STT07-01   会場:421   時間:4 月 29 日 09:00-09:15

海洋電磁探査法データ処理における仮想領域法の適用性の研究
Applicability of fictitious domain method in data processing of marine CSEM exploration

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　在来型化石資源の代替としてメタンハイドレート (MH) が有望視されており、その探査手法として、電磁探査の一種である海洋 CSEM 探査が注目されている。近年、電磁場解析に仮想領域を用いることで、電磁場の伝播を高速で計算できる手法が提案されており (Mittet,2010)、順計算の高速化手法として用いられてきた。しかしながら、波動場である仮想領域内での電磁場解析は、拡散場における実領域での電磁場解析よりも MH 層からの応答が向上すると考えられる。そこで本研究では、仮想領域の概念がメタンハイドレートの海洋 CSEM 探査における観測データ解析に応用できると考え、3次元 FDTD 法による数値シミュレーションにより検証した。その結果、実領域での受信波形では海水中を伝播する電磁場と海底下を伝播する電磁場の分離が困難であったのに対して、仮想領域ではそれらが分離できたため、MH 応答の識別性が向上することがわかった。次に、実領域から仮想領域への変換に関しても試みた。本研究では、特異値分解を利用して変換を行った。その結果、仮想領域内での MH 層の感度は、実領域よりも約 2 倍程度向上することがわかった。

キーワード: 電磁探査, 仮想領域, メタンハイドレート
Keywords: CSEM, Fictitious wave domain, methane hydrate

STT07-02　　　　　　　　会場:421　　　　　　　　　　　　時間:4 月 29 日 09:15-09:30

地表磁場成分を用いた電磁マイグレーションによる地下比抵抗構造の可視化
Subsurface imaging with EM migration of magnetic fields from multiple frequencies

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These days, the supply of water is facing a crisis due to the dramatic growth of population, industrialization, etc. As a result, the groundwater demand is becoming more and more stronger than before. Electrical prospecting is a method usually attempted for groundwater exploration, but setting the observation equipment in desert regions, where water shortage is a serious problem, causes us difficulty using this method there, since there is nothing that assures electrical contact between electrode and the earth. In these circumstances, some other methods that do not require any contact of electrode are needed. VLF or ULF is the method that satisfies the condition. However, none of these methods could provide information necessary to locate groundwater and it is strongly necessary to locate water head of survey areas. There is some shortcomings in the present processing of these VLF and ULF data. In this study, the phase-shift method, which is used in seismic migration, is applied to the horizontal magnetic components with multiple frequencies in order to image subsurface resistivity structures to locate groundwater. The survey is conducted more easily and shortly, if only the magnetic sensors above the surface are enough for estimating the structures. As in the seismic migration, both upward/downward imaging and the exploding reflector concepts can be applied to the horizontal magnetic components. The synthetic data examples show that the migration method is effective for imaging the conductive anomaly. However, it is necessary to select appropriate frequency bands in order to estimate correct subsurface structures. We conclude that this technique gives an approximate resistivity structures quickly and that the migration of magnetic components is expected to provide information on the subsurface. This method is also useful for geological interpretations and for an initial model of the more complicated inversion method.

キーワード: 電磁探査, マイグレーション, 見掛比抵抗構造
Keywords: electromagnetic exploration, migration, apparent resistivity structure

STT07-03 　　　　会場:421 　　　　　　　　　時間:4 月 29 日 09:30-09:50

海洋CSEM法フォワード計算への粒子法の適用
Application of particle method to forward modeling of marine controlled-source electro-magnetic survey

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A new marine controlled-source electromagnetic (MCSEM) forward simulation is presented in this study. The benefit of the method is the better treatment of complicated seafloor topography and/or buried structures than before. Here, we focused on the moving particle semi-implicit (MPS) method. In our method, the Maxwell's equations are discretized with particle arrangement without grid structure, which is usually used in finite-difference method (FDM). Each particle denotes the three components of electromagnetic fields at each particle. MPS method has some advantages over the other methods such as finite-element method (FEM), FDM, integral method (IE), etc. An obvious advantage of this approach is a numerical model that can flexibly form arbitrary topography shapes. Although FEM is sometimes employed to treat the topographic structure, especially for MCSEM, pre-process for creating grid or mesh structures require a time-consuming procedure especially in three-dimensional cases. A second advantage is that the three components of electric field and electric current as well as magnetic field and source are defined at the same location of every particle, while not at the same location in the case of Yee's grid.

We tested our three dimensional MCSEM forward simulation using the particle method and confirmed that the accuracy of the forward simulation with the simple tilted layered model would be improved. Our forward modeling results show the accuracy sufficient to discuss with the analytical results. The local and arbitrary refinement of particle is conducted to obtain more accurate result using the same model. The local refinement is applied only near the transmitter and receiver dipoles. The accuracy of MPS becomes higher in the local refinement than in the use of isodiametric particles. Our results suggest that the method using MPS with locally refined particles is useful for the forward simulation of electromagnetic field with arbitrary topography in the MCSEM modeling.

