Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

STT11-01 Room:203 Time:May 21 14:15-14:30

Self-potential inversion for the permeability and streaming current coefficient using the rock physical empirical law

Yusuke Ozaki[1*], Hitoshi Mikada[1], Tada-nori Goto[1], Junichi Takekawa[1]

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Recently, several quantitative analysis methods of Self-Potential (SP) profile have been developed for the estimation of groundwater flow. SP is a function of the permeability, the streaming current coupling coefficient and the electrical conductivity in the subsurface. For the accurate analysis of SP data, it is, therefore, important to have the rock physical relationship between these parameters either theoretically or empirically. The integration of the rock physical relationship, however, in the analysis of SP data has not been tried. It is known that the streaming current coefficient and permeability satisfy an empirical power law relationship regardless of the soil and rock types. We used this empirical law as the rock physical relationship to integrate our inversion method. Our inversion modifies both the permeability structure and streaming current coefficient according to this power law. For the test of our inversion program, we used the SP profile numerically simulated on the heterogeneous model of permeability, streaming current coefficient and electrical conductivity structure. Our inversion program successfully reconstructed the given permeability structure and streaming current coefficient structure from the calculated SP profile. From our result, we conclude that both permeability and streaming current coefficient structure, which includes the information of zeta potential, can be estimated from the SP profile and a priori estimated electrical conductivity structure.

Keywords: Self-Potential, Inversion, Permeability, Streaming current coefficient

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

STT11-02 Room:203 Time:May 21 14:30-14:45

Resolution of full waveform inversion using controlled-source electromagnetic exploration

Naoto Imamura[1], Tada-nori Goto[1*], Junichi Takekawa[1], Hitoshi Mikada[1]

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A 3D full waveform inversion method is applied to a controlled-source electromagnetic (CSEM) method. For the 3D forward simulation, we employed a finite-different time-domain (FDTD) method in the fictitious wave domain in order to simulate electromagnetic wave propagation with large time steps to minimize the cost of numerical computation. Convolutional perfectly matched layers are employed for the absorbing boundary condition. After the electromagnetic fields are simulated using the FDTD method, we apply the Fourier transform to obtain the electromagnetic fields in the frequency domain. Using the full waveform inversion in the frequency domain, we first demonstrate that conductive anomalies beneath the surface could be estimated. We then discuss the resolution of our CSEM inversion method, in terms of the distribution and the orientation of dipoles of transmitter and receivers deployed for our CSEM survey. We consider two cases in the alignment of x-oriented receiver and transmitter dipole arrays: (i) 2D inline alignment of the arrays, and (ii) pseudo 3D parallel offset alignment. Our synthetic inversion examples show that the latter could lead to the higher resolution than the former, in particular deeper part of our sub-seafloor model. We also confirm that the utilization of tricomponent transmitters and receivers could give better locations both in horizontal and vertical directions in inversion results than that of x-oriented dipoles only. These differences of the inversion results could be explained by the distribution of electric flux and charge around the boundary of conductive anomalies. We finally conclude, from these results, that it would be important to consider the deployment of multi-component transmitter and receivers whose arrays are aligned in 3D for reliable inversion.

Keywords: CSEM, Full waveform inversion, FDTD

Japan Geoscience Union Meeting 2013
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STT11-03 Room:203 Time:May 21 14:45-15:00

Data processing and analyzing of magnetotellurics survey data in time domain

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Data processing is one of essential techniques to obtain optimum response function of the earth. The processing of magnetotelluric survey (MT) has been based on the Fast Fourier Transform (FFT) since the response function of the earth is the function of the frequency. FFT processing gives us spectrums of time series easily. In addition, FFT gives us optimum response function of the earth when S/N ration is high or the length of the time-series is long enough. However, the error of the response function is very large when we apply FFT processing to the low S/N data or short time-series. We suppose that applying FFT processing to MT data may not be optimum. MT survey data is in general non-stationary since the source of MT is the transient electromagnetic fluctuation in the ionosphere. On the other hand, FFT assumes time series to be stationary so that we develop the novel data processing of non-stationary data without FFT.

Here, we focus on a digital filter called pole on pedestal that extracts the signal at specific frequency. This filter defines Z transform. We can calculate the phase of the electromagnetic using the filter and Hilbert transform. In addition, it is important to select the segment included in the signal. We calculate cross correlations between filtered magnetic data at different sites, and chose some segment in which the coherence among the sites has high values. In this way, we can select the segment included in the signal objectively. On the other hand, we must remove the segments contaminated by strong noise. We apply the Maximum Entropy Method (MEM) to select low S/N segments. We include robust and jackknife method in our processing and developed the data processing in time domain without FFT. We applied time domain processing to real MT survey data acquired at the Nankai trough. The data acquired at Nankai trough is low S/N ratio or short term when the signal penetrated to the earth. We obtain optimum response functions using novel data processing successfully. We conclude that the processing and analysis in time domain is important and effective.

