R003-01
D 会場 ：11/25　PM1 （13:15-14:45）
13:15〜13:30

インフェルノ火口湖における EM-ACROSS 法時系列解析

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Time series analysis of EM-ACROSS observations at Inferno Crater Lake, New Zealand

#Norihiro Kitaoka1), Yasuo Ogawa1), Grant Caldwell2), Keiichi Ishizu3), Takuto Minami4), Alison Kirkby2)
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ニュージーランド北島タウポ火山地帯に位置するインフェルノ火口湖は水位と水温が 38 日周期で変動する活発な火口湖である。この変動の原因として地下約 100m に位置する気液二相領域の変動が電気探査により示唆されており、水蒸気噴火発生場との類似している。しかし高比抵抗領域の時空間的変動を詳細に求める手法はまだ十分には開発されていない。我々は高比抵抗領域に敏感な電磁探査手法である EM-ACROSS 法を用い、インフェルノ火口湖周辺で連続観測を半年間行った。観測された送信電流と受信電場の比をとり伝達関数を各観測点ごとに求めた。伝達関数の振幅である見かけ比抵抗と位相であるフェーズテンソルは特に湖の水温の変動とよく一致していた。一方で、見かけ比抵抗は本観測で副次的に得られる自然電位や周囲で観測された体積含水率とは明瞭な相関が得られなかった。これらのことから観測データは地表面や湖水の上下だけでは説明できず、地下構造の変動を反映していることが分かった。本研究では 3 次元有限要素法を用いて観測データから推測される地下構造とその時系列変動を議論し、火山熱水系モニタリングへの有用性を報告する。

R003-02
D 会場 ：11/25　 PM1 （13:15-14:45）
13:30〜13:45

地下比抵抗構造変化検出を目的とした電磁場連続観測－能登半島群発地震域を対象に－

#吉村 令慧 [1], 山崎 健一 [1], 小松 信太郎 [1], 山崎 友也 [1], 中川 潤 [1], 宮町 凛太郎 [1], 吉川 昌宏 [1], 石川 尚人 [2], 平松 良浩 [3], 畑 真紀 [1]
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Continuous EM Field monitoring to Detect Changes in Subsurface Resistivity Structure around Noto Peninsula Seismic Swarm Area

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We have been conducting continuous electromagnetic field observations since the end of FY2022 in the area around Suzu City, Ishikawa Prefecture, where seismic swarms and localized transient crustal deformation have continued since the end of 2020.This seismic swarm activity is considered to be related to the movement and diffusion of subsurface fluid, and we are attempting to capture the fluid dynamics through continuous observation of the electromagnetic field.

The continuous electromagnetic field observation consists of two types of broadband electromagnetic field instruments (ELOG-MT and ELOG-Dual manufactured by NT System Design) that measure five components of the electromagnetic field and two components of the electric field, and records electromagnetic field data at sampling intervals of 15 Hz, 150 Hz (UTC13:00-21:00), and 2400 Hz (UTC15:00-20:00). The continuous observation started at the end of FY2022 with one 5-component station and five 2-component stations, at present we are operating two 5-component stations and two 2-component stations for a total of four stations. For the M6.5 and M7.6 earthquakes of May 5, 2023 and January 1, 2024, respectively, a total of four stations were able to obtain long-term pre- and post-earthquake electromagnetic field records.

In this presentation, we will report whether long-term temporal changes in the geomagnetic transfer function and magnetotellurics (MT) response are observed, and whether short-term electromagnetic field signals are present before and after earthquakes of magnitude M6 or greater.

我々は、2020 年末より群発地震活動と局所的な非定常地殻変動が継続している石川県珠洲市周辺において、2022 年度末より電磁場連続観測を展開している。この群発地震活動は、地下流体の移動拡散に関係する活動と考えられ、その流体の動態を電磁場の連続観測により捉えようとする試みである。

電磁場連続観測は、電磁場 5 成分と電場 2 成分を計測する 2 種類の広帯域電磁場観測装置（NT システムデザイン社製 ELOG-MT ならびに ELOG-Dual）で構成し、サンプリング間隔 15Hz（連続）, 150Hz（UT13 時-21 時）, 2400Hz（UT15-20 時）の電磁場データを収録している。連続観測は、5 成分観測点 1 点、2 成分観測点 5 点の計 6 点で 2022 年度末に開始し、現時点では 5 成分観測点 2 点、2 成分観測点 2 点の計 4 点を運用している。2023 年 5 月 5 日の M6.5、2024 年 1 月 1 日の M7.6 のそれぞれの地震に対して、計 4 点で地震前後の長期間の電磁場記録を取得できた。

本発表では、地磁気変換関数や MT（Magnetotellurics）応答に長期的な時間変化がみられるか否か、M6 以上の地震発生前後に短期的な電磁場信号が存在するか否かについて報告する。

R003-03
D 会場 ：11/25　PM1 （13:15-14:45）
13:45～14:00

斜め良導柱に伴う異常位相に関する考察

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Considerations on the anomalous phases associated with an inclined conductive column

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Magnetotelluric data are sometimes accompanied by anomalous impedance phases in the off-diagonal components that deviate from the first (0~90°) or third (-180~-90°) quadrants, particularly in long period-bands. This phenomenon is called phases out-of-quadrant (POQ). Particular 3-D structure with a strong resistivity contrast or the anisotropy of the medium are often introduced in explaining POQ. In other words, POQ can be one of the important guides for model estimation in 3-D resistivity inversion modeling.