Keywords: Marine controlled-source electromagnetic, Forward simulation, Particle method

STT07-04　　　　　　　会場:421　　　　　　　　　　　時間:4 月 29 日 09:50-10:10

透水係数、比貯留係数及び流動電位係数分布推定のための自然電位分布逆解析手法の研究
Simultaneous inversion of self-potential for estimating hydraulic parameters and streaming current coefficient

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In this study, we develop an inversion scheme for the simultaneous estimation of hydraulic conductivity, streaming current coefficient and specific storage, using transient self-potential (SP) data. SP is a natural electrical potential, which is thought to be caused by subsurface fluid flow through the electro-kinetic coupling. Recently, several SP measurements are performed during pumping tests to characterize the parameters of the aquifer. Almost of all SP analysis methods are adaptable to the static SP data, but a huge amount of the transient SP data is not used efficiently. Therefore, we develop an inversion scheme for the analysis of transient SP data. The electrical conductivity, streaming current coefficient, hydraulic conductivity and specific storage are parameters effectively influencing the SP profile on the surface, and can be solved in the inversion. The distribution of electrical conductivity structure can be used if the electrical resistivity tomography (ERT) or other EM measurements are performed with the SP measurement. We employ the relationship between hydraulic conductivity and streaming current coefficient to decreases the number of estimating model parameters, and to enable the simultaneous estimation of hydraulic conductivity and streaming current coefficient. First in this study, we check the sensitivities of the hydraulic conductivity and specific storage obtained at different times. The sensitivities of the hydraulic conductivity and specific storage are different with respect to the phase. The simultaneous inversion of hydraulic conductivity and specific storage from the transient SP profile is turned out possible from the difference in phase. Finally, we apply our inversion scheme to a synthetic SP profile, and reconstruct the subsurface structure of hydraulic conductivity, streaming current coefficient and specific storage simultaneously. As a result, our inversion technique allows us to obtain the hydraulic parameters from SP data on the ground surface, although the conventional hydraulic tomography strongly relies on the borehole data.

Keywords: Self potential, Inversion, Time domain, Hydraulic conductivity, Specific storage, Streaming current coefficient

STT07-05　　　　　　　　会場:421　　　　　　　　　　　時間:4 月 29 日 10:10-10:25

粒子法による複雑な自由表面を有する岩石の破壊進展解析
Numerical study for failure behavior of rock masses including complex free-surfaces using a particle method

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Failure of rock mass including complex free surfaces is of importance in many engineering and scientific fields. This paper applied an advanced discretization approach to simulate quasi-static failure of rock mass within a Hamiltonian particle method (HPM) framework. In HPM, a free surface is introduced in a simple way, just by removing or ignoring outer particles. This potential can be developed to discretize numerical models including complex free surfaces without the increment of time for pre-processing. In the present study, we developed the numerical simulator based on HPM with a staggered particle technique for simulating brittle failure and AE activities in rock mass with incorporating the elasto-plastic damage model. We, first, conducted uni-axial compressive tests for validating the effectiveness of our approach. Next, we adopted rectangular and circular disc specimens with a hole as complex free surface models. Our numerical results had good agreement with those from laboratory experiments. This suggests that HPM would be a method to simulate failure behavior of rock mass without time-consuming pre-processing.

キーワード: 粒子法, 破壊進展挙動, 岩石
Keywords: particle method, failure behavior, rock mass

MPS 法による MT 法フォワード計算
Forward calculation of Magnetotelluric responses with MPS method

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　地表面の地形によって観測される MT レスポンスが変化する問題について、地形の影響を考慮できる Forward 計算手法の開発した。地形の変化は観測される MT レスポンスに影響を与え、見かけ比抵抗や位相が変化することが知られている（例えば、[Wannamaker, P., et. al., (1986)]）。つまり、地形の影響を考慮せずに地形を水平面であると仮定し解析した場合、本来は存在しない偽像を作ることや本来の異常体の構造を歪めてしまう可能性が有る。

　特に、頻繁に MT 法観測が用いられる環境として地熱地帯や断層帯などがある。そのような環境は局所的な比抵抗異常体が存在すると同時に急峻な地形を有する地域であることが多い。そのような環境での MT 法による地下の可視化をより精度よく行うためには地形が観測される MT レスポンスに対して与える影響を考慮する必要がある。しかしながら、現在 3 次元法インバージョンでは地形の影響を考慮し解析を行った例は少ない。これは 3 次元 MT 法インバージョンにおいて MT レスポンスを計算するために有限差分法が主に用いられていることが理由であると考えられる。有限差分法では計算格子上において電場、磁場をそれぞれ格子の辺上で定義するため地形のような、なだらかに変化する形状を扱うことは容易ではない。一方で、2 次元及び 3 次元 MT 法において、地形の影響を計算した研究も存在する [Nam, M. J.,et.al., (2008)]。これらの研究では地形を容易に扱うことのできる有限要素法を用いて MT レスポンスを計算している。しかしながら 3 次元 MT 法インバージョンに有限要素法を適用することは計算コストの点で難しい。このような現状を踏まえ、本研究では地形の再現性および計算コストの両立を目指し MPS（moving particle semiinplicit）法を用いて MT 法レスポンスの Forward 計算手法の開発を行った。本研究では地形を考慮できる 2 次元 MT 法、TE モード及び TM での MT レスポンスの計算手法を開発した。

キーワード: MT 法, MPS 法
Keywords: Magnetotelluric, MPS, topography

STT07-07　　　　　　　　　会場:421　　　　　　　　　　　　　　　時間:4 月 29 日 11:00-11:15

格子ボルツマン法を用いたシリカスケール成長に係る流体物理学的シミュレーション研究
Fluid-physical simulation of silicate scale formation using lattice Boltzmann method

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　　Scaling behavior has an important role in various geosciences fields. For example, precipitation of silica can cling to pipes and wells, and prevent the geothermal power generation. Silica precipitation strongly affects the circulation of hydrothermal systems by changing the permeability structure, which is related to the nucleation of seafloor massive sulphide. Self-sealing is of importance in the understanding of long-term radionuclide mobility and the safety of deep geological repositories of radioactive waste.