In addition, as an example of efficiency of time-domain data analysis, we demonstrate the plane wave decomposition to the MT. The observed wave is decomposed into up-going and down-going wave. The up-going wave contains of the information of the earth. We calculate the wave from synthetic data and apply the plane wave decomposition. The calculated result matches the theoretical solution, so we can apply the plane wave decomposition to the array-like MT data. We again confirmed the future availability of the analysis and processing of the MT data in time domain.

Keywords: magnetotelluric, data processing, time domain, plane wave decomposition

Japan Geoscience Union Meeting 2013
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STT11-04 Room:203 Time:May 21 15:00-15:15

A Hamiltonian particle method with staggered technique for simulating strong ground motion

Junichi Takekawa[1*], Hitoshi Mikada[1], Tada-nori Goto[1]

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We applied staggered particle technique to a Hamiltonian particle method (HPM). In finite differece methods (FDM), staggered grid technique has been used for improving the accuracy of calculations. Staggered grid in FDM difines the variables at the different positions. However, the variables in HPM are defined at the same position in the previous studies. In the present study, we displace the variabules at the staggered positions same as FDM.

We calculate surface wave propagation using a half space model, and compare the result from HPM with analytical solution. Our results indicated that the staggered technique improve the accuracy of HPM.

Keywords: particle method, staggered particle, seismic wave propagation

Japan Geoscience Union Meeting 2013
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STT11-05 Room:203 Time:May 21 15:15-15:30

Numerical simulation of dynamic fracturing using a particle method

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Better understanding of failure mechanism of rocks benefits researches in many fields from rock engineering to earth sciences. Especially, it is essential to understand how fractures are initiated and to propagate under various loading conditions in order to clarify real rock fracture processes. For the interpretation of rock failure, many attempts have been made experimentally or using theories in fracture mechanics. Although much of the knowledge available today is based on experimental observations and the theory successfully represented the propagation of predefined cracks, the failure mechanics are not fully understood by experimental results and it is difficult to describe the initiation and coalescence of cracks using existing theories. Thus, in the recent years, numerical modeling, which might be less restrictive, has been often applied to study crack behaviors, and we also approach to the rock failure based on numerical simulations. To represent rock failure, we use a Hamiltonian Particle method (HPM), one of particle methods. In the HPM, we do not need to use grids or meshes to discretize the rock model, and thus we could deal with the failure relatively in a simple way. In spite of this advantage of the HPM, the applicability of the method to the failure phenomena has yet to be revealed fully. In the present study, we apply the HPM to rock failure under some different specimens and different loading conditions. As a result of our simulations, the HPM successfully reproduces failure patterns of brittle fractures observed at rock fracture experiments, and can indicates micro cracks initiation and propagation. This suggests that the HPM is the useful tool to analyze rock failure.

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STT11-06 Room:203 Time:May 21 15:30-15:45

Parametric inversion of volumetric variations of two subsurface pressure sources from pre-eruptive ground deformation

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We numerically developed a parametric inversion scheme to infer a time-dependent magma accumulation process in the magma plumbing system beneath an active Showa Crater of Sakurajima Volcano (Japan). Our objective is to find what would be dominant geophysical parameters in the accumulation process before eruption. Geodetic observations showed that a periodic inflation and deflation events had lasted 30 hours before an explosive eruption on April 9, 2009. Our model consists of two reservoirs, one shallower filled mainly with gas and the other deeper filled with magma, connected by a volcanic conduit as inferred from the past geophysical observations. A pressure difference between the two reservoirs forces the magma to move from the deeper up to the shallower reservoir. We assumed a constant rate of magma supply to the deeper reservoir as an input to the magma plumbing system. In a cylindrical volcanic conduit, a viscous multiphase magma flow is simulated by either Hagen-Poiseuille or permeable flow with the effects of the relative motion of gas in magma, the exsolution of volatiles in melt, the crystallization of microlites in groundmass, the change in height of magma head, etc. As a result of the parametric inversion of the observed volumetric variations, we found the observed event before the eruption could be reproduced not by the Hagen-Poiseuille model but by the permeable model. We also found that the radius of the volcanic conduit, the bulk modulus of the deeper reservoir, and the gas permeability, and the initial gas volume fraction in the conduit are the key parameters to reproduce the observed volumetric variation. Among these parameters, our sensitivity analysis indicates that the initial height of magma head and the temperature reservoir would have much less influence on the volumetric variations of the reservoirs than the key parameters. We propose our parametric inversion as one of quantitative simulation methods that could be applied to the future eruptive events not only at Sakurajima Volcano but for the other volcanoes.