Most recently, Inoue and Hashimoto (2024) proposed the model for an inclined conductive column (ICC) generating POQ. They used the ModEM code (Kelbert et al., 2014) to calculate the impedance at each depth and concluded that the induced currents are channeled into the ICC. However, it was practically difficult to calculate the vertical component of the E-field using based on the impedance between horizontal components. Therefore, in this study we re-evaluated the numerical models using the FEMTIC code (Usui, 2015), which can directly output the distribution of electromagnetic fields and current density, including their vertical component.

In the synthetic tests, we introduced an ICC (1 Ω m) within a uniform medium of 1000 Ω m. The model was composed of cubic cells, each with dimensions of 1 × 1 × 1 km. We assumed the conductive column was inclined at 45° toward the -Y (west) direction. We prepared three synthetic model patterns, with the upper end set at the ground surface (Z_u=0 km) and the lower end set at Z_l=5, 10 and 20 km, respectively. We obtained the impedance, the E-field and the current density by frequency.

We confirmed that variations in the length of the conductive column may alter the E-field pattern and lead to the generation of POQ. In the model with a shorter column (Z_l=5 km), the E-field, corresponding to the magnetic field variation in the X (north-south) direction is not significantly affected by the conductor. In contrast, in the models with relatively longer columns (Z_l=10 or 20 km), the E-field tends to concentrate or diverge at the top and bottom ends of the conductor. In addition, on the inclined side (west side) of the conductive column, the electric Y and Z components are reversed compared to the surroundings, and within that region, POQs present in the Z_{yx} component. Furthermore, the electric current density through the column increases as the column extends deeper. The stronger current may expand the area of the reversed E-field on the surface. This could potentially influence the region where POQ occurs.

マグネトテルリック法探査において，インピーダンスの非対角成分の位相が長周期帯で 0～90° または-180～-90° の範囲を逸脱する場合がある．こうした現象は phases out-of-quadrant (POQ) と呼ばれており，強い比抵抗コントラストを伴う特異な 3 次元構造や媒質の異方性で説明されることが多い．そのため，POQ は 3 次元比抵抗インバージョン解析におけるモデル推定に重要な情報の 1 つである．POQ を発現させるモデルに関する研究はいくつか行われており，直近では我々が斜め良導柱モデルを提案している（Inoue and Hashimoto, 2024）．

Inoue and Hashimoto (2024) では，有限差分法を用いた ModEM コード（Kelbert et al., 2014）で深さごとにインピーダンスをフォワード計算し，良導柱の上端と下端で電流の吸い込みと湧きだしが起きているとして結論づけた．しかし，インピーダンスのみでは電場の鉛直成分を計算することは困難であった．そこで本研究は，電磁場や電流密度の分布を直接出力できる FEMTIC コード（Usui, 2015）を用いて数値実験をやり直し，斜め良導柱モデルに伴う POQ に関する考察を行った．

数値実験には，1 km (x) × 1 km (y) × 1 km (z) の六面体メッシュに切った 1000 Ω m の一様な媒質内に傾いた柱状の良導体（1 Ω m）を組み込んだモデルを作成した．本研究では，-Y（西）方向に 45° に傾斜させた斜め良導柱を想定し，上端を地表面 (Z=0 km)，下端を Z=5, 10, 20 km にそれぞれ設定した Synthetic モデルの 3 パターンを準備した．そして，それぞれのモデルを用いてフォワード計算を行ってインピーダンス，電場，電流密度を周波数ごとに算出した．

斜め良導柱の長さを変化させると，誘導電流の流れ方も変化し，POQ を発生させることが確認できた．柱の長さが短いモデル（Z=5 km）では，X（南北）方向の磁場変化に誘導される電場は，深さごとに違いは見られず，斜め良導柱の西側から東側に向いていた．一方で，柱が相対的に長いモデル（Z=10, 20 km）では，Inoue and Hashimoto (2024) と同様に誘導電流は良導柱の下端から上端に集中して流れる傾向であった．また，良導柱の傾斜側（西側）の地表面で電場の Y 方向と Z 方向の成分が周囲と反転しており，その領域で Z_{yx} 成分に POQ が発生していた．以上の結果に加えて，本研究では，斜め良導柱の長さを伸ばしていくと，良導柱内部の電流密度が増加することを確認できた．吸い込まれる電流が増加することによって，地表面で周囲と反対方向を向く電場の領域が増加し，POQ の発現範囲に影響を及ぼしていると考えられる．

R003-04
D 会場 ：11/25　 PM1 （13:15-14:45）
14:00〜14:15

#臼井 嘉哉 [1), 上嶋 誠 [1), 坂中 伸也 [2), 山谷 祐介 [3), 小川 康雄 [4,5), 市來 雅啓 [5), 本蔵 義守 [6), 黒木 英州 [7), 北関東 MT 観測グループ [8)
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Magnetotelluric explorations of the three-dimensional electrical resistivity structure under the Nikko-Ashio area

