R003-01
D 会場 ：11/5　 PM1 （13:45-15:30）
13:45～14:00

#臼井　嘉哉 [1)]
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New remote reference method using multivariate regression S-estimator

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In magnetotelluric data processing, the remote reference method is commonly used. In the standard remote reference method, the auto- and cross-powers of the local electromagnetic field are replaced with the cross powers between the local and remote electromagnetic fields. It is sometimes difficult to apply a robust approach, which is used for reducing the influences of outliers and leverage points, to the standard remote reference method because it cannot be represented as a simple input/output model. Two generalized remote reference methods have been proposed to overcome the disadvantage. One generalized remote reference method, the two-stage bounded influence remote reference method, solves multiple-inputs-multiple-outputs systems in two stages. Although the other method solves a multiple-inputs-multiple-outputs system in one stage, in the second method, the dependent variables contain all channels of local stations, and a multivariate regression solves the system. However, those generalized remote reference methods have disadvantages: the first one can lead to bias when the weights of the first stage and the second stage are different; the second approach is not robust to the leverage points because M-estimator is used. Therefore, the author proposes a new remote reference method using the multivariate regression S-estimator. This estimator seeks the response functions which minimize the scale of the Mahalanobis' Distance of residuals. The newly developed method can avoid the disadvantages of the previous generalized remote reference method and is generally applicable to magnetotelluric data processing.

R003-02
D 会場 ：11/5　 PM1 （13:45-15:30）
14:00〜14:15

#南　拓人 [1)]
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Effects of the difference in sensitivity between ACTIVE and MT on the joint inversion in volcanic regions

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Resistivity structures are important for understanding the internal systems of volcanic edifices. While MT measurements are in common use to investigate the resistivity structure of volcanos (e.g. Kanda et al. 2019), controlled-source electromagnetic sounding methods are also useful in many points. ACTIVE (Utada et al. 2007) is an electromagnetic volcano monitoring system using the TEM (Transient Electro-Magnetic method) technique. ACTIVE consists of transmitters that transmit the electric currents of a square waveform through two earthing electrodes and an array of induction coil receivers for measurement of the vertical component of the induced magnetic field. The TEM measurement with controlled-source has an advantage in high S/N ratio and independence from the galvanic distortion and static shift in MT measurements.

I am currently developing a joint inversion code for ACTIVE and MT data, where the ACTIVE and MT data contribute in different ways to optimal models with their different sensitivities. I calculated and compared the sensitivities of MT and ACTIVE measurements at a single frequency of 99 Hz with a single receiver site using the method of Schwalenberg et al. (2002). The sensitivity of MT for a single site distributes as an hemisphere centered by the receiver location. On the other hand, the sensitivity of ACTIVE distributes beneath both the transmitter and the receiver and complicated compared to that of MT. The difference in sensitivity potentially not only enhances the spatial resolution of the inferred resistivity structure but also resolves some anisotropy of the subsurface resistivity. In the presentation, I will report the sensitivity analysis of MT and ACTIVE measurements and discuss how the difference in sensitivity could enhance the model resolution and accuracy in the joint inversion using both MT and ACTIVE data

R003-03
D 会場 ：11/5　 PM1 （13:45-15:30）
14:15〜14:30

海底地形効果を考慮した 3 次元比抵抗構造解析手法の開発

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Development of 3D resistivity structure analysis method considering the effects of seafloor topography.

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The purpose of this study is to advance the understanding of the magma supply system leading to giant caldera eruptions. The Kikai caldera volcano, the subject of our research, is located in the southern part of Kagoshima Prefecture and has repeated giant caldera eruption. The existence of lava dome inside the caldera suggests that the magma was supplied to this volcano even after the latest giant caldera eruptions at 7.3Ma (Tatsumi et al., 2018). We explore the magma supply system by estimating the resistivity structure beneath the seafloor of Kikai caldera volcano. For this reason, we are acquiring new seafloor MT data by installing and recovering Ocean Bottom ElectroMagnetometer (OBEM), and developing a method to analysis obtained data. In locations with highly variable seafloor topography, such as around Kikai caldera sea area, an analytical method that can accurately account for topographic effects is necessary because the electromagnetic field distortion caused by topographic undulations affects the estimated subsurface structure. Baba and Seama (2002) proposed the FS technique as an easy way to represent seafloor topography with a small computational grid. In this method, they set two horizontal layers of equal thickness (hereafter referred to as FS-seawater layer and FS-crustal layer) in the depth range where the seafloor surface exists, and represent the undulations of the seafloor topography by varying their resistivity values. Araki et al. (2021) applied the FS technique into ModEM (Egbert and Kelbert, 2012; Kelbert et al., 2014), which is the three-dimensional inversion code for subsurface resistivity structures. In an ideal tanh-functional bathymetry model, they confirmed that the inclusion of a thin boundary layer between the FS-seawater layer and the FS-crustal layer produces results similar to those obtained when topographic changes are directly represented by a large number of small-sized grids.

Aiming to estimate the resistivity structure by effective analysis of the observed data in the Kikai caldera sea area, we 1) have further improved the ModEM method by applying the FS technique, 2) show the effectiveness of this method in inversion, and 3) investigate the sensitivity of the method to the expected subsurface structures such as magma chambers. 1) For Further improvement of the analysis method, we solved the problem in the conventional method where the calculated MT impedance at short periods deviates from the predicted value. Since it became clear that this problem was caused by the conversion of the resistivity values of the FS-crustal layer, we developed a method to convert only the resistivity values of the FS-seawater layer and named this method ”ModEM+FS”. Forward modeling with ModEM+FS showed that more than 20% decrease in apparent resistivity from the predicted value at a period of 10s, was reduced to about 2% on a cos-functional mountain bathymetry model when the FS layer was set so that the vertical length of the crustal grids at the summit was transformed by half. Note that the results obtained using ModEM with a finer discretization of the model were closer to one obtained with ModEM+FS. This indicates that ModEM+FS can accurately represent topographic effects without fine discretization of the grid. 2) Inversion is performed using the pseudo-data. We get pseudo-data (pseudo-data including topographic effects) by calculating the forward result by ModEM+FS in a model with resistive and conductive bodies placed underground and cos-functional mountain bathymetry, and adding noise. Inversion results are confirmed by the degree of recovery of the anomalous body. In addition, we compare the inversion results of the pseudo-data without topographic effects assuming a flat bathymetry, and confirm that the developed ModEM+FS inversion can take proper account of the topographic effects in the data. Furthermore, we compare the inversion results of the pseudo-data including topographic effects assuming flat bathymetry, and confirm the importance of properly accounting for the undulations of the seafloor topography in the model when inverting data with topographic effects. 3) In the sensitivity test, the resistive and conductive bodies are placed in the subsurface of a model that represents the seafloor topography around the Kikai caldera, and inversion is performed using ModEM+FS. The calculation position is adjusted to the observation points in the Kikai caldera sea area. The sensitivity to magma chamber is checked by changing the size of the resistive and conductive bodies.