Keywords: Magma flow simulation, Magma plumbing system, Pre-eruptive ground deformation, Sakurajima Volcano, Parametric inversion

Japan Geoscience Union Meeting 2013
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STT11-07 Room:203 Time:May 21 15:45-16:00

Multi-phase analysis of surface wave survey data obtained by Land Streamer

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High-resolution surface wave survey using Land Streamer has been widely employed in engineering geophysical field to obtain S-wave velocity structure at the near-surface. The survey parameter of the surface-wave survey is fundamentally the same as that of high-resolution seismic reflection survey when utilizing Land Streamer developed by the author. The difference between the parameters is only in the used geophones. Namely, in contrast to the seismic reflection survey, which usually uses 14 to 28 Hz geophones, 4.5 Hz vertical geophones are mainly adopted for the high-resolution surface wave survey. Owing to high dynamic ranges and wide frequency ranges in recent digital type geophones, the surface wave survey data often include relatively high-frequency P-wave reflection, direct SV like reflection phases along with dominant low frequency surface waves. Then it is possible to apply not only conventional multichannel analysis of surface wave (MASW), but also usual P- and S-wave reflection data processing to the acquired data. To ensure whether observed S-wave like refection phase was SV-SV reflection or the converted one from P-waves, comparative measurements was conducted along the same line set on the soft ground. A 120-channel, at 50-cm intervals, SH-wave type Land Streamer was adopted for the high-resolution SH seismic reflection survey. Both data were processed through routine S-wave processing steps. As a result, the time sections were fundamentally the same as each other. P-waves reflection processing also successfully provided the near-surface P-wave time sections. In a recent case, a migrated depth section delineated a dipping bearing layer, and the depths of the layer were consistent with those directly identified by drilling and piling. In conclusion, when conducting surface wave survey compatible to the high-resolution seismic reflection survey, multi-phase analysis or P- and S-wave reflection data processing as well as MASW is available to the data to obtain the near-surface structure.

Keywords: Land Streamer, Surface wave, Reflection, Near-surface

STT11-08 Room:203 Time:May 21 16:15-16:30

Relationship between attenuation of coda wave and crustal stress

Kyosuke Okamoto[1*], Hitoshi Mikada[1], Tada-nori Goto[1], Junichi Takekawa[1]

[1]Kyoto University

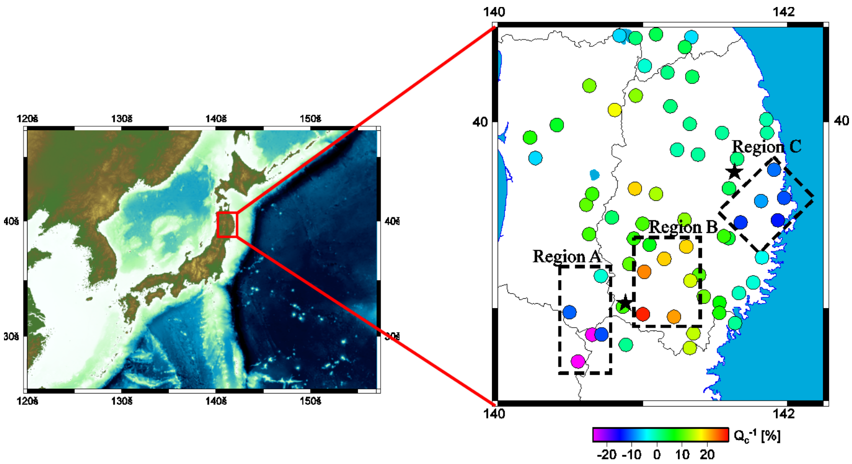
It is important to monitor stress changes in the crust at seismogenic depth to understand seismic activities in advance. Stress field has been measured using the stress relief experiment for sampled core or in borehole, strain-meters buried in the subsurface, etc. In these techniques, stress field is either indirectly estimated using stress-strain relationship or directly obtained after releasing loaded stress to the underground medium after costly construction of tunnels or drilling. For the seismogenic depth, we could, however, hardly access using schemes that are available at present. Sano (2004) pointed out that the measurement of deep stress field is still a challenge with the present technologies.

Recently, Hiramatsu et al. (2000, 2010) discussed a change in coda-Q (denoted as Q_c, hereafter) of local earthquakes in the vicinity of the 1995 Southern Hyogo Prefecture earthquake before and after the main event. He also mentioned the relationship between Q_c and magnitude of the loaded stress to the crust. Aki (2004) proposed a Brittle-Ductile Hypothesis after a long-term observation of the seismicity around the San Andreas Fault that has led him to find a high correlation of the seismicity with Q_c. The recent results (Aki, 2004; Hiramatsu et al., 2000, 2010) indicate that the order of inhomogeneities may vary in the course of long-term earthquake generation cycle, i.e., before and after the failure of crustal material are created. We therefore hypothesize that the state of stress acting in the subsurface medium could be estimated in the course of routine seismic observation.

In this study, we employ a 2-D Finite Different Method to calculate seismic wave propagation through the lower and upper crust. We confirmed that the $Q_c{}^{-1}$ (reciprocal of Q_c) would vary with the stress loaded to an elastic medium using the numerical simulation. The $Q_c{}^{-1}$ roughly shows a proportional relationship with magnitude of the stress. Also we consider if there is a relationship between $Q_c{}^{-1}$ calculated from field data and the strain obtained by geodetic GPS measurement, which is considered as a proxy of the crustal stress near surface. We revealed that $Q_c{}^{-1}$ changes according with the stress change before and after a large earthquake from the observation around the Tohoku area in Japan.