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The Nikko-Ashi area is one of the best areas in the world for elucidating the mechanisms of volcanic and seismic activities and the link between them. There exist a number of quaternary volcanoes (e.g., Nikko-Shirane and Nantai volcanoes) in the Nikko-Ashio area. Swarm earthquakes have been occurring in the area. Moreover, M6- and M7-class inland earthquakes have occurred to the east of the area. Some previous studies have suggested that the existence of volcanoes may have a bearing on those seismic activities. Both volcanic and seismic activities are associated with crustal fluids, and the magnetotelluric method is one of the most effective methods to reveal the distribution of the crust fluids. Ogawa et al. (1997) conducted magnetotelluric measurements around the Nikko-Ashio area and estimated the two-dimensional electrical resistivity structure under the Nikko area. Because, however, the subsurface structure under this area is considered to be three-dimensional, the elucidation of the three-dimensional structure is essential to investigate the mechanisms of seismic and volcanic activities. Therefore, we conducted new wideband magnetotelluric measurements around the Nikko-Ashio area in 2021, 2023, and 2024. From the newly measured time-series data, we estimated the impedance tensor, the vertical magnetic transfer function (tipper), and the inter-station horizontal magnetic transfer function using a robust data processing method. Because the geomagnetic field activity is relatively high during the measurement periods, particularly in 2024, we obtained reliable response functions up to several thousand seconds. We combined those new data and the data measured by Ogawa et al. (1997) to reveal the three-dimensional electrical resistivity structure down to the deep crust under the Nikko-Ashio area. The combined station array is composed of over 40 stations and covers the Nikko-Ashio area and the epicenter area of large historical earthquakes to the east of it. In this presentation, we show the characteristic features of the response functions of the combined dataset and discuss their implications for the subsurface structure.

List of Authors
Many people joined the MT measurements in 2021, 2023, and 2024, in addition to the researchers on the main author list. The names and institutes of these participants are listed below by University and Institute.
Takao Koyama, Tasuku Hashimoto, Koji Miyakawa, Masataka Masuda, Taro Nishimoto, Akira Watanabe, Dieno Diba, Han Song (The University of Tokyo);
Toshiki Kaida (Tohoku University);
Kanju Bahati Haji, Kelym Reynald Martinez Mena, Riho Takahashi, Hayato Takahashi
Junichi Kitadokoro (Akita University);
Hayata Sato, Hiroko Tendo, Takuro Kanetsuki, Yuki Tomioka, Kei Nakayauchi, Takafumi Murakita, Takao Miura, Momoka Yamakawa, Shogo Masuda, Masamichi Ikeda, Yoshiaki Harashima, Shunsuke Yaegashi, Kota Suzuki (Japan Organization for Metals and Energy Security)

R003-05
D 会場 ：11/25 PM1 （13:15-14:45）
14:15〜14:30

#ディバ ディエノ [1)], Song Han[1,2)], Uyeshima Makoto[1)], Usui Yoshiya[1)], Ichiki Masahiro[3)], Sakanaka Shin'ya[4)], Tamura Makoto[5)], Yuan Yiren[1,6)], Gresse Marceau[1,7)]
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MT study in the southern part of Tohoku region: Unveiling electrical resistivity structure and its geological implications

#Dieno Diba[1)], Han Song[1,2)], Makoto Uyeshima[1)], Yoshiya Usui[1)], Masahiro Ichiki[3)], Shin'ya Sakanaka[4)], Makoto Tamura[5)], Yiren Yuan[1,6)], Marceau Gresse[1,7)]
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The southern part of Tohoku, Northeast Japan, is abundant in volcanic and seismic activities due to the subduction system. In the central part of the region, there are active volcanoes located on and around the volcanic front (Mt. Azuma, Mt. Adatara, and Mt. Bandai) and one on the back-arc side (Mt. Numazawa). The spatial distribution of deep, low-frequency earthquakes (DLFEs) aligns with these volcanoes and is oblique to the volcanic front. It is widely recognized that fluids play a significant role in subduction zone magmatic and seismic activities, and electrical resistivity is sensitive to the presence of fluids. Therefore, we estimated three-dimensional resistivity structures from the inversion of a wideband magnetotelluric (MT) dataset. In addition to applying the conventional MT inversion scheme to the data (as described in Diba et al., 2023), we also utilized the structure-guided inversion scheme, which enforces structural resemblance between the inverted resistivity model and a guiding seismic velocity model (Diba et al., 2024, JpGU). Both inversion schemes reveal a large conductive zone from the lower crust to the upper mantle beneath the volcanic area, consistent with the hypocenters of DLFEs, which may indicate the presence of a fluid-rich area. Although the velocity model lacks a similar feature, this conductive zone remains robust in the structure-guided inversion result. We then investigated the possible scenarios for the origin of this fluid-rich conductive zone and its impact on volcanism and seismic activities to enhance our understanding of the geology of the study area. More of the geological interpretation will be discussed in the presentation.

R003-06
D 会場 ：11/25　 PM1 （13:15-14:45）
14:30～14:45

男鹿半島申川断層の電気探査と磁気探査による断層傾斜角の推定

#坂中 伸也 [1)], 田沼 亜咲 [2)], 西川 治 [1)], 坪江 桂吾 [4)], 西村 優花 [3)], 津永 紫音 [5)]
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An estimation of the dip angle of the Sarukawa fault at Oga peninsula by use of electric sounding and magnetic survey

#Shinya Sakanaka[1)], Asaki Tanuma[2)], Osamu Nishikawa[1)], Keigo Tsuboe[4)], Yuka Nishimura[3)], Shion Tsunaga[5)]
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Several damaged earthquakes have taken place around the area of Oga peninsula in Akita prefecture, northeast of Japan. In 1810, a damaged earthquake called Ugo earthquake or Bunka-Oga earthquake estimated magnitude M6.5 occurred in Oga peninsula. In 1939, successive earthquakes of magnitudes M6.8, M6.7 and M6.5 took place around the peninsula. Off the Oga peninsula in Japan Sea, the earthquake off Oga of 1964 (M6.9) and the central Japan Sea earthquake in 1983 (M7.7) are known as well.

