurements were conducted June to December, 2011 at Mt. Fuji volcano. The objective of this survey is to investigate the resistivity structure around the focal region of M6.4 earthquake, which occurred beneath Mt Fuji 4 days after M9 Tohoku Oki earthquake. MT Data were collected at 25 sites by using Metronix ADU07 system. The sampling frequency were 32Hz (15:00~20:00 UT), 1024Hz (17:00~17:30UT), and 32768Hz (14:50~15:51). Because of the high noise circumstance of this area, typical duration of data sampling was one month for one site. By applying the comb filter to reduce the harmonics of 50 and 60Hz and the robust MT response function estimation code (Chave and Thomson, 2004), we obtained the impedance tensor in the frequency range of 10,000 ~ 0.001Hz. In this presentation, we will show the resistivity structure by inversion, and will discuss the mechanism of the M6.4 earthquake beneath Mt. Fuji.

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SEM22-P03 Room:Convention Hall Time:May 25 15:30-16:45

Resistivity imaging by magnetotelluric method on Taal volcano, Philippines -Evaluation of the sea effect-

YAMAYA, Yusuke[1*], SASAI, Yoichi[2], TAKEUCHI, Akihiro[2], MOGI, Toru[3], Paul Alanis[2], HASHIMOTO, Takeshi[3], NAGAO, Toshiyasu[2]

[1]ERI, Univ. Tokyo, [2]EPRC, IORD, Tokai Univ., [3]ISV, Fac. Sci., Hokkaido Univ.

Taal volcano, located in the Taal caldera lake, the southern part of the Luzon Island, is one of the most active volcanoes in Philippines. We conducted a magnetotelluric resistivity survey to clarify the distribution of ground water and magma reservoir beneath the volcano. AMT and wideband MT data were measured along two lines, which were crossing the main crater lake (MCL) at the center of the volcano island, and the southwestern flank. The impedance tensor and induction vector were calculated from the time series data. Prior to a 2-D analysis, the phase tensor analysis suspected the electromagnetic strike direction in the study area as N35E, which is approximately perpendicular to our survey lines. Here, during the 2-D analysis, it is required to consider the sea effect to the MT data because the study area is surrounded by the ocean, being about 15 km distant from there. The measured induction vectors pointing toward the ocean are obviously affected by the seawater. The 3-D forward model assuming a simplified bathymetry with 0.3 ohm-m seawater evaluated this effect. The calculated induction vectors explained well the observed ones at a frequency band below 0.01 Hz, reflecting the sea effect. However, this effect to the impedance above 0.3 Hz was not so large as to give critical artifacts to a resistivity structure suspected by a 2-D analysis. Therefore, the apparent resistivity and impedance phase above 0.3 Hz were inverted to resistivity sections, by using the 2-D resistivity inversion scheme developed by Ogawa and Uchida (1996). The 2-D bathymetry was fixed during the inversion. The inverted resistivity section across the MCL indicates a relatively resistive body (30-100 ohm-m) at 1-3 km (b.s.l.) surrounded by conductive layer. Since this feature is common to the other resistivity section, the conductor can shape a kind of the shell spherically covering the resistive body. This resistive body can be interpreted as a volcanic gas reservoir or intruded rocks during past eruptions. The saturation of lake water and alteration due to volcanic fluid and heat can generate a surrounding conductor.

Keywords: volcano, Taal, magnetotelluric, resistivity structure

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

SEM22-P04 Room:Convention Hall Time:May 25 15:30-16:45

Audio-frequency magnetotelluric surveys across the Yasutomi and Kuresaka-touge faults (2)

KUBOTA, Takahiro[1*], YAMAGUCHI, Satoru[1], UEDA, Satoshi[2], MURAKAMI, Hideki[3], KATOH, Shigehiro[4], MISHIMA, Toshiaki[1], MINAMI, Yuichiro[1]

[1]Graduate School of Sci., Osaka City Univ, [2]JOGMEC, [3]Faculty of Science, Kochi Univ, [4]Division of Natural History, Hyogo Museum of Nature and Human Activities

The Yamasaki Fault System consists of the Ohara, Hijima, Yasutomi, and Kuresaka-touge Faults (northwest active faults group) and the Biwako ,Miki, and Kusatani Faults (southeast active faults group).The total length of the fault system is about 90 kilometers long. The Nagisen Fault zone is a reverse fault system that runs between southern foot of the Mt. Nagisen and the Tsuyama Basin. The general strike of the zone is EW and about 32 kilometers long.