　　The deposition of amorphous silica is controlled probably by many processes. There have been a number of experimental studies made on the chemical kinetics of silica deposition as a function of the degree of super-saturation. However scaling estimated by the simple chemical precipitations cannot explain the measured features in laboratory and field experiments. On the other hand, a high rate of deposition could be found where fluid flow stagnates. Although it has been empirically observed that the fluid flow structure can influence silica scaling, relatively little research have been conducted to investigate hydrodynamic effect on silica scaling. The aim of this work is to evaluate the importance of both chemical kinetic and hydrodynamic effects on silica scale growth with a method of numerical simulation.

　　Here using the lattice Boltzmann method, we calculated velocity, temperature and concentration of dissolved silica in the 2D parallel plate channel and predicted the silica deposition of both chemical kinetic and hydrodynamic deposition processes. The laboratory results by Hosoi and Imai (1982) can be as the reference. We also predicted the silica deposition along the channel with sudden expansion of width. For the latter case, the similar field example in the production pipes of the geothermal well was reported (Mercado et al., 1989).

　　In our numerical simulations, the silica deposition predicted by the kinetic process has the magnitude extremely lower than the amount of laboratory experiment, but shows the similar magnitude if the hydrodynamic process is considered for scaling. In addition, at the another channel model with the sudden expansion scaling predicted by the hydrodynamic process can explain the observed feature at the geothermal well.

　　It is found that consideration of the simple kinetics process solely is not sufficient for explanation of the real silica deposition. Therefore, we emphasize the importance of hydrodynamic effect on silica scaling. To predict the silica deposition more quantitatively, an advanced-simulation including behaviors of colloid silica particles in flow.

Keywords: scale prediction, silica scaling, kinetics, hydrodynamics, the lattice Boltzmann method

STT07-08　　　　　　　会場:421　　　　　　　　　　　時間:4 月 29 日 11:15-11:30

水圧破砕法の適用時における固体・流体連成問題の個別要素法シミュレーション研究
Distinct element method for solid-fluid coupled interaction in the application of hydraulic fracturing

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The hydraulic fracturing is of great interest in many scientific and engineering fields in hydraulic fracturing, such as the hot dry rock geothermal power(HDR). However, the natural fractures have significant influence on the nucleation and growth of fractures created in hydraulic fracturing. In addition, the viscosity of fluid used in hydraulic fracturing also influences the geometry of hydraulically created fractures. Although the influence of both natural fracture and fluid viscosity has been intensively investigated on the distribution of hydraulic fractures, none of the studies has dealt with natural fractures and fluid viscosity at the same time and the interaction between them has not been revealed yet. We, therefore, performed a series of numerical simulations for hydraulic fracturing in naturally fractured rock using a 2D flow-coupled DEM code to examine the influence of the fluid viscosity on the interaction between hydraulic and natural fractures. In this study, a low viscosity fluid of 0.1 m^2/s and a high viscosity fluid of 100.0 m^2/s are used. Our model is a square block with a borehole at the center under a stress field whose maximum and minimum stresses are 10 and 5 MPa, respectively. We apply the hydraulic pressure to the borehole wall, and observe how induced hydraulic fracture would propagate in the presence of a single natural fracture located adjacent to the borehole. The viscosity of fluid and the angle between the maximum stress direction and fracture orientation are the parameters of the numerical simulation. The results show that the lower the oblique intersection angle is, the less linearly the induced fracture crosses the pre-existing fracture. However, when a high viscosity fluid is used, the interruption of natural fractures decreases and the induced fracture tends to go straight along the direction of maximum compression. Our numerical example implies that high viscosity fluid could be used in hydraulic fracturing to reduce the influence of a natural fracture when the hydraulic fracture intersects the pre-existing fracture with certain angles .
Keywords: hydraulic fractureing, viscosity, natural fracture, discrete element method

弾性波を用いた見かけの粘性変化
Numerical simulation for apparent viscosity change under oscillating boundary condition using lattice Boltzmann method

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　Unsteady fluid dynamics in Newtonian and non-Newtonian fluid is the main concern of aeronautical engineering, mechanical engineering, chemical engineering, resource engineering and civil engineering. It is also true to the oil industry because the amount of oil production in the world is decreasing recently, it is of importance to seek the technological development for enhanced oil recovery (EOR) in place in the subsurface. 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. Seismic stimulation is known as one of the EOR methods and unsteady flow problem. Numerous observations show that seismic stimulation of oil reservoir may improve oil production. However, for effective usage of seismic EOR, we need to understand the characteristics of changing apparent viscosity under oscillating solid-phase. In this study, we attempt to demonstrate the apparent viscous change in laminar flow under oscillating boundary condition with the models of single pore throats and porous media.

　We use Lattice Boltzmann method (LBM) describing Boltzmann equation. We use 2-dimensional 9-velocity (2d9v) model to simulate 2-dimensional incompressible viscous flow. We assume that the background pressure difference between inlet and outlet is constant. The flow is generated by a constant pressure difference.

　We discuss the apparent viscosity of a single pore throat and porous media.