The earthquake fault in associated with above earthquakes inland of Oga peninsula is not clearly known although several researchers have proposed the candidates. The lineament in the topography mainly bending low cliffs can be seen along the eastern edge of Iriai lowland in Oga peninsula. The lineament is called the Sarukawa fault and it is one of the candidates of past damaged earthquakes.

We cannot see the fault outcrops at Sarukawa fault and excavated researchers have not carried out so far. The dislocated fault angle buried under the ground surface is not so clear. In the regional stress state of the tectonic background in recent geological stage, compressional stress in the direction of east-west. Reverse fault planes are expected under the Sarukawa fault based on the consideration of surface topography and stress state in the region.

The low dip angle of the reverse faults in Akita area are known e.g., in the Senya fault with Rikuu earthquake in 1896, at parts of shallow zone of Kita-Yuri thrust faults

We conducted ERT (Electric Resistivity Tomography), GPR (Ground Penetrating Radar), the seismic refraction survey and magnetic survey at the Sarukawa fault. With the reference to the result of the resistivity structure model and the magnetic survey in total intensity across the Sarukawa fault, we try to estimate the dip angle of the Sarukawa fault, especially focusing it is high angle or low angle.

In this study, ERT survey lines were installed and collected data on September 16, September 26, October 25, and December 7, 2022. Four 235 m long straight survey lines were set up along a farm road in the Iriai-Chuishi area, on the eastern boundary of Iriai lowland. The Dipole-Dipole and Wenner were used for the electrode array, with 48 electrodes and 5 m electrode spacing. GNSS positioning was also used for detailed topographic analysis. RES2DINV was used as the analysis software to create a resistivity model of the subsurface within the exploration area.

We referred the resulted models of the resistivity section across the Sarukawa fault by ERT. General speaking of estimating the location of the dislocation fault surface, we align the thin layer of low resistivity or seek the sharp boundary of resistivity values. Based on the resistivity model, we have two candidates of the buried fault surface of the Sarukawa fault. One is low angle model and the other is high angle model. It is easier to take the low angle model in the subsurface image of surficial soil like as the soften alluvial fan or sand dune deposit in the background of regional stress in the direction of east-west in the northeast of Japan. At present we can refer the 20 m boring result at the site. In the assumption of the low angel fault, the dislocation has to recognized in the boring core, but we cannot see such kind of rupture in the sand dune in the sample of the core.

So far we tentatively concluded the dislocation angle to the ground surface of the Sarukawa fault would be high. But we feel the further investigation is necessary in consideration of detailed topography, rheology and elasticity of the geology, stress and strain of this region etc.

R003-P01
ポスター４：11/26　AM1/AM2（9:00-12:00）

2022年1月のHunga Tonga-Hunga Ha'apai火山活動によるトンガ・アテーレ観測点における磁場変動

#清水 久芳[1)]
(1 東大・地震研

Magnetic field variations in Tongatapu due to Hunga Tonga-Hunga Ha'apai volcanic activities in January 2022

#Hisayoshi Shimizu[1)]
(1Earthquake Research Institute, University of Tokyo

This presentation will characterize and discuss the magnetic field variations observed at ʻAtele in Tongatapu due to the January 2022 Hunga Tonga-Hunga Ha'apai (HTHH) volcanic activity.

Magnetic field variations due to the volcanic activity on January 15, 2022, observed at Apia, Samoa (about 835 km NNE from HTHH) has been reported by Iyemori et al. (2022) and Yamazaki et al. (2022). They identified a variation with a period of about 4 minutes with amplitude of about 3 nT at the station. This variation is due to electric currents induced in the ionosphere by atmospheric acoustic resonance caused by the eruption. At the 'Atele station, which is about 74 km south of HTHH, magnetic field variations with a similar period but with an amplitude ten times larger than that at Apia were observed. Differences in the magnetic field variations are seen not only in the amplitude but also in the direction of variations. The trajectory of the magnetic field variations in the horizontal plane is in the NE-SW direction at 'Atele, while it is almost in the East-West at Apia. The observed characteristics is consistent with the electric current model proposed by Iyemori et al. (2022).

In addition to the variations due to the atmospheric acoustic resonance, a magnetic field variation that started soon after the time of volcanic eruption and lasted for about two hours is observed at the two stations. The variation is the most significant in the Z (vertically downward) component at ʻAtele, and it is a one-sided variation with an amplitude of about 80 nT. The dominance in the Z component implies that the variation is not caused by the induction in the heterogeneous Earth, and this is formally confirmed by modeled Z variation using the geomagnetic transfer function at ʻAtele. On the other hand, the variation started about the same time at Apia seems to be compatible with geomagnetic transfer function at the station. These suggest that the two-hour variation at ʻAtele is likely due to the local electric current near the station, but its signature may not be detected at Apia.

The field variation at ʻAtele seems to be synchronized with the plume activity of the eruption. Several electric current models that might be realized by the interaction of plume (neutral air) and ionosphere were examined whether they can reproduce the variation at ʻAtele or not. These models will be presented to discuss the phenomena that had occurred near the area.