本研究の目的は、巨大カルデラ噴火を導いたマグマ供給系の理解を進めることである。研究対象とした鬼界カルデラ火山では、鹿児島県の南方に位置し、巨大カルデラ噴火が繰り返されてきた。また、現在、カルデラ内部で溶岩ドームの存在が確認されており、直近の巨大カルデラ噴火 (7.3ka) 以降もマグマが供給されている可能性が指摘されている (Tatsumi et al., 2018)。我々は、鬼界カルデラ火山海底下の比抵抗構造を推定することによりマグマ供給過程を調べている。このために、海底電位差磁力計 (OBEM) の設置、回収による海底 MT データの拡充を進めるとともに、得られたデータの解析手法の開発も進めている。鬼界カルデラ周辺のような海底地形の変化が激しい場所では、地形の起伏によって生じる電磁場の歪みが推定される地下構造に影響を与えるため、地形効果を精度良く考慮できる解析手法が必要である。少ない計算グリッドで海底地形を容易に表現する方法として、FS 法 (Baba and Seama, 2002) がある。この手法では、海底

面が存在する深さ範囲を厚さの等しい 2 つの水平層 (以下、FS 海水層、FS 地殻層と呼ぶ) に置き換え、それらの比抵抗値を変化させることで海底地形の起伏を表現する。荒木ほか (2021) は、地下比抵抗構造の三次元インバージョンコード ModEM(Egbert and Kelbert, 2012; Kelbert et al., 2014) に FS 法を導入した。理想的な tanh 関数型の海底地形モデルにおいて、FS 海水層と FS 地殻層の間に薄い境界層を入れることで、地形変化をサイズの小さな多数のグリッドで直接表現した場合と近い結果が得られることが確認された。

本研究では、鬼界カルデラ海域における観測データの効果的な解析による比抵抗構造の推定を目指して、１）FS 法を導入した ModEM 手法の更なる改良を行い、２）同手法によるインバージョンでの有効性を示し、３）期待されるマグマだまり等の地下構造に対する感度を調べる。１）の解析手法の更なる改良では、従来手法における、短周期での MT インピーダンスの計算結果が予測値から離れる問題を解決した。この問題は、FS 地殻層の比抵抗値の変換によって生じることが明らかになったため、FS 海水層の比抵抗値のみを変換する手法を開発し、『ModEM+FS』と名付けた。cos 関数による山型海底地形モデルに対して ModEM+FS でフォワードモデリングを行ったところ、山頂における地殻側のグリッド鉛直長さが半分に変換されるように FS 層を設定すると、周期 10 秒で生じていた見掛け比抵抗の予測値からの 20% 以上の低下幅が、2% 程度に減少した。なお、より細かく離散化したモデルで ModEM を使用した結果ほど、ModEM+FS による結果に近づいた。このことは、ModEM+FS を用いると、グリッドの細かい離散化を行わずとも、地形効果を精度良く表現できていることを示している。２）のインバージョンでは、cos 関数による山型地形において、地下に抵抗体・導電体を置いたモデルの ModEM+FS によるフォワード結果にノイズを加えた擬似データ（地形効果を含む擬似データ）を用い、ModEM+FS でインバージョンを行う。インバージョン結果は、異常体の回復度合いにより確認する。また、地形効果を含まない擬似データを、平坦な地形を想定して行うインバージョンの結果と比較し、開発した ModEM+FS インバージョンがデータの地形効果を適切に考慮できていることを確認する。さらに、地形効果を含む擬似データを、平坦な地形を想定してインバージョンを行う結果と比較し、地形効果を含むデータのインバージョンにおいて、海底地形の起伏をモデル中で適切に考慮する重要さを確認する。３）の感度調査では、鬼界カルデラ海域周辺の海底地形を表現したモデルの地下に抵抗体・導電体を置いて、ModEM+FS でインバージョンを行う。計算位置は鬼界カルデラ海域における観測条件に合わせる。抵抗体・導電体のサイズを変化させて、マグマだまりに対する感度を確認する。

R003-04
D 会場 ：11/5 PM1 （13:45-15:30）
14:30〜14:45

ラウ海盆における潮汐起因磁場の 3D 順計算

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3D forward calculation of tidally Induced magnetic field in the Lau Basin

#Tokuma Nakaya[1)]
([1]Kobe University

Electrically conductive seawater moving in the geomagnetic main field causes electric currents in the ocean. The ocean tides, which cause periodic seawater motion, generate periodic electromagnetic field variation. It is expected that the electromagnetic field can be used to estimate the resistivity structure beneath the seafloor.

Grayver et al. (2016) has already performed inversion of satellite tidally-induced magnetic data observed at the satellite altitude. We aim to use tidally-induced magnetic fields observed at the seafloor to infer the resistivity structure beneath the seafloor. By using observations at the seafloor, it is possible to use toroidal magnetic fields that are not observed at satellite altitudes.

In our previous study (Nakaya et al. 2022, JpGU), we developed a forward calculation code to calculate the magnetic field due to the electric current excited by the tidal seawater velocity field coupled with the earth's main magnetic field in the conductive ocean layer. The seawater flow field was obtained from the TPXO model (Egbert and Erofeeva 2002) and the earth's main magnetic field from IGRF-13 (Alken et al. 2021).

In this study, we improved the developed forward calculation to include a subducted slab in the numerical domain. A 3D slab domain mesh was created based on the slab model of Hayes et al (2018) and incorporated into the forward calculations. We tested the sensitivity of the tidally-induced magnetic variation at the Lau basin to resistivity of the subducting slab and found no sensitivity to resistivity changes above the slab resistivity of 5000 Ω m, but when the slab resistivity was changed from 5000 Ω m to 2000 Ω m, there is a maximum of 5% change in amplitude of the north-south component of the magnetic field.

This presentation will report the results of the forward calculations including the sensitivity test, and the progress toward implementation of the inversion of the tidally-induced magnetic data observed at the seafloor of the Lau basin, which is currently underway.

導電性流体である海水は地球主磁場中を移動することで励起電流を発生させる。周期的に海水が運動する海洋潮汐は周期的な電磁場を作る。その電磁場は海底下の比抵抗構造の影響をうけるため、海底下比抵抗構造推定への利用が期待されている。衛星高度での観測磁場を用いたインバージョンは Grayver et al. (2016) ですでに実施されている。我々は、海底で観測される潮汐起因の磁場を用いて海底下の比抵抗構造を推定することを目指している。海底での観測値を用いることで衛星高度では観測されないトロイダル磁場を利用することが可能である。

我々は、これまでに、潮汐起因磁場を地下比抵抗推定に利用することを目標とし三次元の潮汐起因磁場の順計算コードを開発した (中家他 2022, JpGU)。計算手法には、三次元有限要素法を用いており、海水電気伝導度、地球主磁場、並びに、海水速度場を用いて表現される海水中励起電流に起因する磁場変動を計算するものである。計算に必要な海水速度場には TPXO model (Egbert and Erofeeva 2002) を、地球主磁場には IGRF-13 (Alken et al. 2021) を用いた。

本研究では、中家他 (2022,JpGU) で開発した順計算コードに、沈み込むスラブのメッシュを加える改良を行った。スラブモデル Hayes et al (2018) をもとにして 3D スラブのメッシュを作成し、順計算に組み込んだ。開発したコードを用いて、ラウ海盆における潮汐起因磁場の沈み込みスラブの比抵抗に対する感度テストを行った結果、スラブ比抵抗が 5000 Ω m 以上の場合にはその変化にほとんど感度がないが、スラブ比抵抗を 5000 Ω m とした場合と 2000 Ω m とした場合では、磁場の南北成分の振幅に最大 5 %の変化があった。

本発表では、感度テストを含む順計算の結果、並びに、現在進めている海洋潮汐起因海底磁場変動データを用いた比抵抗インバージョン実施に向けての進捗について報告する

R003-05
D 会場 ：11/5　PM1 （13:45-15:30）
14:45〜15:00

2016 年鳥取県中部の地震の余震と電磁場データに現れる特徴的な波形の関係

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Relationship between aftershocks of the 2016 Central Tottori earthquake and characteristic waveforms appearing in EM field data

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Characteristic variations in the electromagnetic field have been reported to be observed before and after earthquakes. Many of these variations occur simultaneously with ground motion (e.g., Honkura et al., 2002; Ujihara et al., 2004). Variations in the electromagnetic field observed for hours to days including the origin time of an earthquake have also frequently been discussed (e.g., Oike and Ogawa, 1986; Izutsu, 2007). On the other hand, there are only a few studies on a relationship with earthquakes regarding variations in the electromagnetic field for seconds to tens of seconds including the origin time (e.g., Iyemori et al., 1996; Okubo et al., 2011; Fujinawa and Noda, 2016).

In this study, we focus on the electromagnetic field data for tens of seconds including the origin time of aftershocks of the 2016 Central Tottori Prefecture earthquake (October 21, 2016; M_j6.6) to clarify the relationship between occurrence of earthquakes and electromagnetic field variations. The electromagnetic field data were obtained by MT surveys conducted at two sites during the period from the day after the main shock to November 9, 2016. A continuous record with 15 Hz sampling is used for the study. Two components of the electric field were measured at both sites, whereas three components of the magnetic field were measured only at one site.