Figure below shows variation in $Q_c{}^{-1}$ [%] at each Hi-net station before and after the two major earthquakes. One is the Iwate-Miyagi Nairiku Earthquake (Jun. 6, 2008, Mw 7.2, 7.8 km depth) locating between the Region A and B and the other earthquake locates near the Region C (Jul. 24, 2008, Mw 6.8, 108 km depth). We take average of the $Q_c{}^{-1}$ at each station respectively before and after earthquakes; May, 2006 - May, 2008 and Oct, 2008 - Jan 2010. Then, we calculate the difference between these two sets of the averaged $Q_c{}^{-1}$.

Keywords: Coda-Q, Attenuation, Scattering, Anisotropy, Crack



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STT11-09 Room:203 Time:May 21 16:30-16:45

Stress concentration in fractured medium due to formation pressure changes

Kurama Ohkubo[1*], Hitoshi Mikada[1], Tada-nori Goto[1], Junichi Takekawa[1]

[1]Kyoto university graduate school of engineering

Hydraulic fracturing technique has been used for obtaining the magnitude and direction of the horizontal in-situ stress field in the subsurface. Recently, this technique is applied to develop new types of hydrocarbon reservoirs, i.e. unconventional resources such as shale oil or gas. It is important to understand the generation and propagation of fracturing under three-dimensional stress conditions since these resources require hydrofracturing through drilled holes.

However, we do not have much information on the stress distributions and pre-existing fractures around the borehole in many cases. Furthermore, the propagation direction of fracturing in heterogeneous rocks with fractures is not well understood.

In the present study, we introduced a numerical simulation based on the extended FEM (X-FEM) to deal with the pre-existing fractures. The utilization of X-FEM allows us to consider various fracture parameters (stress intensity, J integral evaluation, etc.) and to deal with the propagation of pre-existing fractures.

Our results under various stress conditions and pre-existing cracks show that the points of stress concentration around the borehole do not match the orientation of the maximum principal stresses because of pre-existing fractures. Our results also indicate that in-situ stress and pre-existing fractures have an effect on the hydraulic fracturing test using borehole breakout and drilling induced fracturing. The propagation of pre-existing fractures could be induced by injection pressure. As a consequence, the orientation of fracture propagation converged to that of maximum principal stresses. The convergence speed depends on injection pressure. The higher injection pressure is added, the stronger tendency to propagate straight fracture propagation is indicated. We would like to conclude that our numerical simulation has revealed the stress distribution around borehole in rocks including pre-existing fractures has a tendency for fractures to propagate in a direction to the maximum principal stresses.

Keywords: Hydraulic Fracturing, X-FEM, in-situ stress, pre-existing fractures

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STT11-10 Room:203 Time:May 21 16:45-17:00

2D elastic full-waveform inversion for estimating fluid distribution in hydrocarbon reservoir

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Seismic full-waveform inversion (FWI) method has been used to estimate subsurface velocity structure. FWI directly utilizes observed waveforms that could include information on the properties of subsurface materials. In seismic time-lapse surveys, we observe the difference between waveforms as a function of time for the change such as fluid alteration. Residual waveforms between the observed before and after a certain time interval are used to estimate the changes in the fluid distribution in terms of seismic velocities in FWI method.

In contrast to the previous FWI applications, our research focuses directly on the properties in the hydrocarbon reservoir in order to estimate the fluid distribution and alteration. We simulate the wave propagation based on the Biot theory that includes the effects of fluid in porous media. The simulation model is composed of a block of sandstone saturated with water and gas. We assume a transition zone around the fluid contact, whose vertical profile of the saturation rate varies gradually in time in this zone. Since the P-wave velocity distribution shows little change during the movement of fluid contact in our model, we focus on the S-wave velocity distribution with an elastic FWI method. The waveforms of the P-S converted contribute to the inversion of S-wave velocity distribution, although those of the direct P could distort the results. The separation of the P-S converted waves from the acquired could be a possible scheme for the estimation of S-wave velocity distribution.

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STT11-11 Room:203 Time:May 21 17:00-17:15

Applications of the full waveforim inversion techniques to the estimation of the sound velocity structure in the ocean.

Yukihiro Kida[1], Hitoshi Mikada[1*], Tada-nori Goto[1], Junichi Takekawa[1]

[1]Yukihiro Kida, [2]Hitoshi Mikada, [3]Tada-nori Goto, [4]Junichi Takekawa

The travel-time inversion method has been developed using a ray-tracing scheme in the Munk's Ocean Acoustic Tomography (OAT) method. The method has some similarity with seismic exploration both in the theory and data processing methods except for the direct utilization of waveform in seismic exploration. The waveform analysis is a powerful tool to investigate the velocities in the areas of interest, and the importance to use waveform is widely recognized in seismic explorations. However there are few precedent studies dealing with waveform inversion in the application of OAT. This study investigates the effectiveness and applicability of the full waveform inversion method to estimate underwater sound velocity structures. We use an adjoint-state method for the calculation of the gradient in an iterative inversion based on a pre-conditioned conjugate gradient method. We first demonstrate results from a full waveform inversion method applied to a synthetic dataset that reflects the sound velocity structure. The results are then compared with those from a conventional ray-based travel time inversion method to evaluate the effectiveness of the method. The results show that the full waveform inversion method could provide more precise image with higher resolution than the ray-based method. The full waveform inversion method is also applied to a VCS experiment field data in Lake Biwa. In spite of very limited path condition using only direct arrival wave, the full waveform inversion method could describe the horizontal velocity structure possibly due to seasonal thermocline in the lake. We conclude that the FWI method could be the key success factor for the higher resolution at estimation of underwater sound velocity structure.