R003-P02
ポスター４：11/26　AM1/AM2 （9:00-12:00）

自然湧水を利用した水上自然電位観測に関する実験的検討

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Experimental study of the self-potential measurement on water surface at a natural spring site

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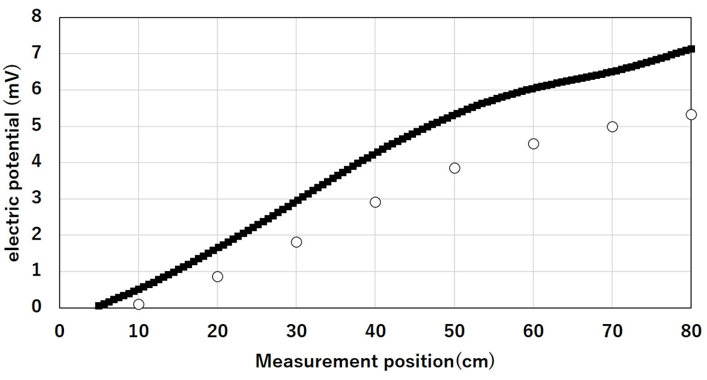
The self-potential(SP) method is known as a geophysical method sensitive to groundwater flow. This method has been used to explore hydrothermal systems formed in volcanic and geothermal regions. The method has recently been widely used in exploring submarine springs, submarine hydrothermal deposits, and other water areas, expanding the range of its applications. As an example, Ikardet al. (2018) fixed a pair of electrodes to the hull of a canoe and made continuous potential measurements while flowing down a river to determine the SP distribution on the river channel, and discussed the exchange relationship between river water and groundwater within a watershed. As described above, many experiences of SP measurement in water areas have been obtained in various regions. However, sufficient data have not been obtained on how the vertical distance from the bottom to the electrode and the speed at which the electrode is moved affect the measurement results. The purpose of this study was to investigate the influence of the measurement conditions on the observed data, and to this end, several experimental measurements were made in a natural spring using an observation boat.

The SP observation was carried out at the “Kasasugi no shimizu” natural spring located in Yokote City, Akita Prefecture, Japan. At this site, water springs out from within a rectangular concrete frame (approximately 1.3 m long, 0.9 m wide, and 0.5 m deep) with its long axis oriented in the WNW-ESE direction. We carried out two types of observations on this spring. The first was an observation to grasp of the two-dimensional SP distribution in the horizontal direction on the surface of the spring. For this observation, the concrete frame of the spring was divided into a grid, and the intersections of the grid were set as observation points. After fixing the two electrodes on the water surface, we waited until the potential stabilized, and recorded the potential value at the point where no change in value was observed. Data were obtained at all of the intersections of the grid of 64 points, and the SP distribution on the water surface of the spring was determined.

In the second type of observation, the potential was measured by moving a small observation boat with electrodes attached on the spring water. A commercially available milk carton (10 cm in length and width) was cut at an appropriate height to serve as the main body of the boat, and self-made electrodes were attached to the front and rear of the boat in the direction of movement. The electrodes were Cu-CuSO4 electrodes, and the saturated copper-sulfate solution was gelatinized with polysaccharide thickener to prevent leakage of the internal solution when the boat shook on the surface of the water. In the observation, the boat was moved along the grid lines that divided the spring, and potential data was measured every 0.1 seconds. Data was obtained on a total of 13 survey lines.

The two-dimensional SP distribution on the surface of the water was observed to gradually decrease from the upstream side (SE direction) of the spring to the downstream side (NW direction). This tendency was confirmed in all observations made in the past. The maximum SP difference in the spring was 12-13 mV, and it was revealed that it has an average potential gradient of about 5.6 mV/m.

The potential data obtained by the observation boat was integrated for the direction of the boat’s movement to calculate the SP value on the water surface. An example of the result is shown in the figure. In the figure, the white circles represent the SP values obtained at the intersection of grids, and the solid lines represent the SP values along the grid lines. Although the two sets of data do not completely match, there were similarities in the elevation relationships shown by the potential distribution and the potential difference values within the measurement line. In this observation, the average boat speed was 6-10cm/sec, and it was suggested that this range of speed, the potential data obtained while the ship was moving could reproduce the SP distribution on the water surface in the direction of the route.



R003-P03
ポスター４：11/26 AM1/AM2 (9:00-12:00)

鬼界カルデラ海域における潮汐起因の電磁場応答の研究

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Study of Tide-Induced Electromagnetic Field Response in the Kikai Caldera Sea Area

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When ocean tides are caused by lunar and solar tidal forces, electromagnetic fields are induced by the flow of seawater, a conductive fluid, through the Earth's main magnetic field. Estimation of this induced electromagnetic field from observation data has the potential to reveal ocean tides affected by surrounding topography and subsurface resistivity. In this study, we focus on the area around the Kikai Caldera, which is located on the seafloor about 100 km south of Kagoshima and has complex submarine topography around it. We estimate tidally induced electromagnetic fields based on electromagnetic field data obtained from observation equipment installed on the seafloor and on land around the caldera, and discuss the mechanism of induced electromagnetic field generation.

Observations were conducted by installing an instrument (OBEMP), which is a combination of a seafloor potentiometer (OBEM) and an absolute pressure transducer, on the seafloor in the Kikai Caldera area. In this study, data from three magnetic field components, four potential difference components, and two tilt components from three observation points were used. In addition, magnetometers were installed on Satsuma Iwo Jima and Takeshima Island around the caldera, and the data of 3 components of magnetic field and 2 components of tilt observed were used.