Examination of the time-series of the electromagnetic field variations revealed characteristic waveforms for seconds to tens of seconds before and after origin time. The waveforms can be classified into several types according to their shapes: some of which were observed even when no earthquake occurred, whereas others were observed only when earthquakes occurred. Variations in the electromagnetic field with the former waveforms are assumed to be caused by artificial noises or natural phenomena other than earthquakes including lightning, while variations with the latter waveforms are assumed to be related to earthquakes.

In this presentation, we will introduce characteristic waveforms that appear in the electromagnetic field data before and after earthquakes and discuss whether these waveforms are related to the occurrence of earthquakes or not.

地震の前後に特徴的な電磁場変動が観測された事例がこれまでに報告されている。その多くは地動と同時に生じる変動であり（例えば、Honkura et al., 2002; Ujihara et al., 2004)、また、発震時刻の前後数時間〜数日間に見られるものについても議論されている（例えば、Oike and Ogawa, 1986; Izutsu, 2007)。一方、発震時刻の前後数秒〜数十秒間の電磁場変動について地震との関係を示した研究は Iyemori et al. (1996）や Okubo et al. (2011)、Fujinawa and Noda (2016) などが挙げられるが、その例は少ない。

本研究では、「2016 年鳥取県中部の地震（2016 年 10 月 21 日、M_j6.6)」の余震を対象として、発震時刻の前後数十秒間に観測された電磁場データに注目し、地震の発生と電磁場変動の関係を明らかにすることを試みる。電磁場データは、本震の翌日から 11 月 9 日までの期間に 2 地点において実施された MT 探査によって取得されたもので、そのうち連続記録である 15Hz サンプリングのデータを用いる。電場 2 成分は両地点で、磁場 3 成分は 1 地点のみで測定されている。

電磁場変動の時系列記録を調べたところ、発震時刻の前後数秒〜数十秒間に特徴的な波形が確認できた。波形は形状により数種類に分類でき、地震が起きていない時にも確認できるものと、地震が発生した時にのみ確認できるものがあった。前者の波形は人工ノイズや、落雷のような地震以外の自然現象によるものと推測されるが、後者の波形は地震との関連が示唆される。

今回の発表では、地震発生前後の電磁場データに現れる特徴的な波形を紹介し、それらの波形が地震発生と関係しているか否かを議論する。

R003-06
D 会場 ：11/5　 PM1 （13:45-15:30）
15:00〜15:25

#赤松　祐哉 [1), 片山　郁夫 [1)]
([1] 広大　先進理工

Interpretation of electrical resistivity structure of oceanic crust based on analysis of seismic velocity structure

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Water transported through cracks in oceanic crust play key roles in various subsurface processes, including seismic activity, heat and chemical exchanges, and microbial activity. Fluid-filled cracks strongly affect geophysical properties, such as seismic velocity and electrical resistivity; therefore, a number of seismological and electrical surveys have been conducted at various locations in the oceanic lithosphere. In order to quantitatively interpret such geophysical data and understand the subsurface fluid behavior, laboratory measurements on rock's physical properties are essential. In this study, we conducted laboratory measurements on the electrical resistivity and elastic wave velocity of oceanic crustal rocks collected from drilled cores of the Oman ophiolite, in which tectonic fragments of ancient oceanic plate are preserved on land. The measurements were performed under dry and brine-water-saturated (wet) conditions using discrete cubic samples that were taken from the drilled cores.

The experimental results show that electrical resistivity and elastic wave velocity under wet conditions are clearly correlated with porosity, suggesting that these properties are closely related to pore structure. Application of effective medium theory, which predicts effective elastic properties containing penny-shaped cavities, shows that the variations in elastic wave velocity can be interpreted mainly by two parameters characterizing pore structure: crack density and crack aspect ratio. Electrical resistivity changes markedly at low crack densities, possibly reflecting percolation of fluids through the crack network. Applying a crack fluid flow model based on statistics and percolation theory proposed by Gueguen and Dienes (1989), variation in the measured resistivity is related to crack porosity and connectivity, which can be estimated from the crack density and aspect ratio. To understand effects of in situ conditions in oceanic crust, we applied the cross-property relationship established by our laboratory measurements to geophysical properties obtained by logging measurements at IODP Hole 1256D. As a result, resistivity structure predicted from sonic velocities is generally consistent with the observation, suggesting that the physical properties of oceanic crust can be interpreted using the same model at both laboratory and in situ scales.

R003-07
D 会場 ：11/5　PM2 （15:45-18:15）
15:45〜16:00

奥能登群発地震震源域の 3 次元比抵抗構造

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[1] 京大防災研,[2] 金沢大,[3] 兵庫県立大,[4] 京大,[5] 北大

Three-dimensional Electrical Resistivity Structure around Earthquake Swarm Region in the Northeastern Noto Peninsula

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In the northeast of the Noto Peninsula, swarm-like seismic activity has been observed since around 2018, and the activity has been active since 2021 and has continued to the present. This seismic activity forms four clusters. Synchronized with this activity, crustal deformation has also been detected by GNSS observation. We planned and conducted a wideband Magnetotelluric (MT) survey to elucidate the structural characteristics of this activity and whether there are structural differences from the 2007 Noto Hanto Earthquake that occurred in the northwestern Noto Peninsula in March 2007. During November-December 2021 and March-April 2022, MT data were acquired at 32 sites in total, and MT responses were estimated by remote-referencing within the survey area. In most of the sites, fair sounding curves were obtained in the band range of several hundred Hz to several thousand seconds. A three-dimensional inversion analysis for the obtained MT responses revealed the existence of a continuous low-resistivity region from the southern cluster, where seismic activity started, to the northern cluster, which is currently the most active.

In this presentation, we discuss the relationship between the obtained resistivity structure and seismic activity and crustal deformation sources, and compare it with the structure of the 2007 Noto Hanto Earthquake.

能登半島北東では、2018 年ごろから群発地震活動が見られ、2021 年より範囲を広げつつ活動が活発化し現在まで継続している。この地震活動は、4 つのクラスタを形成している。この活動に同期して、GNSS による地殻変動も検出されている。そこで我々は、この群発活動が構造的にどのような場所で発生しているのか、また、2007 年 3 月に能登半島北西部で発生した能登半島地震との構造的違いがあるか否かを解明するために、地下比抵抗構造調査を計画・実施した。2021 年 11 月〜12 月および 2022 年 3 月〜4 月にかけて、計 32 か所で広帯域の電磁場データを取得し、調査域内の相互参照により探査曲線の推定を行った。一部の観測点を除き、数 100Hz〜数 1000 秒の広帯域で比較的良好な電磁応答が求まった。得られた MT 応答について、3 次元逆解析を行った結果、地震活動の開始した南側のクラスタから現在最も活動が活発な北側のクラスタにかけて連続する低比抵抗領域が存在することが明らかになった。

本発表では、得られた比抵抗構造と地震活動・地殻変動源との関連性を議論するとともに、2007 年能登半島地震の構造と比較を行う。

R003-08
D 会場 ：11/5　 PM2 （15:45-18:15）
16:00〜16:15

#相澤　広記 [1), 井ノ又　伍 [1), 北村　圭吾 [2), 澤山　和貴 [3), 大久保　歩夢 [4,5), 安仁屋　智 [4,5), 松島　健 [1), 稲垣　陽大 [6), 齋藤　博樹 [6), 西島　潤 [2)
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Low-resistivity zone between Kuju Iwo-yama volcano and Otake-Hatchobaru geothermal power plant