Headquarters for Earthquake Research Promotion (2003) classified the Yamazaki Fault zone into three seismogenic faults, the Nagisen Fault zone, main strand of the Yamasaki Fault zone (the Ohara Fault - the Miki Fault), and the Kusatani Fault. The main strand of the Yamasaki Fault zone is divided into the northwestern part and the southeastern part. They evaluated the probability of earthquake occurrence within 30 years will be 0.07-0.1% for the Nagisen Fault zone, 0.06-0.8% for the northwestern part of the main strand of the Yamasaki Fault zone, 0.03-5% for the southeastern part of that, and about 0% for the Kusatani Fault. Audio-frequency magnetotelluric (AMT) surveys were undertaken along three lines (E-, C-, and W-line) across the Yasutomi and Kuresaka-touge Faults in 2009-2011 in order to reveal subsurface structure beneath the fault system. In this presentation we will show the results along W-line and E-line.

The survey was made at eight stations in 2010 and at four in 2011 along the E-line. Ueda et al. made observations at six stations to the north of the Yasutomi Fault and five to the south of the Kuresaka-touge Fault in 2009 along the W-line. Additional AMT survey was made at two stations in the area between the Yasutomi and Kuresaka-touge Faults in 2011.

MT responses of the frequency range between 10,400-0.35Hz were obtained at each site using the remote reference processing (Gamble et al., 1979). We determined dimensionality and strike direction of each line using the phase tensor analysis (Caldwell et al., 2004). Both of two lines showed the dominant two-dimensional nature. Then, we determined strike directions of each line; N60W-S60E for the E-line and E-W for the W-line.

Qualitative insights from pseudo-sections of the apparent resistivity and phase data of the TM and TE modes as follows.

E-line

In both modes, the apparent resistivity value is $<$100 ohm-m to the south of the Yasutomi Fault and $>$1000 ohm-m to the north of this Fault. But, in TE mode, a slightly high resistivity is recognized in the frequency range lower than 500 Hz beneath the surface trace of the Kuresaka-touge Fault and beneath 3km south of this fault.

Phase values between 30 - 40 deg. are widely recognized in both modes with a slightly high phase value of 45 deg. in the frequency range of 100-1000Hz beneath the Yasutomi Fault.

W-line

Low apparent resistivity ($<$100 ohm-m) region covering from the highest to the lowest frequency is recognized to the north of the Yasutomi Fault. Another low apparent resistivity region is recognized in the frequency range higher than 1000 Hz to the south of this fault. High apparent resistivity ($>$1000 ohm-m) in the frequency range lower than 1000Hz is found to the south of this fault, this high resistive zone is divided into two in TE mode.

Phase value is 50 - 60 degree to the north of the Yasutomi Fault in both modes. To the south of the Yasutomi Fault low phase value of 30 - 40 deg. covering from the highest to the lowest frequency is recognized in TM mode. In TE mode, low phase value of about 30 deg. is found in the frequency range higher than 500 Hz and it is about 45 deg. in the frequency range lower than that.

In this presentation we will also show the resistivity models of E-line and W-line across the Yasutomi and Kuresaka-touge Faults.