In the data analysis, the first step was to transform the coordinates of the observed data (3 components of the electric field calculated from 3 components of the magnetic field and 4 components of the potential difference) from the instrument coordinate system to the geographic coordinate system. The transformation was performed by tilt correction using the data of the two tilt components and horizontal rotation of the coordinate system by comparing the observed magnetic field with IGRF-13 (Alken et al., 2021). Tidal cycle components were extracted from the three components of the magnetic field and two components of the horizontal electric field using the tidal analysis program Baytap08 (a modified version of Baytap-G (Tamura et al., 1985)) for the transformed observation data. Then, among the results obtained, we focused on the M2-min tidal component. This is because 1) the M2 equinox is a lunar equinox with a period of 12.42 hours, which avoids the influence of daily changes in the magnetic field caused by the sun, and 2) it has the largest amplitude of all the lunar equinoxes, so the magnetic field signal caused by ocean tides is expected to be the largest. The obtained components of the M2 ebb tide were compared with the numerically calculated values of the magnetic field due to ocean tides. Based on the calculated velocity fields of the tides from the ocean tide model NAO.99Jb (Matsumoto et al., 2000) and the seafloor topography, we used TMTGEM (Minami et al., 2017) to calculate the electromagnetic fields originating from the M2-minutes tides in the study area.

As an initial result, we analyzed the data from the three stations and compared the results with tentative numerical calculations (e.g., the subsurface resistivity structure is uniform), and found that the amplitude and phase values at Bx and Bz were similar to the numerical results. On the other hand, in By, the phases were approximately opposite. In addition, a comparison of the local phase of the tide at M2 min with the local phase at the time of the maximum amplitude of the tidally-induced magnetic field shows a phase shift of about 200 degrees. In this presentation, we show the three components of the magnetic field and two components of the horizontal electric field of the M2-minute tide at all stations. By comparing these results with numerical calculations of the electromagnetic field due to the ocean tides of the M2 tidal cycle, the mechanism of the induced electromagnetic field generation will be discussed.

月や太陽の起潮力により海洋潮汐現象が起こる際、導電性流体である海水が地球主磁場中を流れることで電磁場が誘導される。この誘導電磁場を観測データから推定することで、周辺の地形の影響を受けた海洋潮汐や、地下比抵抗を明らかにできる可能性がある。本研究では、鹿児島の南方約 100km の海底にあり、その周辺に複雑な海底地形を持つ鬼界カルデラの周辺地域を対象とする。カルデラ周辺の海底と陸上に設置した観測機器から得られた電磁場データをもとに潮汐起因の電磁場を推定し、誘導電磁場の発生メカニズムについて考察する。

観測は、海底電位差磁力計 (OBEM) と絶対圧力計を合わせた機器 (OBEMP) を鬼界カルデラ海域の海底に設置して実施した。本研究では、３点の観測点の磁場 3 成分、電位差 4 成分、傾斜 2 成分のデータを使用している。また、磁力計を

カルデラ周辺の薩摩硫黄島と竹島に設置し、観測された磁場 3 成分、傾斜 2 成分のデータを使用している。
　データの解析では、はじめに、観測データ（磁場 3 成分と電位差 4 成分から計算した電場 3 成分）の機器座標系から地理座標系への座標変換を行った。座標変換は、傾斜 2 成分のデータを使用した傾斜補正と、観測磁場と IGRF-13(Alken et al., 2021) の比較による座標系の水平回転により行った。座標変換を行った観測データに対し潮汐解析プログラム Baytap08（Baytap-G(Tamura et al., 1985) の修正版）を用いて、磁場 3 成分と水平電場 2 成分から潮汐周期の成分を抽出した。そして得られた結果の中で M2 分潮の成分に着目した。理由は、１）M2 分潮は、月に起因する 12.42 時間周期の分潮であるため、太陽による磁場の日変化の影響を回避できることと、２）月に起因する分潮の中で最も振幅の大きいため、海洋潮汐を起因とする磁場信号が最も大きくなることが期待されるからである。得られた M2 分潮の成分と海洋潮汐に起因する磁場の数値計算値を比較した。海洋潮汐モデル NAO.99Jb(Matsumoto et al., 2000) による潮汐の速度場の計算値と海底地形をもとに、TMTGEM(Minami et al., 2017) を用いて、研究領域での M2 分潮を起源とする電磁場の計算を行った。
　初期的な結果として、3 点の観測点のデータを解析し、その結果と暫定的な数値計算値（地下比抵抗構造が一様であるなど）とを比較をすると、Bx,Bz においては数値計算の結果と似たような振幅と位相の値をとっていた。一方、By では位相がおおよそ逆位相となっていた。また M2 分潮の潮汐のローカル位相と潮汐起因磁場の振幅が最大となる時のローカル位相を比較すると、位相がおよそ 200 度ずれる結果となった。本講演では、すべての観測点での、M2 分潮の磁場 3 成分と水平電場 2 成分を示す。そして、この結果と、M2 分潮の海洋潮汐に起因する電磁場の数値計算値を比較することで、誘導電磁場の発生メカニズムについて考察する。

構造カップリングを用いた４次元インバージョン

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4D inversion method using structural coupling

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In recent years, 4D analysis, or the attempt to detect temporal changes in the spatial distribution of fluids in the subsurface, has been widely used for resource development purposes or monitoring of active volcanoes. Several 4D analysis methods have been proposed, the simplest of which is parallel inversion. This method estimates temporal variations by separately inverting data at multiple observation times and taking their differences, and has been applied to many real data (e.g. Miller et al., 2008; Minami et al., 2018). Sequential inversion, which was proposed in Wirianto et al. (2010), uses the model estimated at the first observation time (baseline model) as the initial model for the inversion at the next observation time, and is mainly used for monitoring oil development (e.g., Asnaashari et al., 2014). However, these methods are very sensitive to differences in data noise and the distribution of observation points at each observation time, and it has been pointed out that apparent temporal changes can be easily detected (Kim et al., 2009; Karaoulis et al., 2010).