　First, we discuss four characteristics of an incident elastic wave: amplitude, frequency, angle, and pressure disturbance (P wave). The characteristics of amplitude, frequency and angle are largely related with the amount of changing apparent viscosity. The flux increases under cases with large amplitude, high frequency, and large angle (S wave) of incident to the wall. On the other hand, the pressure disturbance (P wave) is not effective for changing apparent viscosity. We then discuss the possibility of changing apparent viscosity in terms of fluid properties. Wall oscillation can cause improving relative permeability. So, if the rock has water wettability, the oil flux largely increase with wall oscillation. After that, we examine the possibility of changing apparent viscosity in terms of pore scales or shapes under the oscillating boundary condition with LBM. The models of single pore throat consists of two half pore and one pore throat. The models of porous media consist of several pore spaces connected by pore throats from one pore to the others. The shapes of single pore throats are also largely related with changing apparent viscosity. The apparent viscosity decreases with increasing length of the pore throats and radius of the pore throats, and with decreasing width of the pore throats and large pore radius. Comparing single pore throat model and porous media model, we find the apparent viscosity change in porous media models cannot be replaced by linear combination of the apparent viscosity changing in single pore throat models.

　Our numerical results imply: i) the flow resistance under oscillating condition increases because the velocity difference between the wall and the center of flow is larger than that in steady flow, ii) the effect of the advection term in oscillating boundary condition is larger than that in steady flow, iii) fluid extrusion is generated by partial pressure gradient near the wall and pore throat, and iv) the oscillating boundary may cause improving pressure loss.

Keywords: Lattice Boltzmann method, Unsteady flow, Seismic EOR, Apparent viscosity, Pore throat scale

地震波散乱現象を用いた延性領域の応力変化推定
Estimation of stress change in ductile part of the crust inferred from seismic scattering

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In the past, stress field in the subsurface has been measured by various techniques. For example, the borehole-breakout, the stress release method, the hydraulic fracturing, the strain gauge buried in the ground are used to measure the stress field after costly drilling the subsurface. Beside the techniques requiring direct access to the subsurface, the stress field is also measured indirectly. The Electro Distance Meter, the Global Positioning System, etc. are used to measure a surface deformation in time, from which the subsurface stress change is estimated. However, the estimated stress change in the subsurface is largely affected by near-surface inhomogeneities. Thus, information on the stress field should be obtained from other indirect techniques.

Here, we focus on seismic scattering wave, particularly the coda-Q value, to measure spatial and temporal variations of subsurface stress field. The coda-Q, derived from the attenuation of coda envelope, is perceived to be an indicator of the inhomogeneity in the subsurface. Meanwhile, it has been proposed that the coda-Q has a proportional relationship with the magnitude of stress using a numerical simulation. In this study, we hypothesize that the coda-Q, obtained from seismic waves traveling over a wide range of the crust, indicates stress change in a deep subsurface. At first we numerically calculate a relationship between the coda-Q and the magnitude of stress using a homogeneous crustal model, and show that the coda-Q systematically increases against the magnitude of the stress. Then we confirm the relationship using a heterogeneous numerical model, which has a low velocity zone near the surface. It is revealed that the coda-Q indicates the magnitude of the stress change in the deep subsurface, beneath the inhomogeneity, while the surface strain distribution is largely affected by the low velocity zone near the surface. For the next step, using real seismic data acquired at the regions of the 2008 Iwate-Miyagi Nairiku earthquake and the 2004 mid-Niigata prefecture earthquake, we examine whether the coda-Q indicates stress change in the deep subsurface. The stress change estimated from the coda-Q corresponds with the theoretical one in the ductile part, calculated by a fault model acquired by a seismic wave analysis, whereas the estimated stress change dose not correspond with the inferred one from GPS measurement. It means that the coda-Q can indicate stress change in the deep subsurface, which could give more accurate investigation than the GPS measurement.

キーワード: 地震波散乱, 応力変化, 延性領域, 不均質
Keywords: seismic scattering, stress change, ductile, heterogeneity

STT07-11　　　　　会場:421　　　　　　　　　　　時間:4 月 29 日 12:05-12:25

人工震源による震動実験を想定した二次元波動伝搬シミュレーションによる、不均質媒質と地表の影響の時間変化モニタリング
2D simulation of seismic wave propagation for time lapse monitoring of heterogeneous structure and near-surface effects