Keywords: conductivity, active fault, magnetotelluric

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

SEM22-P05 Room:Convention Hall Time:May 25 15:30-16:45

A preliminary report on resistivity structure survey in southern Tokai region

YAMASHITA, Futoshi[1*], KUMAGAI, Hiroyuki[1]

[1]National Research Institute for Earth Science and Disaster Prevention

In the Tokai region, great earthquakes have occurred repeatedly and such one is also expected to occur in the near future. Several studies estimated the fault models of past earthquakes in this region based on the historical, the geological and the geodetic data (e.g., Ando, 1975; Ishibashi, 1981). Recently, Sagiya (2007) and Kumagai *et al*. (2009) proposed the model which suggested a buried branching fault in the southern part of the Tokai region in addition to the main fault along the plate boundary, because the existence of such fault can better explain the observed geodetic and geological data. But the clear geographical evidence has not been found yet. So we decided to conduct a MT survey to investigate the resistivity structure in the southern part of the Tokai region (Kakegawa city). In this region, since the commercial electrical noise is expected to contaminate the observed electromagnetic signals, we planned the observation for longer period relative to usual observation. For conducting such longer period's observation, we developed a new measurement system using general commercial data loggers. We have conducted a preliminary test observation using this system. Although the new system needs less electric power and enables a long term observation, its sampling frequency is restricted to 200 Hz at most. So, we conducted the short term observation to obtain the data with higher frequencies before the main observation. We located ten observational sites on a line in the direction of N33^{o}W with the length of 20 km approximately. The observation line is perpendicular to the strike of the buried fault estimated by Kumagai *et al*. (2009). Although we successfully obtained the data with the frequency from 10^{-3} to 10^2 Hz, the data with the lower frequency are contaminated by the artificial noise at some sites. So, we processed the observed MT data with the remote reference technique, which resulted in great improvement of data quality. The apparent resistivity with the higher frequency is low and is approximately equal to 10 ohm-m at all sites. It might be derived from the sedimentary layers. The apparent resistivities with the lower frequency tend to increase in the northern sites and they attain to 1 k ohm-m. We will obtain more precise data with lower frequency by conducting long term observation for a few years and estimate the resistivity structure in this region.

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Keywords: resistivity structure, Tokai region, Tokai earthquake, buried fault

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

SEM22-P06 Room:Convention Hall Time:May 25 15:30-16:45

Upwelling Fluids and Island-Arc Volcano in Subduction Zone: 3D Electrical Resistivity Structure of Lithosphere in Kyushu

HATA, Maki[1*], OSHIMAN, Naoto[2], YOSHIMURA, Ryokei[2], UYESHIMA, Makoto[3]

[1]Graduate School of Science, Kyoto University, [2]Disaster Prevention Research Institute, Kyoto University, [3]Earthquake Research Institute, The University of Tokyo

In the subduction zone, an aqueous fluid (seawater) brought into the Earth's mantle with subducting oceanic plate takes an important role on the formation of the island-arc volcano. The fluid is released by a dehydration reaction as reaching to a certain pressure-temperature condition. It is one of the most important factors for triggering partial melt of the mantle. The physical heterogeneity differences of downgoing plates have an influence on the partial melt and the igneous activity in the mantle. The Kyushu island in the SW Japan arc is a subduction zone, at which the Shikoku basin; a young Philippine Sea plate (PSP), and the old PSP subduct beneath the Eurasian plate. Many quaternary active volcanoes occur along the volcanic front (VF) associated with the PSP, whereas an active volcano in the backarc area of the northern Kyushu exists. Moreover, a non-volcanic zone of about 100 km long is seen along the VF. It is geophysically important to understand the origin of the unique volcanic distribution in Kyushu.

In this study, the Network-Magnetotelluric (MT) data sets, of which the exploration depth covers to the upper mantle, were used in order to determine regional scale electrical resistivity structure. The Network-MT method is particularly effective to the existence of fluids (the slab-derived aqueous fluid and/or melt) due to the electrical means. We applied three-dimensional (3D) inversion analyses using the WSINV3DMT inversion code for the Network-MT data [Uyeshima et al., 2008] for the purpose of investigating the correlation between fluids and the volcano distribution. The most important feature is a conductive anomaly of which the bottom extends to the backarc side exists beneath the each volcano. The existence of such anomaly suggesting upwelling from the back arc side to the VF has been reported in the NE Japan arc with the MT method [Mishina, 2009] and seismic tomography method [e.g., Hasegawa et al., 1991]. However, our results suggest that the conductive anomaly associated with each volcano has its characteristic scale in the horizontally and vertically. In this presentation, we would like to show details on the 3D resistivity structure related to the subducting PSP and the volcano distribution in terms of the fluids migration.