In this study, we propose a new 4D inversion method that uses structural coupling to detect time variations. Structural coupling is a constraint used in joint inversion where different physical models (magnetization structure and density structure, resistivity structure and seismic velocity structure) are combined to impose that each physical model has a high correlation. Specifically, cross-gradient (Meju and Gallardo, 2004), fuzzy c-means clustering (Pasche and Tronicke, 2007), and Group Lasso (Utsugi, submitted) have been proposed. By using these methods, each physical model has high correlation, while allowing the differences in structure to partially reproduce each data set. By applying this method to the estimation of time variation, the models at each observation time are highly correlated, so the time-invariant structure is in phase at each time, and as a result the detection of apparent changes is suppressed, and differences in structure, or temporal changes, can also be detected.

We have developed a 4D inversion code using structural coupling by Group Lasso for magnetic inversion, which is a linear problem. As a synthetic test, we subjected the data at each observation time to noise with different amplitudes and standard deviations, and performed a 4D analysis. The results suggest that our method has the effect of suppressing the apparent time variation compared to conventional methods, and may be able to detect the time variation more accurately. In the future, we will apply our method to resistivity inversion, which is a nonlinear problem.

近年、資源開発や火山活動のモニタリングを目的として、地下に存在する流体の空間分布の時間変化を検出する試み、すなわち４次元解析が盛んに行われている。４次元解析の方法はこれまでに複数提案されているが、そのうち最も単純な方法は parallel inversion である。この方法は、複数の観測時刻のデータを個別にインバージョンし、それらの差分を取ることによって時間変化を推定するものであり、これまでに多くの実データに適用されている（e.g. Miller et al., 2008; Minami et al., 2018）。また、Wirianto et al. (2010) が提案した sequential inversion は、最初の観測時刻で推定されたモデル（ベースラインモデル）を初期値として、次の観測時刻のインバージョンを行うものであり、主に石油開発のモニタリングに使用されている（e.g. Asnaashari et al., 2014）。しかし、これらの手法は各観測時刻のデータノイズや観測点配置の違いに非常にセンシティブであり、見かけの時間変化が検出されやすいことが指摘されている（Kim et al., 2009; Karaoulis et al., 2010）。

そこで本研究では、構造カップリングを用いて時間変化の検出を行う新たな４次元インバージョン手法を提案する。構造カップリングとは、通常異なる物理モデル（例えば磁化構造と密度構造、比抵抗構造と地震波速度構造）を組み合わせた joint inversion で用いられる制約であり、これにより各物理モデルが高い相関を持つことが課される。この制約を与える具体的な手法としては、cross-gradient (Meju and Gallardo, 2004) や fuzzy c-means clustering (Pasche and Tronicke, 2007)、Group Lasso (Utsugi, submitted) などが確立されており、これらを用いることで各物理モデルは高相関を示しつつ、部分的には各データを再現するために構造の違いが許容される。この手法を時間変化の推定に応用することで、各観測時刻のモデルは高相関となるため、時間的に不変な構造は各時刻で同相となり、結果として見かけの変化の検出が抑制されるとともに、構造の違い、すなわち時間変化も検出可能となる。

これまでに、線形問題である磁気異常解析を対象として、構造カップリングを用いた４次元インバージョンコードを開発した。最小化すべき目的関数に Group Lasso に基づく構造カップリング項を導入し、計算アルゴリズムには交互方向乗数法（Boyd et al., 2011）を用いた。各観測時刻のデータに異なる振幅・標準偏差のノイズを与えてモデル計算を行ったところ、本研究の手法には従来手法と比較して見かけの時間変化を抑制する効果があり、真の時間変化がより精度良く検出されることが示唆された。今後、非線形問題である比抵抗インバージョンにも本研究の手法を適用していく予定である。

R003-P05
ポスター４：11/26　AM1/AM2 （9:00-12:00）

紀伊半島における長周期ＭＴデータの解析結果について

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Analysis of Long-Period MT Data using LEMI recording equipment in the Kii Peninsula, Southwestern Japan

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The Kii Peninsula in the forearc region of southwestern Japan has distinct structural and tectonic features due to the subducting Philippine Sea (PHS) slab. These include high-seismicity, deep low-frequency tremors (DLTs), and high-temperature hot springs. The Kii Peninsula is key to understanding the relationship between deep fluids and seismic activities.

In my previous research, we analyzed the network-MT data acquired in the Kii Peninsula, including the data used in Yamaguchi et al. (2009), to estimate a 3-D regional deep resistivity model for the first time with the Network-MT data in this region. The resultant model seems to be the most reliable as for the deep subsurface structure, which has a complex 3-D nature. The model shows a high-resistivity zone, considered as a Kumano acidic rock body (KAR), beneath the Kii Peninsula and corresponds well with the seismic high-velocity zone and the high-gravity anomaly zone. A low-resistivity region surrounds the high-resistivity region, and a prominent low-resistivity region extends from the top of the slab to the crustal surface. In the model, this correspondence between the resistivity structure and the spatial distribution of the hot springs may explain the fluid contribution in the subsurface of the Kii Peninsula.

The network-MT method (Uyeshima et al., 2001; Uyeshima, 2007) used in this study employs a commercial telephone network to measure voltage differences over long dipole lengths (10 to several tens of kilometers). This method has three advantages over conventional MT methods: wider spatial coverage (covering almost the entire Kii Peninsula), a wider period range (from tens of seconds to 50,000 seconds), and better data quality in terms of a high signal-to-noise ratio and less susceptibility to static effects. However, while the network-MT data had high sensitivity to deep structures, it had low resolution for the middle and upper crust due to the lack of high-frequency data. Additionally, observations were limited to areas with telephone lines, creating some spatial observation gaps. To address these deficiencies, we plan to compile existing conventional MT data and conduct observations to fill the observation gaps in frequency and spatial domain.