Keywords: FWI, Tomography, Ocean Acoustic

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STT11-12 Room:203 Time:May 21 17:15-17:30

Electromagnetic scattering by fine ceramic spheres and scattering-induced suppression of insolation heating

Jun Horie[1*], Hitoshi Mikada[1], Tada-nori Goto[1], Junichi Takekawa[1]

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1.INTRODUCTION

The temperature of materials rises when they are exposed to the sunlight (insolation heating). Insolation heating could be suppressed when the materials are coated with paint admixed with fine silica spheres (insulating paint). By coating buildings walls and roofs with such paint, the temperature in rooms could be kept lower without air-conditioners. These phenomena are well known and have been utilized in the past, but have hardly been analyzed theoretically yet. Theoretical analysis could greatly enhance the effects of the suppression of insolation heating if we understand the mechanism of insolation. We focus on the light scattering by fine spheres assuming that the scattering attributes to the phenomena.

In this study, we consider fine silica spheres randomly distributed in a paint layer coating a material, and analyze its scattering characteristics using a Monte Carlo ray tracing method based on the Mie theory. We finally investigate how the structure of the paint attributes to the scattering characteristics.

2. METHOD

We assume three layers: air, paint, and iron that is coated with the paint. Fine spheres are randomly distributed in the paint layer by using Distinct Element method (DEM).

A number of photons comprising the light vertically incident to the paint at random coordinate from the air. We then count the total number of photons that reaches the iron and estimate the amplitude and the intensity of the transmitted light wave.

We use the Fresnel Equations to consider the reflection and the transmission effects. The reflection and the transmission coefficients are used to determine photons behavior stochastically using a random value. Moreover, the Mie theory was used to calculate the scattering distribution of sphere when photons incident to spheres.

3. RESULT

We calculated the transmission intensity distribution associated with two factors: the size parameter of the sphere (the ratio between sphere radius and incident wavelength) and the contrast between the refraction coefficients of the paint and spheres.

The transmission intensity decreases as the contrast becomes larger or as the sphere radius becomes smaller. These phenomena are observed due to the characteristics of the Mie scattering, i.e., (a) the scattering cross section of a sphere becomes larger simultaneously with the contrast and (b) the backscattering becomes dominant when the size parameter of the sphere got smaller.

Furthermore, the local minimum values are observed on a specific wavelength band when a sphere radius is given. It therefore indicates that the specific wavelength band could be selectively weakened depending on the appropriate chosen sphere radii.

4.Summary

Our goal is to analyze the light scattering to find the most efficient structure of the scatterer. We calculated the total intensity of transmitted waves assuming that fine silica spheres are randomly distributed in a paint layer.

For effective insulating paint, it is found that the sphere radius should be less than 1.0um and the refractive index of sphere is less than 1.5 or more than 1.7 if we want to decrease the transmission intensity to less than about 0.2-0.3. Moreover, the distribution of the transmission intensity does not show monotone increase/decrease but shows peaks and troughs in these results. Thus, there could be an optimum sphere radius and an optimum material of spheres with respect to improving the effects of the insulating
paint.

Keywords: scattering, electromagnetic wave, ceramic sphere, Mie scattering, energy saving, insolation heating

Japan Geoscience Union Meeting 2013
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STT11-P01 Room:Convention Hall Time:May 21 18:15-19:30

Estimation of S-wave impedance in ground surface layer due to vertical load excitation

Nobuaki Tanaka[1*], Hiroyuki Goto[2], Sumio Sawada[2]

[1]Kyoto univ., [2]DPRI

Estimation of S-wave impedance in ground surface layer due to vertical load excitation

Dynamic response of structures during earthquakes depends on physical parameters in the ground due to the dynamic soil-structure interaction. The influence is complicated, but it is known that elastic impedance of ground layer associates with the radiation damping.

Normalized Energy Density (NED; Goto et al., 2011a) is a physical quantity related to wave propagation in multi-layered ground, and it becomes a constant value through each layer independent of how layer structure is. That is, S-wave impedance is an important physical parameter to decide dynamic ground response.

We develop a method to estimate S-wave impedance in half space, and in the most upper surface layers based on numerical experiments.

Hiroyuki Goto, Sumio Sawada and Toshiyuki Hirai: Conserved quantity of elastic waves in multi-layered media: 2D SH case -Normalized Energy Density-, Wave Motion, 48, pp.602-612, 2011.