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　CO_2 の地中貯留や EOR などを行う際の時間変化モニタリング手法として、地震波アクロスを用いる方法が検討されている。しかし地表震源の場合、地中の不均質媒質や地表付近の影響を受けることが多い。本研究では人工震源による震動実験を想定した二次元波動伝搬シミュレーションを実施した。シミュレーションのための地下構造として、地表付近に堆積層を持ち、地中に空洞（不均質媒質）がある地震波速度構造モデルを作成した。震源の深さは、人工震源を想定した地表震源と、自然地震を想定した深部震源の 2 種類とした。震源は地表震源の場合は上下加震シングルフォース、深部震源の場合は P 波爆発型震源とし、どちらも 15Hz、0-位相のリッカーウェーブレットを用いた。深部震源の場合は、遠方の自然地震を想定して、15Hz だけでなく 2Hz、0-位相のリッカーウェーブレットも用いた。地震観測点は地表アレーおよび坑井内地震計とした。坑井内の地震計は、震源車による実際の震動実験では地中 2 点（深さ 70m、200m）としたが、本シミュレーションでは地表アレーと同様のアレーとした。実験目的はシミュレーションを用いて、震源の深さ、構造の不均質、表層の影響を評価することである。
　シミュレーション結果では、空洞帯のあるところで地震波がわずかに減衰した。これは、もし観測波形に減衰が見られた場合に、震源からその観測点までの経路上に空洞帯のような不均質構造がある可能性を示している。
　地中に空洞帯のある地震波速度構造モデルを用いた地震波形シミュレーションでは、空洞帯による地震波の散乱が出現し、空洞帯が二次的な震源となることがわかった。
　地表震源を用いた場合のシミュレーション結果をみると、地中に設置した地震計は、地表に設置した地震計より不均質構造による散乱波の振幅が大きくなり、不均質構造の時間変化モニタリングに適していると言える。
　地表震源を用いた場合のシミュレーション結果をみると、水平動地震計は、上下動地震計より不均質構造による散乱波の振幅が大きくなり、不均質構造の時間変化モニタリングに適していると言える。
　自然地震を想定した深部震源 (15Hz, 2Hz) を用いた場合のシミュレーション結果でも、空洞帯による散乱が出現した。広範囲の地中構造をみるためには自然地震観測が役立つだろう。

電磁式地震波震源を用いたグリータフ層での数日間の地震波形変化のタイムラプス試験観測
A time lapse test of seismic waveform changes during several days at the green tuff area in Japan using a seismic vibrat

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CCS や EOR やシェールガスなどにおいて地下状態の変化を常時監視するようなタイムラプスモニタリングは大変有用と考えられる。著者等はアクロス震源を用い、サウジアラビアの揚水状でタイムラプス観測を行っている。
しかし、サウジアラビアのアクロスは長期観測を目指しているため装置の移動は容易では無い。そこでより簡便な移動式電磁場イブレータを用いタイムラプスの試験を行った。
観測は 2kmx3km の広さの国内グリータフ地域で夜間の 12 時間の観測を 5 日間行った。2 カ所の坑内地震計と 104 カ所の短周期地震計を用いた。10〜50Hz を 100 秒間でスイープした。
一時間で 100 秒間のデータを 32 個スタックし S/N を向上した。1 時間のデーでも 2km の距離まで明瞭な波形を見る事ができる。一日 12 時間のスタック波形を比較し残差波形を作った。残差波形から微少は波形の変化をみることができる。これらから、慎重な震源の取り扱いをすれば移動型の電磁震源でもある程度地下のタイムラプス研究の使う事が出来るだろう。

キーワード: タイムラプス, アクロス, 地震学的手法, 残差波形, バイブレータ震源, グリーンタフ
Keywords: time lapse, ACROSS, seismic method, residual waveforms, vibrator source, green tuff

STT07-13　　　　　　　会場:421　　　　　　　　　　　時間:4 月 29 日 14:15-14:30

A Reflectivity Guided Elastic Full Waveform Inversion

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Full Waveform Inversion (FWI) of seismic reflection data has become a common technique for producing subsurface images based on local minimization of least squares misfit between observed data and calculated model. Usually, an initial model that is close to the global solution of the problem is needed to obtain satisfactory results without being trapped in a local minimum of the misfit function. Due to the limitations in quantity of the observed data, e.g. using seismic traces from surface receivers to make an image of earth model, the full waveform inversion problem is ill-posed and underdetermined. The problem becomes even worse when dealing with elastic waveforms which require increased number of model parameters, i.e. P wave velocity, S wave velocity, density etc. In order to overcome this problem, inserting a priori model information in to the inversion process helps the algorithm to converge to a solution in the vicinity of the global minimum. This kind of information could be included in the gradient of the misfit function by adding model terms, when using conjugate gradient method to iteratively update the model parameters.

On the other hand, producing reliable velocity model is a key for successful Pre Stack Depth Migration (PSDM) of seismic data. Assuming an available depth section of seismic reflection data, e.g. by time to depth conversion of time migrated section, we estimate the P wave velocity from seismic section by first extracting reflectivity and then using Gardner equation (Gardner 1974) as stated by Hondori et. al 2013. This will produce a P wave velocity model which is used in full waveform inversion as a priori information. Our frequency domain elastic full waveform inversion is developed using finite difference method and perfectly matched layers are used on the boundaries of the computational area. A preconditioned conjugate gradient method is used together with improved pseudo Hessian matrix for updating the model parameters. At each iteration the gradient is calculated using adjoint state method, and then l_2 norm of the model term is added to the gradient to constrain the inversion. We suggest that this method not only improves the full waveform inversion results, but also resulting FWI models provide a good velocity model for pre stack depth migration of seismic data.