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SEM22-P07 Room:Convention Hall Time:May 25 15:30-16:45

Three-dimensional electrical resistivity structure around the 2007 Noto Hanto Earthquake

YOSHIMURA, Ryokei[1*], OSHIMAN, Naoto[1], ICHIHARA, Hiroshi[2], UYESHIMA, Makoto[3]

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

The 2007 Noto Hanto Earthquake (M6.9) occurred near the west coast of the Noto Peninsula which is located in the back arc area of Central Japan, on 25 March 2007. The focal mechanism of this damaging earthquake shows a reverse fault with a small amount of strike-slip component with a strike of approximately N55E and high angle dip. The two largest aftershocks, both M5.3, occurred within one day near the offshore and onshore edges of the aftershock region. Yoshimura et al. [2008] carried out a wide-band magnetotelluric survey in the onshore area covering the eastern half of the source region, and obtained two-dimensional resistivity models along five profiles as a preparatory step for imaging three-dimensional structure, As the results, they pointed out that a conductive body, which seems to represent fluid-filled zone, is located beneath the mainshock hypocenter and the active aftershock region.

In order to verify the relationship between seismicity and electrical resistivity structure, we carried out additional two-dimensional modelings and three-dimensional analysis by using data of Yoshimura et al. [2008]. As a consequence of additional two-dimensional models, it is revalidated that the distributions of deep conductors correspond with the aftershocks activity. Using the results of two-dimensional analyses along nine profiles as initial and prior models, three-dimensional inversion (WS-INV3DMT: Siripunvaraporn et al., 2005) was applied to the data of Yoshimura et al. [2008]. The full components the impedance tensor at 14 periods 26 sites were inverted. Significant characteristics of the obtained preliminary model are: (1) distribution of resistive blocks at shallow depth seems to correspond to undulation of gravity basement structure (AIST, 2007); (2) a conductive body, beneath the mainshock hypocenter, spreads to the eastern edge of the active aftershock region.

In this presentation, we will show a whole image of two-dimensional and three-dimensional resistivity models compared with main and aftershock activity and discuss the sensitivity of remarkable features of models.

Keywords: resistivity, the 2007 Noto Hanto Earthquake

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

SEM22-P08 Room:Convention Hall Time:May 25 15:30-16:45

3-D magnetotelluric inversion with minimum gradient support

ZHANG, Luolei[1*], KOYAMA, Takao[1], UTADA, Hisashi[1], Peng Yu[2], Xiao Chen[2], Jialin Wang[2]

[1]Earthquake Research Institute, University of Tokyo, Tokyo, 113-0032, Japan, [2]School of Ocean and Earth Science, Tongji University, Shanghai, 200-092, China

3-D MT inversion has progressed fast in recent a few decades. Madden and Mackie (1993) developed first practical 3-D inversion of magnetotelluric (MT) data by using the conjugate gradients (CG) to solve equations of inversion. Newman et al. (2000) introduced non-linear conjugate gradients (NLCG) in 3D MT inversion. Zhdanov (2000) used quasi-linear approximation in 3-D Electromagnetic inversion. Siripunvaraporn et al. (2005) proposed a new scheme of 3-D inversion in data space. Most of the inverse algorithms cited above involve a regularized inversion using a smoothness constraint. These algorithms provide smooth solutions, but few are suitable for clearly imaging geo-electrical interfaces. In the present study, we introduce a new constraint to address this limitation. Portniaguine and Zhdanov (1999, 2002) proposed a focusing geophysical inversion using the minimum gradient support (MGS) functional and used the MGS functional in gravity and magnetic inversion. Zhang (2009, 2010) used this theory to invert 2-D MT data and obtain clear images of geo-electrical interfaces.