STT11-P02 Room:Convention Hall Time:May 21 18:15-19:30

Q factor of elastic wave propagating in poroelastic medium

Kazuki Ishikura[1*], Hitoshi Mikada[1], Tada-nori Goto[1], Junichi Takekawa[1]

[1]Kyoto University

Sonic logging has been widely used for many years to understand physical properties of hydrocarbon reservoirs. For understanding the reservoir characteristic, quality factor based on the Biot's equation is often used. Although the Biot theory considers viscous attenuation induced at the interface between rocks and pore fluids, intrinsic attenuation caused by internal friction in the matrix is ignored. In the present study, we first hypothesized that the effect of the intrinsic attenuation could influence the evaluation of pore fluid properties, i.e., reservoir properties, based on the quality factor. We employ a 2D finite-difference scheme to simulate seismic wave propagation in a poroelastic medium for the confirmation of the hypothesis. The intrinsic attenuation is included in our model by using the filter of frequency-independent quality factor (constant-Q). We compare the results with and without the intrinsic attenuation in our numerical simulations. Our results clearly show that the amplitude and phase of the waveforms are strongly influenced by the intrinsic attenuation, and the calculated quality factors could be seen shifted to show different value from the real value derived from the Biot theory. We conclude that the evaluations of hydrocarbon reservoir based on the quality factor might require the inclusion of the intrinsic attenuation as well as the viscous attenuation.

Keywords: quality factor, poroelastic medium, constant-Q, intrinsic attenuation, viscous attenuation

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Numerical electromagnetic simulation for high resolution eddy-current testing method

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The applicability and feasibility of eddy current detection method for the measurement of wall thinning and surface crack of steel structure have been practically confirmed by field and laboratory experiments. Recently, we could roughly understand the location and size of defects by this method. But the estimated size and shape are qualitative ones. For more accurate inspections, there has been a demand to quantitatively evaluate the defects. Therefore, we developed a numerical simulator to consider whether we could refine the high accuracy eddy current method.

In the eddy current method, we use the information of excitation and induced magnetic field.In order to calculate the induced magnetic field, we used 2.5 dimensional finite-difference frequency domain technique (2.5D-FDFD) to solve Maxwell's equations numerically. In this technique, we assumed the two-dimensional structure and the three-dimensional electromagnetic field. We used two-layer structure consisting of seawater and steel plate containing defects. To estimate characteristic of the induced magnetic field, we simulated for various defects and compared what effects appear.

As a result, we could confirm the effect of surface defects of steel plate on receiving magnetic field intensity. The induced magnetic field intensity increases near the edge of the defects and decays above the defects. The larger the defects length and width are, the more attenuation the magnetic field intensity becomes. Our simulation results indicated that we could calculate the response of magnetic field intensity whose detectable scale of defects is no smaller than mm order.

Keywords: Eddy current, Maxwell's equation, NDE, 2.5D-FDFD, Magnetic field

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STT11-P04 Room:Convention Hall Time:May 21 18:15-19:30

Removable of galvanic distortion on 3-D MT inversion.

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The galvanic distortion is caused by localized resistivity anomalies near the surface and creates artificial false images in the inversion of MT data. Although the effects of galvanic distortion should be imaged locally, they tend to appear as gradual resistivity changes at deeper part of survey area, that is in general close to the target depth for hydrocarbon resource exploration of several kilometers, due to the smoothness constraint. Therefore, the galvanic distortion has to be removed to improve 3-D MT inversion results. In our study, we refine the smoothness function to image local anomaly on the surface layer in the inversion to cope with the effects of galvanic distortion. In the refinement, we modify a model covariance matrix in 3-D MT inversion algorithm, WSINV3DMT. We applied WSINV3DMT to several synthetic datasets to evaluate how local anomalies on the surface influences the result of 3-D MT inversion. The synthetic resistivity models used in this experiments have low resistivity anomalies in the subsurface with and without the surface local heterogeneities, respectively. The thickness of surface blocks is 10m. We estimated synthetic MT response functions from these two models for 7 periods; 0.01s,0.05s,0.1s,0.5s,1s,5s,10s. Then we applied WSINV3DMT to those synthetic datasets. For the removable of the effect of galvanic distortion, we applied a modified model covariance matrix to MT response functions calculated from the model with local anomalies on the surface. Finally, we first confirm that the effects of galvanic distortion would generate false resistivity anomalies in the inversion, in particular in the deeper part. This problem would not be negligible in the imaging of realistic resistivity structure in the subsurface. The results from the modified model covariance matrix we have introduced show more reliable results than those from the original model covariance matrix. Since a thin surface layer is an analogue of the galvanic distortion, we could deal with the galvanic distortions by thin layers placed at each observation site.

Keywords: Magnetotelluric, Inversion, Distortion

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Visualization of subsurface resistivity anomalies in VLF-EM method