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The Kuju volcano group (Kuju Volcanoes), which is located in north of the Kyushu Island, hosts numerous geothermal zones. The delta13C and 3He/4He ratios of geothermal zones indicate that the magmatic fluid contributes to the volcanic and geothermal activities. Indeed, the phreatic eruptions, which occurred at Iwo-yama volcano on December 1995, contained significant amounts of vesiculated glass shards, suggesting a magmatic contribution (Nakada et al. 1996; Hatae et al. 1997). Otake − Hatchobaru power plant (120MW), which is the largest geothermal power plant in Japan, is located 4.5 km WNW of the Iwo-yama volcano. The recent magnetotelluric surveys (Aizawa et al. 2022) have imaged low-resistivity zone between Iwo-yama and Otake − Hatchobaru power plant deeper than 1 km below sea level (bsl), where the high temperature >250 degree is estimated from drilling data (Kitamura et al. in revision). Considering its location, the low-resistivity zone is possibly related to the magmatic fluid pathways for both of the Iwo-yama and the geothermal power plant. However, in the previous study, MT sites were not densely deployed near the low-resistivity zone, and the shape of the low-resistivity zone was not strongly constrained. The purpose of this work is imaging of the 3-D shape of this low-resistivity zone for discussing the relationship between Iwo-yama and the Otake-Hatchobaru power plant. For this purpose, we have acquired broad-band MT and telluric data at 53 sites around the low-resistivity zone on November to December 2021. Preliminary analysis with new and old data confirmed the presence of the low-resistivity zone. One of the new suggestions is that the low-resistivity zone is separated to shallower (0 to 2 km bsl) and deeper (below 3 km bsl) region. The shallower low-resistivity zone is elongated NW-SE direction, which is comparable to the fault strike near the Hatchobaru-Ohtake power plant. Along the southwestern edge of the shallower low-resistivity zone, two NW-SE trending faults are located. The deeper low-resistivity zone is located approximately 1 km northeastward relative to the shallower low-resistivity zone. Seismic activity is low in the deeper low-resistivity zone. In this work, we will show the 3-D resistivity structure and investigate its significance for volcanic activity of Iwo-yama and the geothermal resources of the Ohtake-Hatchobaru power plant.

References
Aizawa et al. (2022), Magmatic fluid pathways in the upper crust: insights from dense magnetotelluric observations around the Kuju Volcanoes, Japan, GJI, 228, 755-772.

Kitamura et al. (Geothermics in revision), Potential evaluation of supercritical geothermal systems in the Kuju region, central Kyushu, Japan.

Acknowledgement
MT site selection was supported by Yuto Yamamoto. MT data acquisition in 2021 was supported by the students of Kyushu University (Hosuke Ikeda, Shunsuke Zaima, Tsukasa Higuchi, Taiki Kono, Hikaru Sakamoto, Issei Hirata, Hiromichi Shigematsu, Ayuka Jodoi, Keita Matsunaga). This work is supported by New Energy and Industrial Technology Development Organization (NEDO) (Potential survey and estimation of power generation of supercritical geothermal resources in East Japan and Kyushu, Japan) and by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), under its Earthquake and Volcano Hazards Observation and Research Program.

R003-09
D 会場 ：11/5　 PM2 （15:45-18:15）
16:15～16:30

MT 法探査による雌阿寒岳の 3 次元比抵抗構造とその解釈

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Modeling and interpretation of the three-dimensional resistivity structure of Meakandake Volcano inferred from MT surveys

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We have conducted broadband magnetotelluric (BBMT) surveys around Meakandake Volcano in Akan Caldera, eastern Hokkaido, since 2018. The previous modeling by Inoue et al. (2022) suggested a tilted low resistivity column from 0.5 km BSL (below sea level) to the deep west below Mt. Meakandake. They also suggested another low resistivity anomaly on the north side of Mt. Fuppushidake, the area bordering Lake Akan from the west. However, the size and shape of the latter anomaly were uncertain because it was outside the measurement area. Furthermore, the relationship between the shallow resistivity structure and volcanic earthquakes at Mt. Meakandake remained controversial because our previous model did not have sufficient resolution for the shallow part of the summit area.

To address these issues, we updated our modeling by including additional ten BBMT data that we acquired from July to August 2021 on Lake Akan's north to northwest sides, as well as some AMT data by Takahashi et al. (2018) obtained in 2013-14 at sites on the middle to the summit of Mt. Meakandake. We used ADU07e (Metronix Geophysics Ltd.) and Elog-1k (NT System Design Ltd.) for the additional BBMT. Thus, we acquired the time series data of five components (2E+3H) at seven sites and only 2E at three sites. Induction vectors and phase tensors calculated from the data indicated that the electromagnetic strike in the vicinity of Mt. Meakandake was in the SE-NW direction. In contrast, the strike was N-S on the north side of Mt. Fuppushidake. In addition, we observed out-of-quadrant phases in the long period bands of the Zyx component at the sites on the west to the northwestern foot of Mt. Meakandake.

We inverted the impedance and tippers at 60 sites using ModEM (Egbert and Kelbert, 2012; Kelbert et al., 2014) to estimate the 3D resistivity structure. A dyke-like low resistivity anomaly C1 (1-10 Ω m) was imaged below Mt. Meakandake. It was roofed approximately at sea level and slightly offset to the north as compared to the corresponding anomaly in the previous model, dipping down toward the northwest to west direction. The sensitivity test of C1 suggested that it extends at least to a depth of 20 km. The northwestward tilting of C1, which electrically connects the deep and shallow parts, may have caused the out-of-quadrant phases on the west to the northwestern foot of the volcano. However, the mechanism should be investigated further in detail.

On the other hand, another low resistivity anomaly, C2 (1-10 Ω m), was imaged again on the north side of Mt. Fuppushidake, the area bordering Lake Akan from the west. The updated model has revealed that C2 has a horizontal diameter of approximately 3 km and vertically occupies a depth from 0 to 3 km BSL. According to the unified earthquake catalog of the Japan Meteorological Agency, C2 itself corresponds to an aseismic zone. Meanwhile, a tectonic earthquake cluster is recognized beneath Lake Akan's northwestern side adjacent to C2. The seismicity if the cluster well correlated in time with that of the shallow volcanic earthquakes at Mt. Meakandake (Japan Meteorological Agency, 2018). In addition, C2 seems to connect to C1 through a moderately conductive region (c.a. 30 Ω m) in a deeper part. Therefore, we suspect that C2 represents a volcanic fluid reservoir with a common source as C1.

Owing to the improved resolution at a shallow part by adding the AMT data, the updated model showed a 100m-thick conductive layer (c.a. 1 Ω m) beneath the Meakandake's summit area. The conductive layer seems to be separated from C1 by the region with an intermediate resistivity (50-100 Ω m). The hypocenters of volcanic earthquakes, which occur quasi-regularly during inter-eruptive periods, are distributed in two columns within this intermediate region. One of these clusters penetrates the conductive layer toward the Ponmachineshiri crater. Furthermore, the volcanic earthquake swarm and the thermal demagnetization that preceded the 2008 phreatic eruption occurred at the bottom of the conductive layer. These facts suggest that the layer is closely related to shallow volcanic activity of Mt. Meakandake, including recent phreatic eruptions in Mt. Meakandake.

Acknowledgments: This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, under its The Second Earthquake and Volcano Hazards Observation and Research Program (Earthquake and Volcano Hazard Reduction Research). The AMT data at Mt. Meakandake used for the 3D resistivity inversion were provided by the National Institute of Advanced Industrial Science and Technology (AIST) and the Japan Meteorological Agency (JMA).