In our research, the subsurface resistivity structure is divided by cubes. The conductivity in each cube is assumed uniform. Through changing the cube's volume, the accuracy of inversion can be ensured. Integral equation (IE) method by modified Neumann series (MNS) which was proposed by Singer (1995) and Avdeev et al. (2000) is used for forward calculation, which allows us to avoid calculation of large-scale linear equations. GPBi-CG is used to get the solution in modified Neumann series, and the efficiency is increased. The quasi-Newton method is used to optimize the objective functional. This approach is a kind of Newton method with simplified calculation of the Hessian matrix by using BFGS update (Koyama, 2002). In addition, BFGS update does not require search for the exact minimum point on line unlike the NLCG, and therefore iteration times of 3-D forward calculation can be reduced. For derivation of the sensitivity matrix, we use the method which was presented by Newman (2000).

We investigated some synthetic models and compared the results with those obtained by a smoothing inversion. For synthetic models having sharp geo-electrical interfaces, the MGS inversion was found to image structures with sharp interfaces more clearly and accurately with smaller RMS data misfit. On the other hand, the synthetic test indicated that the MGS inversion provides larger RMS data misfit and so is not advantageous compared to smoothing inversion for models with smooth interfaces.

Keywords: magnetotelluric, inversion, minimum gradient support, quasi-Newton method

Japan Geoscience Union Meeting 2012
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SEM22-P09 Room:Convention Hall Time:May 25 15:30-16:45

Influence of statics shift in 3D magnetotelluric inversion

TANI, Masanori[1*], MIKADA, Hitoshi[1], GOTO, Tada-nori[1], TAKEKAWA, Junichi[1], SIRIPUNVARAPORN, weerachai[2]

[1]Graduate School of Enginnering, Kyoto University, [2]Mahidol University, Thailand

Recent years, three-dimensional magnetotelluric(MT) inversions are widely used for geophysical investigation. These techniques have been reveal conductivity structure reasonably well, in case of simple structures. Compered with two-dimensional MT inversions, three-dimensional MT inversions can recover more realistic and clear conductivity structure, in the complicated geological settings.

However, the three-dimensional MT inversions have been applied to observed data recently. So many refinement should not been considered. An effect of local conductivity anomalies around observation points to a three-dimensional MT inversion is one of the major problems. This research reveals so-called "static effects" to three-dimensional MT inversion. The static shift is an example that local anomalies distort amplitudes of electric field and effect on MT response functions.

In order to improve results of three-dimensional MT inversion with static effects, we developed a three-dimensional MT inversion code in which static shift is adjusted local surface anomalies on the top layer of the model. This research shows static shift makes distortion in the result of former three-dimensional MT inversion code, and new code can reduce the distortion on an inversion result by static shift. But, in order to improve the result of three-dimensional MT inversion, we must develop the technique to correct the static shift based on the new code . In this research we modified WSINV3DMT(W. Siripunvaraporn et at, 2005) for a three-dimensional MT inversion code.

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SEM22-P10 Room:Convention Hall Time:May 25 15:30-16:45

Remote monitoring using mobile network for magnetotelluric observation

KAIDA, Toshiki[1*], ICHIKI, Masahiro[1], DEMACHI, Tomotsugu[1], HIRAHARA, Satoshi[1]

[1]Tohoku University

Introducing the state-of-the-art mobile magnetotelluric(MT) observation system (LEMI-417), a long-period MT observation project has been observing MT data at Tohoku district, northeastern Japan for the aim of 3-D electrical conductivity distribution in the wedge mantle. A result analyzing obtained data indicates that electrically conductive zones correspond with seismic low velocity zones. The MT observation is operated in stand-alone. In past observations, there were many accidents in which wild animals and others harmed telluric cables and electrodes. Therefore it is important to perceive those anomalies as soon as possible.