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Electromagnetic waves of narrow-band frequencies generated by VLF transmitters induce electrical currents in the subsurface due to localized electrical conductivity anomalies. Secondary induced components of magnetic field would be observed above the surface due to the induced electrical currents. Therefore, the secondary induced magnetic field could be used to detect the induced currents in the subsurface. This method, so-called VLF-EM, has been recognized as a powerful tool for mapping subsurface conductivity anomalies because of its low cost and short survey terms. Conductivity anomalies are in general mapped on the surface but have not been estimated as a vertical pseudo-resistivity section nor in a 3D cube. We hypothesized that both the apparent resistivity and the depth of conductive anomalies could be estimated using the measured magnetic components with a single frequency. In this study, the Normalized Full Gradient (NFG) method, generally used for the downward continuation of the potential filed data, is applied to the observed magnetic data on the surface in order to estimate the 3D distribution of conductivity anomalies in the subsurface. A synthetic VLF-EM data set was created numerically to test our hypothesis. The cross section of NFG values derived from the horizontal component of magnetic field clearly peaks at the edges of a low resistivity anomaly zone buried below the surface, while the value of the NFG from the vertical component at the centre of the anomaly. Finally, we estimate a pseudo-section of apparent resistivity from the VLF-EM data weighted with the NFG values at each depth. We confirm that the weighted apparent resistivity values are lower in the vicinity of low resistivity anomaly than in the surrounding area, although the estimated value is a little higher than the original value. We conclude that our simple technique gives approximate subsurface resistivity structures quickly, which is useful for geological interpretations and also for building an initial model of three-dimensional inversion.

Keywords: VLF-EM, downwardcontinuation, NFG, apparent resistivity

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Electromagnetic survey around the seafloor massive sulfide using autonomous underwater vehicle

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The recent growth of world-wide requirement of metals demands advanced explorations for finding metal mine and deposits. The feasibility studies demonstrated that the electromagnetic responses are very sensitive to the conductive layer simulating the submarine massive sulfide (SMS) deposits, which is buried at the depth of several tens meters. On the basis of the results, we developed instruments for the marine controlled-source electromagnetic (CSEM) survey with autonomous underwater vehicle (AUV), on which a transmitter was attached. For the real field test, R/V Yokosuka and AUV Urashima were used. The target region is a real deep-sea mine in a caldera structure called Bayonnaise, located in the Izu-Bonin island arc, south of Japan. We succeeded in the test experiment along four survey lines with current shooting from AUV. Six ocean-bottom receivers (OBEM) simultaneously recorded those signals. The maximum source-receiver distance, in which we can detect the artificial current signals, exceeds to about 500m. Therefore, the inferred maximum sounding depth will be 150m or more below the seafloor. For evaluating the anomalous attenuation or amplification of received electric field at OBEMs, the three-dimensional forward modeling including the real bathymetry and a simple subsurface structure having an uniform resistivity (1 Ohm-m) was employed. Comparison between the observed and synthesized received field gives us a three-dimensional pseudo-section of anomalous received field, which can visualize heterogeneity of sub seafloor structure qualitatively. On the basis of the preliminary result of our AUV-CSEM survey around the SMS, high conductive features are observed not only in the SMS exposed area, but also the surrounding area of SMS. It would reflect both the mineral deposits in and around the SMS and highly conductive pore water below the surface due to warm temperature by hydrothermal activities below the SMS. We conclude that our new technology imaging the near sub-seafloor structures will be useful for discussion about the geological background of SMS, and also be a powerful tool for the SMS detection and developments.

Keywords: CSEM, AUV, seafloor massive sulfide, OBEM

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Three-dimensional joint inversion of gravity and magnetic anomalies using fuzzy c-means clustering

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The gravity and magnetic surveys have been widely carried out over the years, especially for the exploration of metallic mineral deposits and geothermal resources. These field intensity data could be acquired in much quicker and simpler way than the other geophysical or geological data. The inversion of potential field data, however, has been known as a non-uniqueness problem expressed in the Green's equivalent layer theory. Because of this problem, gravity and magnetic data have no inherent resolution in depth. We, therefore, would like to develop a way to make use of high exploration efficiency that takes the advantages of the convenience to conduct gravity and magnetic surveys.

We present a 3D joint inversion method to estimate two physical parameters, density and magnetization of subsurface materials. In the method, we introduce the fuzzy c-means (FCM) clustering technique in our joint inversion algorithm to consider the petrophysical relation between density and magnetization of subsurface materials. The fuzzy c-means clustering technique we introduce does not necessitate any empirical equation but deals with a linear combination of the influence from multiple clusters given a piece of data to belong to plural clusters in the parameter space formed by the petrophysical parameters.

In this study, we focus on natural resources such as submarine massive sulphides (SMS), which are attractive material due to the recent rapid growth of global economical activities, but their deposit locations below deep seafloor restricts the access. This necessitates detailed exploration using potential field data. We test our inversion method using synthetic numerical experiments for SMS. The joint inversion results using gravity and magnetic data sets show higher accuracy and resolution than the individual ones, and especially have improved horizontal resolution. We conclude that our joint inversion method demonstrates the accuracy of our method in the estimation of SMS in terms of the gravity and magnetic anomalies.