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キーワード: Full Waveform Inversion, Frequency Domain, Elastic, Reflectivity
Keywords: Full Waveform Inversion, Frequency Domain, Elastic, Reflectivity

STT07-14　　　　　　　会場:421　　　　　　　　　　時間:4 月 29 日 14:30-14:45

３次元電磁誘導探傷法を用いた金属探傷
3D-FDFD simulation for high resolution eddy-current testing method

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The applicability and the feasibility of eddy-current testing method for the measurement of wall thinning and surface crack of steel structure have been practically confirmed by field and laboratory experiments. Where and how large the cracks would be are roughly understood by this method. However, it is difficult to estimate the exact size and shape of them. For more accurate inspections, there has been a growing demand to quantitatively evaluate the cracks. Therefore, we have developed a numerical simulator for the high accuracy eddy-current method. Eddy-current method measures excitation magnetic and induced magnetic fields, the latter of which is caused by the eddy-current in the inspecting material. In order to calculate induced magnetic field deformed by the cracks, we used three-dimensional finite-difference frequency domain technique to solve Maxwell's equations numerically. As a simulation model, two-layer structure consisting of seawater and steel plate including cracks is used. We simulated a variety of cracks to estimate characteristic of the induced magnetic field, and compared the results in terms of what kind of difference in the induced field would appear. As a result, the effect of surface cracks of steel plate on receiving magnetic field intensity was confirmed as follows: the induced magnetic field intensity increases near the edge of cracks and decays above the cracks with the distance to the edge. The deeper and wider cracks are, the more the magnetic field intensity becomes attenuated. Due to the limitation of our simulation schemes, the response of magnetic field intensity whose detectable scale of cracks was no smaller than mm order. We are introducing a method that could allow us to confirm much finer detectability.

キーワード: 非破壊検査, マクスウェル方程式, 渦電流, 数値計算
Keywords: NDI, Maxwell's equations, Eddy Current, numerical simulation

STT07-15 会場:421 時間:4 月 29 日 14:45-15:00

フルウェーブを用いた坑井間トモグラフィーによる弾性定数推定法の研究
Elastic parameter estimation in full waveform well-to-well tomography

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Seismic full-waveform inversion (FWI) method has been used to estimate velocity and density structures in the subsurface. The waveform analysis is a powerful tool to investigate the properties in the areas of interest, and the importance to use the waveform is widely recognized in the seismic explorations. As the wave propagation is influenced by elastic parameters, Vp, Vs, density, it is necessary to include these parameters in FWI (Virieux and Operto 2009). However, there are few previous studies dealing with density as a parameter in the application of elastic FWI. Density is usually estimated using an empirical formula such as Gardner's relationship (Gardner et al., 1974), or is fixed to a constant value. Almost all elastic FWI studies have neglected the influence of approaches how density parameter is estimated. The objective of this study is to investigate how difficult the estimation of density structure is, and propose a new approach to overcome the problem. We employ 2D numerical simulations in order to investigate the important factor in the inversion of density structure. Our results show that it is difficult to estimate density structure because density structure is less sensitive to waveform than Vp and Vs. Therefore, we hypothesize that the simultaneous inversion of Vp and density structures, using a selected dataset can improve the accuracy of the FWI. For testing this hypothesis, various ways for estimation of Vp, Vs and density using different datasets and approaches. We conclude that Vp and density structures should be estimated simultaneously in the elastic FWI, in which P-wave data separated from the seismic records is used as the input data.
Keywords: full-waveform, tomography, density

STT07-16　　　　　　会場:421　　　　　　　　　　　　時間:4 月 29 日 15:00-15:15

減衰 Q 値による流体境界層の推定
Estimation of fluid contact in terms of attenuation

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　Sonic logging has been widely used for many years to acquire physical properties of formations in the vicinity of hydrocarbon reservoirs. When gaseous phase exists in the formation fluid, the compressional waves traveling through the formation could be strongly attenuated due to low bulk modulus of gas in the fluid, while the shear waves are not. For acquiring physical properties of fluid in the formation, Biot physics or poroelastic analysis would be the best method. Among the available technologies, quality factors based on the Biot's equation could be used. Although the Biot's theory considers the viscous attenuation induced at the interface between pore wall and fluids, the intrinsic attenuation caused by the internal friction in the matrix is ignored.

　In the present study, adding the intrinsic attenuation we investigate if we take the effect of the viscous attenuation from the acquired quality factor, and then, on the basis of the result, if we estimate the fluid contact (e.g. gas-oil contact and oil-water contact). We employ a 2D finite-difference scheme to simulate seismic wave propagation in a poroelasic medium. The intrinsic attenuation is included in our model using a filter for frequency-independent quality factor (constant-Q). We then achieve the results of compressional and shear wave in our numerical simulations. Our results show that on compressional and shear waves, obtained the quality factors different from each other. We acquire the effect of the viscous attenuation by subtracting the quality factor of shear wave from the quality factor of compressional wave. We conclude that the effect of viscous attenuation is extracted and the gas-oil contact is estimated.

Keywords: Q, attenuation, poroelastic, Biot, sonic logging

STT07-17　　　　　　　会場:421　　　　　　　　　　　時間:4 月 29 日 15:15-15:30

遷移領域の存在する流体境界面に対する AVO インバージョン
AVO waveform inversion for estimating the fluid contact with fluid transition zone

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The fluid distribution in the hydrocarbon reservoir affects waveforms acquired in reflection seismic method. A reflected wave changes its waveform at the transition zone of the interface of two different fluids as a function of volume fraction of the two. AVO is in general used to estimate the difference in the P and S wave velocities for the interfacing two media at the interface without any assumptions on the existence of the transition zone. The consideration of the effect of the volume fraction of a fluid to the other in the waveform could be a key for evaluating the fluid mixture around the fluid contact in the reservoir. Therefore, we try to use the waveform directly to estimate fluid distribution in the transition zone that has not been done in the practice of AVO.