2018 年以降，我々は北海道東部の阿寒カルデラ内に位置する雌阿寒岳周辺で広帯域 Magnetotelluric（MT）法探査

を行ってきた．これまでの構造解析結果から，雌阿寒岳の 0.5 km BSL から深部西方に向かってやや傾いた柱状の低比抵抗異常の存在が示唆されていた（Inoue et al., 2022）．一方，フップシ岳の北側から阿寒湖西岸における領域にも低比抵抗異常が解析されていたが，観測点分布の外側の構造であるため，規模や形状は不確かであった．また，これまでの解析では雌阿寒岳火口域の浅部については解像度が十分でないため，比抵抗分布と火山性地震の関係についても議論の余地が残っていた．

これらの問題に対処するため，我々は，2021 年 7-8 月に阿寒カルデラの北側から北西側の 10 地点で新規に観測した広帯域 MT データと，Takahashi et al. (2018) が雌阿寒岳中腹〜山頂域で 2013-2014 年に観測した AMT データの一部も含めて構造解析をやり直した．測定には ADU07e（Metronix 社製）と Elog-1k（NT システムデザイン社製）を用い，それぞれ電場 2 成分と磁場 3 成分の時系列データ（7 地点）と電場 2 成分の時系列データ（3 地点）を取得した．得られたデータから算出されたインダクションベクトルやフェーズテンソルは，雌阿寒岳付近における電磁気的走向が南東-北西方向にある一方で，フップシ岳よりも北側の電磁気的走向は南北方向にあることを示した．また，雌阿寒岳西麓から北西麓の観測点では，Zyx 成分の長周期帯域に通常の範囲（-180 〜 -90 º）を外れる異常な位相が確認された．

比抵抗構造の推定には ModEM（Egbert and Kelbert, 2012; Kelbert et al., 2014）を使用し，合計 60 地点のインピーダンスとティッパーを入力データとして与えた．3 次元インバージョン解析の結果，雌阿寒岳付近には，従来の解析結果よりもやや北側にずれた位置の 0.5 km BSL から北西方向に向かって深部に伸びるダイク状の低比抵抗異常 C1（約 1-10 Ω m）が解析された． C1 の感度テストを行なったところ，C1 の下端は深さ約 20 km まで達していることが示された．また，C1 が北西方向に傾き下がり深部と浅部を電気的につないでいることが，西麓から北西麓に異常な位相を生じさせている原因となっている可能性があるが，メカニズムの詳細は検討中である．

一方，フップシ岳の北側にも前のモデルと同じく低比抵抗異常 C2（約 1-10 Ω m）が推定された．今回のモデリングにより，C2 の比抵抗分布が制約され，C2 は水平方向に直径 3 km 程度の広がりをもち，深さ方向には約 0-3 km BSL に分布することが明らかになった．気象庁の一元化震源カタログによれば，C2 は非地震域であるが，C2 に隣接する阿寒湖からやや北西の領域には構造性地震のクラスタがある．このクラスタの地震活動は，雌阿寒岳の火山性地震数が増加した時期と対応するように活発化している（気象庁，2018）．また，C2 は約 30 Ω m のやや低比抵抗な領域を介して深部で C1 に接続するようにイメージングされている．これらのことから，C2 は C1 と供給源を同じくする火山性の高温流体の貯留槽である可能性がある．

また，AMT データの導入で浅部の解像度が上がったことにより，雌阿寒岳火口域の直下には，厚さ 100 m の低比抵抗層（約 1 Ω m）が推定された．この低比抵抗層は，やや高比抵抗（約 50-100 Ω m）な領域を挟んで C1 からは明瞭に分離しているように見える．静穏期にも準定常的に起こっている火山性地震の震源は，主にこのやや高比抵抗な領域内に 2 本の柱状に分布しており，そのうちポンマチネシリ火口に向かうクラスタは低比抵抗層を貫いている．また，2008 年の水蒸気噴火に先行した火山性地震や熱消磁はこの低比抵抗層の下端で発生していた．これらのことから，この低比抵抗層は，雌阿寒岳の近年の水蒸気噴火を含む浅部の火山活動と深く関連する構造であることが伺える．

謝辞：本研究は文部科学省による「災害の軽減に貢献するための地震火山観測研究計画（第 2 次）」の支援を受けた．3D 比抵抗インバージョンに使用した雌阿寒岳の AMT データ（Takahashi et al., 2018）は，データ所有者である産総研と気象庁から提供を受けた．

R003-10
D 会場 ：11/5　 PM2 （15:45-18:15）
16:30〜16:45

東北地方中央部の広帯域 MT データコンパイルとインバージョン

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Broadband MT data compilation and inversion for the central Tohoku region

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Since 1990, many broadband MT observations in the central Tohoku region have elucidated the 2-D or 3-D structure in volcanic and inland seismogenic areas, and revealed the distribution of deep crustal fluids (e.g., Ogawa et al, 2014; Ichihara et al, 2014). However, previous analyses have been limited to a region with an extent of about 20 km x 20 km due to the limitation of computational resources. On the other hand, long-period MT observations on a 20-km grid (Ichiki et. al., 2015) have revealed 3D structures of melts and fluids due to subduction of the Pacific plate, but detailed links to crustal structures shallower than 30 km in depth are not clear.

In this study, we aim to elucidate the detailed regional crustal structure and mantle structure in three dimensions using broadband MT data from 590 stations collected over the past 30 years in the central Tohoku region.

We will begin by examining the data from the 590 stations. To aid in understanding the physics of impedance, the electric field distribution generated by hypothetical northward and eastward source electric field events in the ionosphere is calculated and mapped from the impedance. Together with mapping the induction vectors, we confirmed that the sedimentary layers along the Kitakami River and south of the Naruko caldera show strong channeling at low frequencies. Furthermore, the distribution of β values exceeding 5 degrees based on phase tensor analysis was found to be more widespread for longer periods and more three-dimensional for deeper areas. The distribution of phase tensors with periods from 4 to 40 seconds suggested the presence of conductors in the south-southeast to north-northeast direction in the northern part of Miyagi Prefecture.

Based on the above, we decided to use data from the central part of the study area and perform inversion model calculations so that channeling, especially at low frequencies, can be realized numerically. The data used were impedances and tippers for 8 periods at 237 stations distributed at 6 km intervals. We used the inversion code WSINV3DMT with error floor 5% for the impedances and 15% for tippers. The final model had rms of 2.194. The model showed the following features. At depths between 2 km and 15 km, isolated vertical low-resistivity structures are analyzed beneath the Quaternary volcanoes such as Naruko, Kurikoma, Onikobe, and Takamatsu-dake. At a depth of 20 km, these low resistivity structures are found to be laterally connected. Furthermore, at a depth of 40 km, a narrow zone of low resistivity was analyzed along the volcanic front. The distribution of these low resistivity structures correlates well with the spatial distribution of seismic velocity structure (Okada et al., 2014) and the coseismic crustal deformation of the 2011 M9 off the Pacific coast of Tohoku earthquake estimated by InSAR (Takada and Fukushima, 2013).

東北地方中央部では 1990 年以降、多くの広帯域 MT 観測が行われ、火山地域や内陸地震発生域の地殻深部流体の分布が明らかにされてきた (例えば、Ogawa et al, 2014; Ichihara et al., 2014)。しかしながらこれまでの解析では、計算機資源の制約から 20km × 20km 程度の地域に限定された 3 次元構造解析が行われてきた。一方、20km 格子の長周期 MT 観測 (Ichiki et. al., 2015) は、太平洋プレートの沈み込みによるメルトや流体の 3 次元構造を明らかにしたが、深度 30km より浅い地殻構造との詳細なリンクは明らかではない。

本研究では、東北地方の中央部にて過去 30 年間に収集された 590 地点の広帯域 MT データを利用し、詳細な広域地殻構造と、マントル構造を３次元的に解明することを目的とする。

まず、590 観測点のデータを吟味するところから開始する。インピーダンスの物理的な理解を助けるために、電離層に北方向および東方向のソース電場の仮想イベントを仮定してそれによって発生する電場分布をインピーダンスから計算してマップ化した。またインダクションベクトルをマッピングすることによって、北上川に沿った堆積層と鳴子カルデラ南方の堆積層が、低周波数で強いチャネリングを示すことを確認した。さらに、phase tensor 解析によるβ値が５度をこえる分布が長周期ほど広がっており、深部ほど 3 次元性が高いことがわかった。また、周期 4〜40 秒の phase tensor の分布からは、宮城県北部の南南東から北北東方向にコンダクターの存在が示唆された。