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Lattice Boltzmann simulation for flux change under oscillating boundary condition

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The amount of oil production in the world is decreasing recently and it is of importance to seek the technological development for enhanced oil recovery (EOR) in place in the subsurface. Seismic stimulation is known as one of the methods of EOR. Recently, many laboratory experiments and field tests have been performed such as water, gas, chemical, or thermal injections to attempt the enhancement of oil production. Numerous observations show that seismic stimulation of oil reservoir may improve oil production. To use seismic EOR efficiently, we need to understand the mechanisms of macroscopic phenomena: flux increment, pore-water pressure increment and relative permeability improvement, in particular in terms of seismic frequency and amplitude, to improve oil production. In this study, we attempt to demonstrate the flux change in viscous laminar flow under oscillating boundary condition with various frequencies and amplitudes for the simulation of interstitial flow. We discuss five characteristics: amplitude, frequency, angle, aspect ratio of pore length to pore width, and scale. All characteristics are largely related with the amount of flux change. The flux increases under cases with large amplitude, high frequency, large angle of incident to the wall, large aspect ratio or large scale. The angle is one of the most important characteristics for the flux change. So, vertically oscillating wall has smaller effect even if the other characteristics satisfy the condition to cause the flux increment. Our numerical results imply: i) the flow resistance increases by the velocity difference between the wall and the center of flow, ii) fluid extrusion is generated by partial pressure gradient near the wall, and iii) the oscillating boundary may cause pressure loss. We then discuss the possibility of flux change in terms of pore scales or shapes under the oscillating boundary condition with LBM. Finally, we try to enhance our simulations to include two-phase flow. We confirm that the oscillating boundary conditions could generate the reduction of interfacial tension to improve the relative permeability of oil droplets.

Keywords: seismic EOR, Lattice Boltzmann method, Computational Fluid Dynamics

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Estimation of 2D shear wave velocity profile of soil layers using surface wave seismic tests

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The 2D shear wave velocity profile of strata is estimated using the active and passive surface wave seismic tests. The experimental dispersion curves were obtained after the recorded signals were transformed by the slant stack procedure. The phase velocity in the relatively high frequency range can be obtained using the dispersion curves deduced from the active tests. On the other side, dispersion curves obtained from the passive tests can be used to estimate the phase velocity in the relatively low frequency range. From the higher frequency portion of the dispersion curves that stand for the fundamental mode, we obtained the phase velocities about 190 m/s for the sandy surface fill. Theoretical dispersion curves can be constructed by the thin-layer-stiffness-matrix method. For theoretical dispersion curves, the soil layers of the test site were modeled as the sandy surface fill overlying a half space soil layer. A real-parameter genetic algorithm was programmed to minimize the difference between the theoretical and experimental dispersion curves. We prove that the real-parameter genetic algorithm is capable to reduce the error between experimental and theoretical dispersion curves. The estimated 2D geometry of the sandy surface fill using the active and passive surface wave seismic tests was verified with the borehole data.

Keywords: Slant stack, shear wave velocity, genetic algorithm, dispersion curve

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Application of Geophysical Methods to investigate the Polluted Site and river bottom mud.

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Investigation of many polluted sites indicates that DNAPL plume in the subsurface is able to penetrate a low permeable layer such as clay or silt-caly layer. These DNAPL plume within the low permeable Layer will gradually diffuse to the high permeable layer to affect the accuracy of investigation and remedial design. As to the deeper zone affected by the penetration of DNAPL, the investigating technique of conventional bore-hole sampling design is always limited to the first unconfined aquifer, it is no longer suitable for DNAPL detecting underneath. Precisely define the boundary and the distribution of high and low permeable layer is the key to conduct a successful DNAPL detecting.

Point information derived from the conventional bore-hole sampling is difficult to be used for locating the DNAPL pollution due to the uncertainty of DNAPL migration and the soluble-phase distribution of the DNAPL partitioned into ground water between the low and high permeable layer. Recently, non-invaded technologies such as geophysical technology have been introduced to provide The plane and space information of pollution in subsurface by referring a few bore-hole dates. The most common used geophysical technologies are ground-penetrating radar method (GPR) and electrical resistivity tomography (ERT). Both methods have their limitations when its survey is affected by the existence of surface objects such as building structure or heavy pavement. This drawback can be overcome by using geophysical well logging. The information of multi-wells logging could be used to interpret the permeability of subsurface, the dominate flow path and the hot-spot for evaluating the distribution of pollution and the efficiency of remediation in different time sequences.

This study would first discuss how the DNAPL and its soluble-phase components invade into the low permeable layer based on the field observation. Then, the geophysical technologies are being introduced and compare to the bore-hole investigation alone. Finally, a case study using various geophysical technologies including geophysical well logging are introduced to snapshot the complex profile of subsurface DNAPL distribution for improving future application.

Geophysical Techniques for Near-Surface Hydrological Investigations:

Traditionally, the location and geometrical characterization of fractures and/or fracture zones are recognized by outcrop observations, knowledge of the geological setting and extrapolation from geological data sets etc... Most geophysical methods, such as electrical resistivity mapping, are able to detect variations in the subsurface that could possibly be due to fracturing, such as increased moisture content but only provide a proxy indicator of true fracture orientation, structure and density. At some point in the last few decades, almost every conceivable geophysical technique has been applied to the problem of locating subsurface, groundwater and pollutant flow though these porous and fractured media. Of the available methods, GPR, ERT and EM techniques are deemed the most appropriate. With EM conductivity (e.g., EM 31) considered but discounted due to the presence of surface metallic structures (e.g., steel pathway stabilizing rods, handrail anchors, etc) and a lack of suitable survey space in the investigation areas.

Keywords: Electrical Resistivity Tomography, Ground Penetrating Radar, Horizontal Loop Electromagnetic Method