In recent years, mobile network comes to be more accessible with the introduction of flat-rate and the expansion of service area. Though the stability and security are inferior to wired network, it is possible to access the Internet anywhere within the service area. In some of seismic and GPS observation sites in Tohoku University performs the remote maintenance and the automated data collection by telemeter system using a mobile data communications terminal.

We propose a data transmission system adopted to LEMI-417 system using mobile network for remote monitoring of MT observation data. We found that some MT observation sites are located within NTT docomo's FOMA service area. By access during pre-determined time, we can check observation data from our university in real-time. Our system was installed at an observation site in Izumi-ku, Sendai in November 21, 2011. In this presentation, we will report overview, operational status and problems of our system.

Keywords: Magnetotelluric(MT) observation, remote monitoring, mobile network

Japan Geoscience Union Meeting 2012
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SEM22-P11 Room:Convention Hall Time:May 25 15:30-16:45

Preprocessing of Network MT electric field data contaminated by leak currents to obtain the accuracy MT response (2)

MURAKAMI, Hideki[1*]

[1]Faculty of Science, Kochi University

We report an improved prepocessing method of Network-MT electric field data affected leak currents for obtaining the accuracy MT response. In previous study we have showed that Principal component analysis was effective to reduce large leak current noises of electrical trains. However, some problems have been left unresolved;the selection method of principal component corresponding to leak currents, azimuthal dependence of the effect of reducing noise, and etc. In this study we interpret the physical meaning of each of principal components and report an advanced preprocessing method for reducing large leak currents.

Keywords: MT response function, Network-MT data, leak currents, multivariable analysis

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

SEM22-P12 Room:Convention Hall Time:May 25 15:30-16:45

Reanalysis of the MT response in the Shikoku district

YAMAMOTO, Kentarou[1*]

[1]Kochi University Graduate School of Integrated arts and Sciences

We report re-evaluated Network-MT MT response functions of Shikoku area, Japan, to restrict the previous resistivity models. There are some differences in resistivity models: the resistivity of area corresponding to lower crust of central Shikoku is 10 k ohm-m, but the resistivity of lower crust of west and east Shikoku is a few hundred ohm-m; Under Kii Peninsula the resistivity of region where deep low-frequency tremors occurred is very low, but the low resistivity region is not found under west Shikoku. Accurate MT response functions in the period range of 100 - 10000 sec are useful to solve these problems.

Keywords: Network-MT, MT response, Deep low-frequency tremor

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

SEM22-P13 Room:Convention Hall Time:May 25 15:30-16:45

Variations in the magnetic field arising from the motional induction that accompanies seismic waves in far-field regions

YAMAZAKI, Ken'ichi[1*]

[1]Disaster Prevention Research Institute, Kyoto University

Variations in the electromagnetic field that accompany earthquakes are generated by various mechanisms, of which the present study focuses on variations in the magnetic field arising from motionally induced electric currents that accompany seismic waves at a large distance (several hundred kilometres) from the epicentre. As a simple but informative case, a situation is considered in which seismic waves are approximated by plane waves and the conductivity of the Earth's crust has a stratified structure. Solutions of Maxwell's equations corresponding to this situation have analytical expressions. Analysis of the solutions verifies that SH waves do not generate variations in the magnetic field, thereby implying that Rayleigh waves are dominant in generating variations in the magnetic field at a significant distance from earthquake epicentres.

