Seismicity of the 2016 Kumamoto earthquakes controlled by resistivity structure

Aizawa Koki Research Group for the resistivity structure around the regions of the 2016 Kumamoto earthquakes[1]
[1] -

The Mj 7.3 Kumamoto earthquake that occurred at 1:25 JST, on 16 April 2016 not only triggered aftershocks in the vicinity of the epicenter, but also triggered earthquakes that were 50 to 100 km away from the epicenter of the main shock. The number of aftershocks and triggered earthquakes that exceeded Mj 3.5 reached 230 on 8 May 2016, located mainly along a NE-SW striking line that is approximate to the western extension of the Median Tectonic Line (MTL). The active seismicity can be divided into three regions: (1) the vicinity of the main faults, (2) the northern region of Aso volcano (50 km northeast of the mainshock epicenter), and (3) the regions around three volcanoes, Yufu, Tsurumi and Garan (100 km northeast of the mainshock epicenter). Notably, the zones between these regions are distinctively seismically inactive. The electric resistivity structure estimated from one-dimensional analysis of the 247 broadband (0.005 to 3000 s) magnetotelluric observation sites clearly shows that the earthquakes occurred in resistive regions adjacent to conductive zones or resistive-conductive transition zones. In contrast, seismicity is quite low in electrically conductive zones, which are interpreted as regions of connected fluids. We suggest that the series of the earthquakes was induced by a combination of local accumulated stress and fluid supply from conductive zones. Because the relationship between the earthquakes and the resistivity structure is consistent with previous studies, evaluations of seismic risk generally can be improved by taking into account the resistivity structure.

Research Group for the resistivity structure around the regions of the 2016 Kumamoto earthquakes consists of following members,

Koki Aizawa, Hisafumi Asaue, Katsuaki Koike, Shinichi Takakura, Mitsuru Utsugi, Hiroyuki Inoue, Ryokei Yoshimura, Ken'ichi Yamazaki,Shintaro Komatsu, Makoto Uyeshima,Takao Koyama,Wataru Kanda, Taro Shiotani, Nobuo Matsushima, Maki Hata, Tohru Yoshinaga, Kazunari Uchida, Yuko Tsukashima, Azusa Shito, Shiori Fujita, Asuma Wakabayashi, Kaori Tsukamoto, Takeshi Matsushima, Masahiro Miyazaki, Kentaro Kondo, Kanade Takashima, Takeshi Hashimoto, Makoto Tamura, Satoshi Matsumoto, Yusuke Yamashita, Manami Nakamoto, and Hiroshi Shimizu.

R003-02 **会場: B** **時間: 11月23日 9:25-9:40**

北海道北部の地震発生境界域における三次元比抵抗構造解析

市原 寛 [1]; 茂木 透 [2]; 内田 利弘 [3]; 山谷 祐介 [4]; 多田 訓子 [5]
[1] なし; [2] 北大・工; [3] 産総研; [4] 産総研; [5] 海洋研究開発機構・D-EARTH

3-D resistivity modeling around a seismicity gap in the Dohoku area, northern Hokkaido

Hiroshi Ichihara[1]; Toru Mogi[2]; Toshihiro Uchida[3]; Yusuke Yamaya[4]; Noriko Tada[5]
[1] KOBEC, Kobe Univ.; [2] Fac. Eng., Hokkaido Univ.; [3] GSJ, AIST; [4] FREA, AIST; [5] D-EARTH, JAMSTEC