以上を踏まえて、特に低周波数におけるチャネリングが数値計算で実現できるように、調査地域の中央部のデータを使用し、インバージョンモデル計算をすることとした。使用データは、およそ 6km 間隔で分布する 237 観測点における８周期 (0.4s~1,300s) のインピーダンスとティッパーである。解析には WSINV3DMT コードを用い、インピーダンスおよびティッパーのエラフロアーはそれぞれ 5%, 15% とし、rms は 2.194 の最終モデルを得た。モデルの特徴は以下の通りである。深度 2km から 15km では、鳴子火山、栗駒山、鬼首カルデラ、高松岳の下に鉛直状の孤立する低比抵抗構造が解析される。深度 20km では、これら低比抵抗が側方方向につながることがわかった。さらに、深度 40km では、火山フロントに沿った狭い領域に低比抵抗の帯が解析された。これら低比抵抗の分布は地震波速度構造 (Okada et al., 2014) や、InSAR によって推定された 2011 年の M9 東北地方太平洋沖地震のコサイスミック地殻変動 (Takada and Fukushima,

2013) と良い相関がある。

R003-11
D 会場 ：11/5　 PM2 （15:45-18:15）
16:45〜17:00

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Resistivity structure beneath Southern Tohoku imaged by joint inversion of magnetotelluric and geomagnetic transfer functions

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The southern part of Tohoku is a volcanically and seismically active region in the Northeast Japan subduction system. Active volcanoes and deep, low-frequency volcanic earthquakes are distributed on and off the volcanic front, implying a complex distribution of deep fluids beneath the area. To comprehend it, we study the electrical resistivity structure beneath the area using the magnetotelluric (MT) method because resistivity is sensitive to the composition and connectivity of fluids. MT stations were deployed on three across-arc profile lines, and we aim for a three-dimensional structure. However, because three-dimensional inversion demands much computational time, this presentation shows the first-order approximation of two-dimensional structures for the respective line. In addition to the standard MT transfer functions, such as the MT impedance and vertical magnetic field transfer functions, we also estimated the inter-station horizontal magnetic field transfer functions because it has been proven to aid resistivity structure modeling, especially in enhancing the resolution of conductive anomalies. The main feature of the result is a deep conductor found in the uppermost mantle, consistently detected beneath the three profile lines. A spatial correlation of the conductor with the hypocenters of deep, low-frequency earthquakes signals the existence of a deep fluid-rich area. However, unlike most studies in subduction zone arc that reveal a deep conductor under the volcanic front, the conductor here is closer to the back-arc side near a back-arc volcano (Mt. Numazawa), triggering some speculation about the deep fluid flow. For example, since volcanic activity in the southern Tohoku began with volcanoes in the volcanic front, such as Mt. Azuma and Mt. Adatara, and then later continued to Mt. Numazawa in the back-arc side over time, deep fluids under the volcanic front might have been spreading toward the back-arc. However, it is still a matter of discussion. Besides, some other compelling features of the resistivity structure will also be discussed in the presentation.

R003-12
D 会場 ：11/5　PM2 （15:45-18:15）
17:00〜17:15

#渡部　熙 [1), 上嶋　誠 [2), 山口　覚 [3), 臼井　嘉哉 [1), 村上　英記 [4), 小河　勉 [5), 大志万　直人 [6), 吉村　令慧 [6), 相澤　広記 [7), 塩﨑　一郎 [8), 笠谷　貴史 [9)
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On time-series analysis of Network-MT data measured in the Kii Peninsula, southwestern Japan

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The Kii Peninsula is a geoscientifically interesting region because of the existence of high temprature hot springs, the Kumano caldera, and the Deep Low-frequency Tremors (DLTs). Therefore, the subsurface structure of the Kii Peninsula has been investigated by various ways. Among them, electromagnetic method is useful for understanding the spatial distribution of temperature, water and melt beneath the surface. New Energy and Industrial Technology Development Organization (1994), Fuji-ta et al. (1997), Umeda et al. (2003) and Kinoshita et al. (2018) studied the subsurface resistivity structure of the Kii Peninsula with the aid of conventional MT method. Besides these EM studies, Yamaguchi et al. (2009) performed the Network-MT survey in the region almost covering whole Kii Peninsula to elucidate the regional and deep structure. The Network-MT method is superior to the conventional MT method in that it enables us to obtain voltage differences with high S/N ratio especially for the longer period and is relatively free from static effects owing to the long baseline. However, they analysed 2-D resistivity structure by using only a part of the data only on one survey line. Three dimensional analysis is very important to investigate the regional and deep structure because coast line distribution is not 2-D and, in addition, strike of the igneous intrusion is not always consistent with the subduction direction of the Philippine Sea Plate. Therefore, we aim to analyse all the avairable Network-MT data in the Kii Peninsula. This presentation will describe the results of the time-series analysis.

R003-P01
ポスター２：11/5　AM1/AM2 （9:00-12:30）

L1 ノルム正則に基づいた磁気インバージョンに対するベイズ的情報量基準のMCMC を用いた有効性の評価

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Effectiveness of the Bayesian information criterion for L1 norm regularized magnetic inversion based on MCMC integral.

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In the regularized geophysical inversion, the selection of the regularization parameter is an important factor in the model selection. While cross-validation, and the heuristic methods such as L-curve are used for the regularization parameter selection in the L1 norm regularized inversion, but one of the other promising methods is the Bayesian information criterion.

In the conventional Tikhonov regularization, ABIC is widely used for the evaluation of the regularization parameter(s). ABIC is used to choose a regularization parameter which maximize the marginal posterior distribution. The Tikhonov regularization assumes a conjugate normal distribution as a prior distribution for the likelihood function, and therefore the posterior distribution is also normal. In particular, the normal distribution can be expressed simply because the marginalization (integration) can be calculated analytically. The Tikhonov regularization assumes a conjugate normal distribution as a prior distribution for the likelihood function, and therefore the posterior distribution is also normal. In particular, ABIC can be expressed simply because the marginalization (integration) can be calculated analytically in this case. However, in the case of the L1 norm regularization, prior distribution is assumed as the Laplace distribution, and the marginal of the posterior distribution cannot be expressed explicitly. Alternatively, several information criteria have been proposed to evaluate the regularization parameter using an approximation of the marginal posterior distribution.

In our presentation, we discuss the usefulness of the Bayesian information criterions based on the marginal posterior distributions for the evaluation of regularization parameters in L1 norm regularized magnetic inversion. One of the considerations is to examine the extent to which these Bayesian information criteria are able to evaluate the marginal posterior distribution. To do so, we compute the marginal posterior distribution using Bayesian Lasso which is the Gibbs sampling based on a hierarchical representation of the posterior distribution.

正則化インバージョンにおいては、目的関数のペナルティ項の係数（正則化パラメータ、ダンピングファクター）をどのように選択するかがモデル選択の実態となる重要な要素となる。L1 正則では、こうした正則化パラメータ選択のために cross validation や、L-curve や L1-curve (Pareto frontier curve) などのヒューリスティックな方法などが用いられているが、この他の有力な方法の一つにベイズ的な情報量基準が挙げられる。特に後者については、比較的少ない計算量で、かつ複数の正則化パラメータの評価も可能といった利点がある。

従来の Tikhonov 正則では正則化パラメータの評価について ABIC が広く用いられており、これを用いて周辺事後分布を最大化する正則化パラメータを選択する。Tikhonov 正則では、正規分布である尤度関数に、事前分布として共役な正規分布を仮定しており、そのため事後分布も正規分布となる。ABIC はこれをモデルベクトルについて周辺化したもの（そしてもう一つのパラメータである残差の分散は最尤推定値で固定したもの）を正則化パラメータ評価に用いる。特に正規分布については周辺化（積分）が解析的に計算できるため、簡便な表現が可能になっている。しかし L1 正則では、事前分布としてラプラス分布を仮定する事となり、事後分布の周辺化は解析的に実行できない。代わりに、周辺化された事後分布を近似的に評価したものを用いてパラメータ評価を行う情報量基準がいくつか提案されている。

本講演では、L1 ノルム正則を用いた磁気インバージョンにおいて、これら周辺事後分布に基づいたベイズ情報量基準が正則化パラメータ評価に有用であるかを検討する。その検討の一つとして、これらのベイズ情報量基準が周辺事後分布をどの程度評価できているかを検討する。そのために、事後分布の階層的な表現に基づいたギブスサンプリングを用いて、周辺事後分布をモンテカルロ積分により近似計算したものとの比較を行う。その他に、バイアス補正項の検討やベイズ情報量基準を磁気インバージョンに適用するにあたっての注意点などについて検討する。