Using the obtained solutions, variations in the magnetic field due to Rayleigh waves are quantitatively discussed in terms of a crust with a simple structure. Numerical examples demonstrate that the amplitudes of the generated variations in the magnetic field show a monotonic increase with increasing conductivity, although depression of the amplitudes due to the skin effect of electromagnetic waves cannot be ignored. In addition, the amplitudes of the generated magnetic field are sometimes sensitive to the conductivity of both the shallow and deep crust. Given the difficulty of precisely determining the conductivity of the deep crust, it is generally problematic to obtain precise estimates corresponding to the actual Earth. Nevertheless, calculations assuming a simplified conductivity structure provide an upper limit to the possible amplitudes of variations in the magnetic field due to seismic waves. For example, the amplitudes of variations in the magnetic field arising from a Rayleigh wave with a displacement amplitude of 10 cm and a period of 30 sec are as large as 0.1 nT, which is close to the limit of detection by fluxgate magnetometers under typical observation conditions. It is also suggested that phase differences between seismic ground motions and EM variations are not influenced by detailed conductivity structures, and they occur within a rather narrow range of values determined by the direction orientation of the ambient geomagnetic field. In the future, when data with an accuracy of 0.01 nT are available, this property may be used to distinguish variations arising from motional induction, from variations arising from other origins.

Keywords: motional induction, seismic wave, magnetic field

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

SEM22-P14 Room:Convention Hall Time:May 25 15:30-16:45

Characteristics of ULF emission for determination of earthquake precursors for strong earthquakes near Sumatra

AHADI, suaidi[1*], gunawan ibrahim[1], sarmoko saroso[2]

[1]Institut Teknologi Bandung, [2]Nasional Institute of Aeronautics and Space, Indonesia

Earthquake precursor studies using magnetic-field power spectra in the ULF band have been affirmed as a way to identify earthquake precursors effective for short-term. In this paper we studied the characteristics of the earth's magnetic waves associated with earthquakes, which we regarded as a sign (signature) before the earthquake.

Several methods of signal analysis have been used in this research, including spectral analysis in the Pc-3 range (10-45 seconds), ratios of the Power Spectral Density (PSD) between Hs (Zs) in Kototabang (KTB, located near the epicenter) and Pelabuhan Ratu (PEL, located far from the epicenter), and the correlation between Hs (Zs) in KTB and PEL. The goal of the signal analyses is to assure that the disturbance signal (perturbation) really reflects the lithospheric activity.

The results of the above-stated analyses are as follows: For a few strong earthquakes in Sumatra in 2008-2011, perturbations in the geomagnetic field had signatures which could be regarded as earthquake precursors. We also found relationships between the earthquake magnitude, epicentral distance, and the magnetic perturbation amplitude averaged over a period before and after the main earthquake (main shock). That is, the magnetic perturbation amplitude had a positive correlation with the earthquake magnitude, and a negative correlation with the epicentral distance..

Keywords: earthquake, precursor, short term, ULF band

SEM22-P15 Room:Convention Hall Time:May 25 15:30-16:45

Characteristics of electromagnetic data at Marumori in Miyagi prefecture before and after Tohoku M9.0 earthquake (2)

HASE, Hideaki[1*], UYESHIMA, Makoto[1], YAMAYA, Yusuke[1], OGAWA, Tsutomu[1], ICHIKI, Masahiro[2]

[1]Earthquake Research Institute, Tokyo University, [2]Graduate School of Science, Tohoku University

Detection of electromagnetic signals associated with earthquake has been conducted in many years. Electromagnetic inductive effect, produced by electromagnetic variation in ionosphere or magnetosphere, is mainly included in observed electromagnetic data in the earth surface. The inductive effect is made by solar activity which varies widely cyclic or irregularly, and the observed electromagnetic data also vary widely. This fact sometimes leads to make mistakes identifying the signals associated with earthquakes. Therefore, when we discuss about electromagnetic signals associated with earthquakes, the signals must be distinguished from electromagnetic inductive effect.

Recently, we attempt to remove the inductive effect on time-series electromagnetic data by using MT frequency response function. This method is able to estimate inductive effect on time-series electric data from magnetic data, or magnetic data from electric data. If the inductive effect on observed electromagnetic data can be removed by the method, the signal should be clearly picked out. We will present the results of the analysis of MT time-series data in Marumori town, the southern part of Miyagi prefecture from the middle of Nov. 2010 to the end of Apr. 2011.

Keywords: The Tohoku M9.0 earthquake, electromagnetic changes, frequency response function, MT induction effect