In our research, we consider the effects of the transition zone at a gas-water contact (GWC) in a horizontally stratified medium on seismic waveforms. The numerical simulation reveals that the fluid distribution of transition zone distorts the seismic waveform both in amplitude and in phase. Then we use the difference in amplitude and in phase for estimating some necessary parameters expressing the fluid-mixture. We apply a waveform inversion method to the fluid substitution problems to see if the method is applicable to estimate the fluid contact with the transition zone, while the conventional AVO only utilizes the amplitude derived from observed data. Our numerical approach uses full waveform and the results imply the advantages in the estimation of the parameters including the thickness of the transition zone under that assumption of linear trend in the volume fraction in a contrast porosity condition. We suggest that the phase information should be used simultaneously for the inversion process to get the closer contact image.

STT07-18　　　　　　　　会場:421　　　　　　　　　　　　　　　時間:4 月 29 日 15:30-15:45

電磁波散乱を利用した微小球を含む遮熱塗料の輻射熱抑制効果
The insulation effects caused by the scattering of electromagnetic waves by fine spheres against insolation heating

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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 the subjacent rooms could be kept lower thanby coating with regular one. The temperature of the former could be enough low so that no air-conditioning becomes necessary even in the mid summer. These phenomena are well known in a practical manner and have been widely utilized. However,the cause of the phenomena has hardly been analyzed theoretically yet. Moreover, micron-scale ceramic spheres have been known as the best commixture than the other metallic commixture of the same size. Theoretical analysis would greatly enhance the effects of the suppression of insolation heating. We focus on the light scattering by fine spheres under the assumption that the scattering of lights, i.e., electromagnetic waves, attributes to suppression of insolation heating and that the imaginary part of scattering coefficients of the spheres is a key to explain the observed phenomena. In this study, we therefore consider commixture sphere materials to be (i)silica, (ii)aluminum and (iii)copper, distributed in a paint layer coating an iron material, and calculate transmission, reflection and absorption coefficient using the Monte Carlo ray tracing method based on the Mie theory. Using these coefficients, the rise in temperature of surface of the iron layer would be estimated. We finally investigate how the structure of the paint attributes to the insulating effects.

We assume three layers: air, paint, and iron, and commixed fine spheres in the paint layer using Distinct Element method (DEM). A number of photons vertically incident to the paint at random position from the air. We then count the number of photons that reaches the iron to estimate the intensity of the transmitted wave, and count the number of photons that are absorbed by spheres to estimate the intensity of the absorbed wave energy. Fresnel Equations are used to identify photons' behavior stochastically using a random number. Moreover, Mie theory is used to calculate the radiation pattern of scattering at each sphere when a photon incident to the sphere. As a result, it is estimated that the transmission coefficient would be less than 0.1 forthe commixture material of silica whose radius is smaller than ca. 0.7 micrometers. On the other hand, the transmission coefficient could be much less than 0.1 if we use conductive spheres. However, in the latter case, the absorption coefficient would be approximately 0.5, which could cause the rise in temperature of the spheres and the paint.

We estimate the rise in temperature of iron layer using coefficients calculated above. Near-infrared radiation of the sunlight is assumed to be the incident wave. As a result, whereas the temperature would be 63 degrees Celsius if no paint is coated. On the other hand, the temperature would be suppressed to 39, 59 or 56 degrees Celsius, respectively, if we use silica, aluminum or copper spheres of the same radii of 0.5 micrometers. The metallic commixture could lower the temperature rise but the absorption of the energy seems deteriorate the efficiency of the insulation.

In conclusion, silica is one of ideal material for insulating paint in contrast with conductive ones such as aluminum and copper, mainly due to the absorption phenomena of electromagnetic waves by spheres.

キーワード: ミー散乱, モンテカルロ・レイトレーシング, 遮熱塗料, 球, 電磁波散乱
Keywords: mie scattering, monte Carlo Ray-tracing, insulating paint, sphere, electromagnetic scattering

STT07-P01　　　　　　会場:3 階ポスター会場　　　　　　時間:4 月 29 日 18:15-19:30

FCM クラスタリングを用いた重力・磁気探査データのジョイントインバージョン
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 intensity data of gravity and magnetic fields could be acquired in much quicker and simpler ways than the other geophysical or geological surveys. The inversion of such 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 equations 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. Adding the simple FCM clustering scheme, we introduced the smoothness constraint to a weight for membership to each clusters, instead of the conventional smoothness constraint to model parameters. Numerical studies using synthetic data indicate the effectiveness of FCM clustering in the joint inversion: the joint inversion results using gravity and magnetic data sets show higher accuracy and resolution than the individual ones.

　As the field example, we focus on submarine volcanoes located at Mozambique Channel, because the world-class gas fields were discovered around that area and it is necessitated to estimate structure of submarine volcanoes near gas fields. We apply our inversion method to the real field gravity and magnetic data of the submarine volcanoes at Mozambique Channel. We conclude that our joint inversion method gives the reliable and detailed density/magnetization structures inside the submarine volcanoes in term s of the gravity and magnetic anomalies.

キーワード: ジョイントインバージョン, 重力, 磁気, 海底火山
Keywords: joint inversion, gravity, magnetic, submarine volcano

STT07-P02　　　　　　　会場:3 階ポスター会場　　　　　　　時間:4 月 29 日 18:15-19:30

孔隙水圧変化による応力分布と亀裂進展
Stress field and fracture propagation due to the change of injection pressure

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OKUBO, Kurama[1*] ; MIKADA, Hitoshi[1] ; GOTO, Tada-nori[1] ; TAKEKAWA, Junichi[1]

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Hydraulic fracturing is an indispensable scheme to stimulate fluid production in hydrocarbon reservoir development in conjunction with various well testing methods such as drill stem, buildup tests, etc. In recent years, it is also well known that hydraulic fracturing plays a major role in the development of shale oil or gas reservoirs.