R003-P02
ポスター２：11/5　AM1/AM2 (9:00-12:30)

東北地方の虚部インダクションベクトルの因果律の検証と海底地形及び海岸線効果の影響について

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Quadrature phase induction vector in NE Japan: Consistency of causality, and contribution of coastline and oceanic effects

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Quadrature phase induction vector (QIV) observed on island is likely less affected by the induction of sea water, and directly indicate a resistivity characteristic in the earth. Assuming the nature, we hypothesized that there would be a conductor in the deep crust or uppermost mantle beneath north of Tsugaru Strait, NE Japan on the basis of the observed QIVs in the period range of 20 to 10000 s (Ichiki et al., 2021 SGEPSS Fall Meeting). On the process of elimination, we simulated QIVs of NE Japan using models composed of uniform-earth and sea water distribution. In this study, we show that QIVs of NE Japan calculated from models with realistic coastline and ocean bathymetry using three-dimensional finite element modeling with tetrahedral elements (Usui, 2015 GJI), and that the coastline and oceanic (bathymetric) effects cannot explain the observed QIVs. We also test quality of the observed QIVs using causality relation between in and quadrature phase geomagnetic transfer functions (Fischer and Schnegg, 1980 Geophys. J. Roy. astr. Soc.; Marchello et al., 2005 GJI).

In the calculation of causality relation, we used the formulation in terms of logarithmic period by Fischer and Schnegg (1980). Marchello et al. (2005) recommended the formulation of 0th order differentiation in terms of logarithmic angular frequency to diminish calculation error. We used both 0th and first-order differentiation formulae, and confirmed that the first-order formula yielded bias errors in the calculated QIVs. The observed QIVs are consistent with those calculated from the 0th order differentiation formula, and are of good quality.

In the QIVs simulation of coastline and oceanic effects, we fixed the horizontal center of model domain in Mutsu Bay and constrained the tetrahedral element edge length to be less than 5 km within 100 km of the center. We used coastline data of GSHHS Fine (Bessel & Smith, 1996 JGR). As a result, the QIVs simulated from the coastline effect do not differ considerably from those calculated from a simple island model. On the other hand, the oceanic effect makes QIV amplitudes in Iwate prefecture diminished. However, neither coastline nor oceanic effects explain the observed QIV attitudes.

日本列島やブリテン島などの島嶼陸上で観測される虚部のインダクションベクトル (Quadrature phase Induction Vector; QIV) は海水の影響が小さく地球内部の構造を反映するという仮定の下，東北地方の周期 20〜10000 秒の QIV の傾向から津軽海峡を含む北側の地殻深部からマントル最上部に高伝導体があるのではないかという仮説を我々は立てた (市來 他, 2021 SGEPSS 秋季講演会)．その上で海水の分布で QIV の傾向が説明できないことを示す為，簡単な離島モデルでの QIV を 3 次元差分法モデリング (Siripunvaraporn & Egbert, 2009) で計算した．本発表は，4 面体要素 3 次元有限要素法モデリング (Usui, 2015) を用いて, 海底深度を一定にして現実の海岸線に近い分布をモデルに組み込んだ場合 (海岸線効果) の QIV の振る舞いと海岸線に海底地形もモデルに組み込んだ場合 (海洋効果) の QIV の振る舞いをシミュレーションにより計算し，それらの影響の度合いと観測された QIV の傾向が海岸線効果や海洋効果で説明できないことを示す．また観測で得られている QIV の信頼性を確認する為，実部と虚部の地磁気変換関数の因果律 (Fischer and Schnegg, 1980; Marchello et al., 2005) に基づいて実部の地磁気変換関数から虚部の地磁気変換関数を計算し，観測された虚部の地磁気変換関数と比較した．

因果律の計算では, Fischer and Schnegg (1980) の対数周期を変数とした定式化を用いた．Marchello et al. (2005) は，実部の地磁気変換関数の対数周波数に対する 0 階微分の計算式を推奨した．我々は対数周期に対する 0 階微分の計算式と 1 階微分の計算式それぞれを用いて計算し，1 階微分の計算式では計算される虚部の地磁気変換関数が観測値に比べるとバイアスエラーを持つことを確認し，Marchello et al. (2005) の示唆を確認した．因果律の 0 階微分の式によって計算した虚部の地磁気変換関数は, 東北地方のほぼすべての観測点で観測値と概ね一致しており，QIV の信頼性を確認した．

4 面体要素 3 次元有限要素法による海岸線効果と海洋効果のシミュレーションでは，陸奥湾を中心にして半径 100 km の領域は 4 面体要素 1 辺の長さが 5 km 以下に設定した. 海岸線データは GSHHS Fine(Bessel & Smith, 1996) を用いた. 計算の結果，海岸線は余り大きな効果が無く，市來他 (2021) の単純な離島モデルと類似の結果が得られた．一方海洋効果については，日本海溝の影響で岩手県内の QIV は単純な離島モデルに比較すると著しく振幅が小さくなることが分かった．しかしながら海岸線効果，海洋効果を取り入れた何れのモデルでも，観測した QIV とは大きく異なることが分かった．

R003-P03
ポスター２：11/5　AM1/AM2 （9:00-12:30）

拡張村上モデルにもとづく流動電位起源静電磁場と重力異常・磁気異常の比較

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([1] 東大・地震研

EM fields due to SP based on the extended Murakami model compared with the gravity and the magnetic anomalies

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Extended Murakami Model (Ogawa, JpGU2022, hereafter referred to as EMM) which can calculate static electromagnetic fields due to the streaming potential in a cuboid region excited by homogeneous fluid flow in a porous conductive homogeneous half space representing a flat earth is an extended model of Murakami (1989). The EMM has advantages: assuming that the shape of the region where the streaming potential is excited is a cuboid instead of a rectangular plane, and making it possible to calculate the electromagnetic fields at arbitrary points outside the cuboid. By assuming that the shape of the region where the streaming potential is excited (hereafter referred to as SP anomaly) is a cuboid, the cuboid can also be regarded as the density and the magnetization anomalies. The present study attempts to compare static electromagnetic fields due to the SP anomaly together with the gravity and the magnetic anomalies due to the density and the magnetization anomalies assuming that the SP, density, and magnetization anomalies are identical in its region.

The Green's functions show that the spatial decay of the fields are reciprocally proportional to the square of the distance between the source and the observation point for main terms of the magnetic flux density and the scalar potential of the EMM and the gravity anomaly, while to the cube of the distance for the magnetic anomaly. The static electromagnetic fields due to the EMM depend on the electrical conductivity of the space: the scalar potential depends on the conductivity of the ground and the ratio of the conductivity in the air to that in the ground, while the magnetic flux density depends only on the ratio, in case that the magnetic permeability can be regarded to be homogeneous over the whole space. The boundary plays an important role for the static electromagnetic fields based on the EMM, which is different from the gravity anomaly which does not depend on the property of the space, and the magnetic anomaly based on realistically homogeneous magnetic permeability over the whole space.

In addition, due to the boundary of the electrical conductivity and the insulating air, the components of the static electromagnetic fields due to horizontal fluid flow are enhanced, while the magnetic flux density due to vertical fluid flow vanishes.

While Murakami model calculates the magnetic flux density due to fluid flow along a rectangular fault plane, the present study shows the calculation results of the static electromagnetic fields based on the EMM assuming a cuboid region representing a conduit of a volcano as the SP anomaly together with those of the gravity and the magnetic anomalies regarding the region as the density and the magnetization anomalies.