The long-period data observed by Ogawa et al. using LEMI recording equipment during 2017-2018 were analyzed, and MT response functions were calculated. In this presentation, we show the characteristic features of the response functions and discuss their implications.

西南日本の前弧側に位置する紀伊半島には，活発な地震活動領域（群発地震・深部低周波地震（微動）・スロースリップ）や多様な 3He/4He 同位体比の高温泉，深部まで伸びる巨大な酸性岩体などが存在する．これらについては，沈み込むフィリピン海スラブや深部流体との関連性が指摘されている．したがって，紀伊半島の地下は，深部流体と地震活動との関係を理解するための重要な鍵を握っていると考えられる．

先行研究である私の修士の研究では，Yamaguchi et al. (2009) で使用されたデータを含む紀伊半島において取得された Network-MT 法データ（電場及び地磁気）を再解析し，紀伊半島で初となる Network-MT 法データを用いた 3 次元広域深部比抵抗構造モデルを推定した．得られたモデルは，紀伊半島の多様な特徴にも対応した，より信頼性の高いものと考えられる．その結果，紀伊半島の地下には，熊野大峰複合火成岩類に対応すると考えられる高比抵抗領域が存在し，地震波高速度領域や高重力異常領域ともよく対応する．また，その高比抵抗領域を囲むように低比抵抗領域が存在し，スラブ上面から地殻表層まで続く顕著な低比抵抗領域が存在している．このような低比抵抗領域の存在は，熊野大峰複合火成岩類の縁を囲むように湧出している高い 3He/4He 同位体比を示す高温泉が深部起源であるという解釈と整合的である．このような地下比抵抗構造と深部流体の特徴的な空間分布との対応から，紀伊半島の地下における流体の寄与が説明されるようになる可能性がある．

先行研究で用いた Network-MT 法データ (Uyeshima et al., 2001; Uyeshima, 2007) は，商用電話網を用い，長期線で (10〜数十 km) の電圧差を測定する．この方法は，従来の MT 法よりも，広域深部の構造を推定する上で次の 3 点において優れている．(1) S/N 比が高くデータが高品質である点，(2) 長周期側 (〜50000 秒) で良好な応答関数の推定が可能である点，(3) 表面近傍の小スケールの比抵抗コントラストの影響を受けにくい点．しかし，使用された Network-MT 法デー

タは深部構造に対する感度が高い反面，高周波データが少ないため，地殻の中上部に対する分解能が低かった．さらに，観測網は電話線のある地域に限られており，空間的な観測ギャップも生じていた．これらの欠点を解決するために，我々は既存の従来の MT 法データもあわせて解析し，さらに，周波数と空間領域における観測ギャップを埋める観測を実施することを計画している．その一環として，2017〜2018 年にかけて LEMI の収録装置を用いて観測された既存の長周期データを解析し，ＭＴ応答関数を算出した．本発表では，それらの空間分布的特徴について示す．

R003-P06
ポスター 4 ：11/26　AM1/AM2 （9:00-12:00）

蔵王山 AMT 探査及び浅部伝導層と深部伝導体の比抵抗信頼区間推定

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An AMT exploration of Zao Volcano, NE Japan, and resistivity confidential interval assessment for the conductive characters

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Studies of the electrical resistivity structures beneath active volcanoes commonly reveal a shallow electrically conductive layer at a depth above sea level and a conductive body at 0 to 3 km depth below sea level (bsl) (e.g. Tsukamoto et al., 2018; Yoshimura et al., 2018; Tseng et al., 2020). The shallow conductive layer is considered a hydrothermal alteration layer and blocks or allows the upwelling of hydrothermal fluids. The deeper conductive body is interpreted as a magma and/or hydrothermal reservoir. Zao Volcano, NE Japan, is the nearest (about 40 km) active volcano to Sendai City and is concerned with erupting in the near future. This study aims to evaluate the resistivity structure down to a depth of 2 km bsl by expanding the audio-frequency magnetotelluric (AMT) observations at Zao Volcano to detect the shallow conductive layer and the deep conductive body. If detected, we assess the sensitivity of those conductive zones.

The AMT impedance and geomagnetic transfer functions in 1-10k Hz were acquired at 60 stations in a 1 km $\times$ 1 km area centered on the crater lake, Okama, Zao Volcano, and inverted into a three-dimensional resistivity model using WSINV3D-MT code (Siripunvaraporn & Egbert, 2009). The resultant three-dimensional resistivity model represents a conductive layer within $\pm$ 1 km from east to west, north to south, centered on Okama, down to 500 m depth above sea level. The model also shows a conductive body centered at a depth of 1.5 km bsl, with a diameter of about 500 m. The shallow conductive zone has a distinct low resistivity (1-10 Ohm-m), while the conductiveness of the deep conductive body assumes weak to moderate (10-100 Ohm-m). The confidence interval resistivity (CIR) with a 99 % level of the shallow conductive zone less than 3 Ohm-m was estimated to be 1.5-2.5 Ohm-m using Welch's t-test. On the other hand, we could not constrain the significant CIR of the deep conductive body. Regarding the shallow conductive layer, we will show an estimation of a smectite volume fraction in the presentation using the confidence interval of resistivity and the smectite surface conduction experimental data (Levy et al., 2018; Revil et al., 2019).