The extension length and the orientation of fractures induced by hydraulic fracturing are strongly influenced by the crustal stress field under which any reservoirs are located. Therefore the propagation of fractures is controlled by the regional stress field. It is, in general, necessary to get some understanding of regional stress field before the application of hydraulic fracturing as well as acquiring the rock physical properties of reservoir formations.

However, hydraulically induced fractures may not be created as planned and could cause some environmental issues such as pollution, induced seismicity, etc. It is, we think, very important to estimate how fractures are induced under various crustal conditions to cope with unexpected behavior of fracture propagation.

We focused the effects of the in-situ stress on the stress field around the pre-existing fracture and the fracture propagation with both steady and non-steady hydraulic pressure conditions. To simulate failures in crustal materials under the complicated stress field, we use an extended finite element method (X-FEM) in this study, which can retrieve the stress distribution affected by fractures effectively and estimate the fracture propagation based on linear elastic fracture mechanics (LEFM). Numerical simulations are conducted for a 2D elastic medium having a borehole and a pre-existing fracture. We put the pre-existing fracture around the borehole initially and simulate the propagation of this fracture by applying the hydraulic pressure. The velocity of fracture propagation and the interval of the stress recovery from the stress drop caused by the propagation are set uniformly for the kinetic simulation.

We first simulate the fracture propagation around the borehole under different steady hydraulic pressures with regional stress field. Then we try to see how the fracture could propagate with the non-steady hydraulic pressure during the propagation.

We confirmed that the orientation of the fracture propagation converges to that of the principal stress. Moreover, the convergence speed could be inversely related to the hydraulic pressure. We also found the time delay of the influence of the hydraulic pressure change to the fracture propagation with non-steady hydraulic pressure condition.

From the results of our numerical simulations, we would like to have two conclusions. First, the curvature of the fracture trace depends on hydraulic pressure, but no matter how the fluid pressure is, the orientation of fracture propagation converges to that of principal stress. Second, the transition of the stress field involves the time delay, which leads to the delayed response of the fracture propagation in the non-steady hydraulic pressure condition.

When we develop a hydrocarbon reservoir using hydraulic fracturing, the orientation of maximum in-situ principal stress and the fluid pressure for fracturing should be quantitatively taken into account for the environmental safety and for the stimulation efficiency. It might be also necessary to consider the time delay of the transition of the stress due to the non-steady hydraulic pressure.

キーワード: 水圧破砕, 亀裂進展, 拡張有限要素法, 初期地圧
Keywords: Hydraulic fracturing, Fracture propagation, X-FEM, Stress field

STT07-P03 　　　　　会場:3 階ポスター会場 　　　　　時間:4 月 29 日 18:15-19:30

Estimation of the Dispersion Curve for Soil Layers with Lateral Heterogeneity Using Continuous Wavelet Transform
Estimation of the Dispersion Curve for Soil Layers with Lateral Heterogeneity Using Continuous Wavelet Transform

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The MASW method is the normal method regarding surface wave testing, but it requires 12 or more receivers to measure the phase velocity for statistical redundancy. Therefore, the SASW method has potential for use because only two receivers are required. A time-frequency domain analysis is used to extract a dispersion image of Rayleigh waves and select a dispersion curve from the seismic signals of two receivers during surface wave testing. The signals are transformed by continuous wavelet transform, and the products of the transformed signals of the two receivers are summed at the same slowness over the intercept time to construct a dispersion image. This method is unnecessary empirical judgment in the unwrapping of phases and a significant number of receivers. To examine the applicability of the method on evaluating the dispersion curve for soil layers with lateral heterogeneity, three synthetic examples and an experience example of surface wave testing are discussed. The method is applicable for extracting a dispersion image for lateral heterogeneity soil layers. A high-resolution dispersion image is generated in this study by increasing the interval of the receivers. The result of the experience example was in accordance with that of the borehole data.

キーワード: Dispersion curve, Continuous wavelet transform, Lateral heterogeneity
Keywords: Dispersion curve, Continuous wavelet transform, Lateral heterogeneity

Issues and Countermeasures for the Geophysics Investigation of Contaminated with Chlorinated Hydrocarbon

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Environmental geophysics survey has the advantages of survey rapidly, high resolution result and less affected by the surface topography and objects. It is suitable to either a wide range of general survey or a small-scale precise survey. Recently, non-invaded technologies such as geophysical technology have been introduced to provide the plane and space information of pollution in subsurface by integrating few bore-hole dates. The most common used geophysical technologies are ground-penetrating radar method (GPR) and electrical resistivity tomography (ERT). The electrical resistivity tomography (ERT) is one of the most widely used geophysical methods in geological, hydro-geological, and geo-environmental investigations.This study would first discuss how DNAPL and its soluble-phase components invade into the low permeable layer based on the field observation. Then, the importance of geophysical technology is introduced with comparing to the limitations of bore-hole investigation. Last, the case studies on using geophysical technologies including geophysical well logging are introduced to snapshot the complex profile of DNAPL distribution for improving future application.

キーワード: Geophysical survey, Electrical Resistivity Tomography, Borehole Radar
Keywords: Geophysical survey, Electrical Resistivity Tomography, Borehole Radar