拡張村上モデル (Ogawa, JpGU2022、以下 EMM) は、村上モデル (Murakami, 1989) を拡張し、導電的半無限均質大地の中に想定した一様な間隙流体流による直方体領域に生じた流動電位による静電磁場を計算するモデルである。流動電位が生じる領域を矩形面から直方体に拡張する一方、直方体領域の外の任意の地点における電磁場を計算可能としている点に EMM の利点がある。異常体の領域を直方体としたことにより、この領域を間隙流体流による流動電位（以下、SP 異常）の発生領域とみなすだけでなく、密度異常領域、磁化異常領域とみなすことも可能である。そこで、SP 異常領域を同時に密度異常及び磁化異常の領域と見なした際の重力異常、磁気異常の計算結果と、EMM による静電磁場の計算結果との比較を本研究で試みた。

グリーン関数の表現より、場の空間減衰は EMM の磁束密度、電位の主要項と重力異常は源泉からの距離の 2 乗に反比例、磁気異常は距離の 3 乗に反比例する。また EMM では空間の電気伝導度に依存した電位及び磁束密度が生じる。電位は大地と大気の電気伝導度の比、及び大地の電気伝導度に依存するが、磁束密度は透磁率が全空間で一様と見なせれば大地と大気の電気伝導度の比にのみ依存する。空間を満たす物性量に依存しない重力異常や、現実的には透磁率が全空間でほぼ一様とみなせる場合の磁気異常とは異なり、EMM による静電磁場には境界が重要な役割を果たす。

また電気伝導度の境界面にあたる地表と絶縁的な大気により、EMM の静電磁場は水平間隙流体流に起因する成分は増幅され、鉛直間隙流体流に起因する成分は磁束密度については消失する。

村上モデルが矩形断層面に沿った間隙流体流に起因する磁束密度を計算したのに対し、本発表では火山の火道を模した直方体領域を SP 異常と想定した、EMM にもとづく静電磁場を計算した結果を、同領域を密度異常、磁化異常とみなして得られる重力異常、磁気異常の計算結果と共に示す。

R003-P04
ポスター２：11/5　AM1/AM2 （9:00-12:30）

福岡県警固断層周辺における広帯域 MT 観測

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Broad-band MT observations around the Kego Fault, Fukuoka, Japan

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We conducted broad-band MT observations of the Kego fault zone (KFZ) in the southeastern part of the Kego fault (KF), which was not ruptured by the 2005 west off Fukuoka earthquake (M7). From 2011 to 2013, various surveys were conducted as a government commissioned project. There were differences in the seismic reflection intensity between the eastern and western sides of the fault, suggesting that KF is located at the region sandwiched by the different lithology. In this study, we conducted broad-band MT surveys on 40 x 80 km area around the Kego fault. Specifically, we aim to investigate how the resistivity structure is correlated with the seismic reflection structure. Another objective is to have an insight why the rupture of the 2005 west off Fukuoka earthquake stopped at the northwestern edge of the Kego fault.

The obtained MT data was greatly affected by artificial noise. However, in the study area, the noise due to the leakage electric current from railways significantly decreases from 0:00 a.m. to 5:00 a.m. Therefore, we have successfully estimated MT response function in the period range from 0.00195 to 3276.8 s. The MT response function indicated the structure is highly three-dimensional. To estimate a realistic structure, we will then perform a 3D inversion analysis, and will show the preliminary resistivity structure.

R003-P05
ポスター２：11/5　AM1/AM2 （9:00-12:30）

ドローンを使用した吾妻山の空中磁気測量

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[1 東北大,[2 北大

An aeromagnetic survey using an unmanned aerial vehicle over Azuma Volcano

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A total intensity aeromagnetic survey using an unmanned aerial vehicle (UAV) was carried out over the Oana Crater of Mt. Azuma on 7 and 9 September 2021, to estimate subsurface alteration zone beneath Mt Azuma, NE Japan. The observation equipment was the Tierra Technica GSMP35U-DR drone aeromagnetic measurement system composed of a GEM GSMP-35U potassium magnetometer and a DJI MATRICE 600 PRO. The survey area was a rectangle of 2 km by 1 km in the NNE-SSW and WNW-ESE directions, respectively, and the flightlines were arranged as 18 equidistant parallel lines in the WNW-ESE direction. The flightline altitudes varied, but the altitude of each line was kept constant. The wiggles of the flight heights were about 0.15 m. The maximum altitude of sampling points was 1978 m (a.s.l). The sampling frequency was 20 Hz, and the flight speed was approximately 6 m/s. The geomagnetic reference station was installed about 600 m south of the Oana Crater, where the magnetic field was not affected by subsurface volcanic activity (e.g., Japan Meteorological Agency, 2020).

The raw data were resampled down to 10 Hz, and the main field and diurnal variations were subtracted from the down-sampled data using IGRF-13 and the reference station data. Equivalent magnetic anomaly was inverted by the Conjugate Gradient (CG) method (Nakatsuka and Okuma, 2006) on a surface about 50 m below the smoothed observation surface. Then magnetic anomaly was reduced on the smoothed observation surface by upward continuation of the equivalent magnetic anomaly, considering observation altitude differences.

We inverted the magnetic anomaly data into a three-dimensional subsurface magnetization model using effective source volume minimization method (Nakatsuka and Okuma, 2014). The horizontal model discretization width was 20 m$*$20 m. The vertical model discretization width was 200 m in 0-800 m altitude above sea level (asl), 150 m in 800-1400 m altitude asl, and 100 m in 1400-2000 m altitude asl, respectively. The magnetization threshold to judge effective source volume was fixed at 0.2 A/m, which was 10 % of the average magnetization (2.06 A/m). The inversion was iterated 20 times using the CG method with an initial value of the average magnetization. The cross-sectional view of the magnetic structure, where the anomalous structure is expected to exist from Reduction to Pole (RTP) map, reveals three highly magnetized regions on the surface layer with low magnetization regions in between. The correspondence between low magnetization regions and alteration zones will be studied in the future.

東北地方で噴火危険性のある吾妻山の地下の変質領域の推定を目的として、2021 年 9 月 7 日、9 日の日程で吾妻山大穴火口周辺においてドローンを用いた空中磁気全磁力測量を行った。観測機器はテラテクニカ社・ドローン空中磁気測定システム GSMP35U- DR（GEM 社製 ポタシウム磁力計 GSMP-35U、DJI 社ドローン MATRICE 600 PRO）を使用した。測定範囲は NNE-SSW 2 km × WNW-ESE 1 km の長方形領域とし、WNW-ESE 短辺方向に平行測線 18 本を 100 m 毎に設定した。測線毎に飛行高度を設定し、側線中では一定の高度で観測を行った。実際の飛行高度のブレは約± 0.15 m であり、最高高度は 1978 m (a.s.l) であった。サンプリング周波数は 20 Hz 、飛行速度は約 6 m/s とした。参照点は気象庁 (2020 第 147 回火山噴火予知連絡会資料) による地上繰り返し全磁力測量から火山活動の影響がないと考えられる大穴火口の南 600 m 付近に設置した。

得られたデータは 10 Hz にダウンサンプリングして、IGRF 補正（IGRF-13）と参照点磁場データでの日変化補正を行った。飛行高度を平滑して観測高度面とし、これを 50 m 下方に移動した面（等価アノマリ面）上での磁気値（等価アノマリ）を，Conjugate Gradient（CG）法を用いたインバージョンによりノルム最小解（Nakatsuka and Okuma, 2006）として求めた。次に等価アノマリの上方接続により、観測高度面上での磁気異常を求めた。これにより、高度差を考慮した磁気異常分布を得ることができる。

処理された磁気異常データを基にして地下の磁化構造を有効ソース体積最小化（Nakatsuka and Okuma, 2014）による 3 次元インバージョンで推定した。水平グリッド間隔は 20 m × 20 m とした。鉛直グリッド間隔は最下面を標高 0 m とし、上から厚さ 100 m × 6、150 m × 4、200 m × 4 の計 14 層とした。有効なソースか判断する閾値は平均磁化（2.06 A/m）の 10 分の 1 である 0.2 A/m とした。等価アノマリによってリダクションしたデータを一様な平均磁化を初期モデルとして CG 法を用いて 20 回のイタレーションを行った。極磁力変換したデータから異常な構造の存在が推定される場所の磁気構造の断面図を作成したところ、表層に３つの高磁化領域とその間に低磁化領域が確認できた。この低磁化領域

と変質帯との対応は今後検討する予定である。