A high seismicity zone associated with rapid crustal deformation is recognized in the eastern margin of Japan Sea (e.g., Sagiya, 2001). Because a heterogeneity in the crust is known as one of the major causes of the localized deformation (Iio et al., 2002), a detailed investigation of crustal structure is essential to understand the crustal dynamics. An obvious seismicity gap, a boundary between high and low seismicity areas, is recognized in the Dohoku area, northern Hokkaido Island (Takahashi and Kasahara, 2005). In addition, a slow earthquake of Mw 5.4 is estimated around the gap (Ohzono et al., 2015). Thus, an imaging of crustal structure in this area will provide us important knowledge to discuss the localized crustal deformation and slow earthquakes. In this study, we conducted a magnetotelluric survey at 45 sites in the Dohoku area and modeled a resistivity distribution based on 3-D inversion procedure. The inverted resistivity model shows the following features. 1) A surface conductive layer is distributed in the most part of the study area. The thickness of the conductor increases toward westward and reaches approximately 5 km at the Japan Sea side. The conductive layer is interpreted as Tertiary-Quaternary sedimentary rocks. 2) A dyke-shaped conductive zone is distributed near the seismicity boundary. It possibly reflects the pore-fluid rich area between Sorachi-Yezo and Hidaka belts which was discussed for the southern Hokkaido Island by Ichihara et al. (2016). It may relate to the cause of the seismicity gap. 3) An ultra-conductive area (0.1-10 ohm-m, 0˜10 km deep) is distributed around the fault of the slow earthquakes. Based on the surface geological distribution, the conductor possibly reflects serpentine-related geological structure, which may be associated with the slow slip events. However, a careful interpretation is required because a serpentine in the same geological unit is not so conductive (10-100 ohm-m) (Okazaki et al., 2011).

豊後水道スロースリップ域周辺の広域比抵抗構造

吉村 令慧 [1]; 山崎 健一 [1]; 小川 康雄 [2]; 中川 潤 [1]; 川崎 慎吾 [1]; 小松 信太郎 [1]; 米田 格 [1]; 大内 悠平 [3]; 岡崎 智久 [4]; 鈴木 惇史 [5]; 齋藤 全史郎 [6]; 臼井 嘉哉 [7]; 寺石 眞弘 [1]
[1] 京大・防災研; [2] 東工大・火山流体; [3] 京大・理・地惑; [4] 京大・理; [5] 東工大 理 地惑; [6] 東工大・地惑; [7] 東工大・理・地惑

Large-scale electrical resistivity structure around the long-term Slow Slip Events in the Bungo Channel

Ryokei Yoshimura[1]; Ken'ichi Yamazaki[1]; Yasuo Ogawa[2]; Jun Nakagawa[1]; Shingo Kawasaki[1]; Shintaro Komatsu[1]; Itaru Yoneda[1]; Yuhei Ouchi[3]; Tomohisa Okazaki[4]; Atsushi Suzuki[5]; Zenshiro Saito[6]; Yoshiya Usui[7]; Masahiro Teraishi[1]
[1] DPRI, Kyoto Univ.; [2] VFRC, Titech; [3] Earth and Planetary, Kyoto Univ; [4] Kyoto Univ.; [5] earth and planetary sciences, Tokyo institute of technology; [6] Department of Earth and Planetary Sciences , Tokyo Institute of Technology; [7] Earth and Planetary sciences, Tokyo Tech.

Recent geodetic observations detect recurrent slow slip events (SSEs), which occurred beneath the Bungo Channel and southwest Shikoku Island, with interval of approximately 6 years (e.g. GSI, 2010). In order to reveal a large-scale three-dimensional resistivity structure around SSEs region, we are carrying out wideband magnetotelluric (MT) surveys. We also plan to establish a permanent long-term MT monitoring network that aims to detect temporal changes of resistivity structure during SSE cycle. As of June, 2016, MT surveys were performed at 31 sites by using Phoenix wideband MT instruments. In the most of sites, high quality MT responses were obtained using the BIRRP code (Chave and Thomson, 2004) for the period range 300 Hz to 10,000 sec. The spatial distributions of the phase tensor ellipses and the induction vectors suggest that resistivity contrasts are located around SSEs.

豊後水道では、約6年間隔でのスロースリップイベント（SSE）の発生が検出されている（例えば、国土地理院, 2010）。SSEは、プレート境界面上で高速破壊域になると考えられている領域の深部延長部に発生しており、その発生場の状態解明は、メカニズムやプレート間カップリングの多様性を理解する上で重要である。そこで我々は、豊後水道SSE発生域周辺の三次元比抵抗構造を明らかにすることを目的に、四国西部域において面的に広帯域Magnetotelluric（MT）観測を計画・実施している。加えて、SSEの発生メカニズムに流体が関与するならば、その分布およびそれを反映した比抵抗構造も、SSEの発生サイクル内で時間変化する可能性があると考え、2015年1月より京都大学防災研究所宿毛観測室において比抵抗構造の時間変化のモニタリングのための長周期MT連続観測も開始した。

本発表では、モニタリングの可能性評価や最適配置を考える上で必要不可欠である、バックグラウンドの三次元比抵抗構造推定の現状を報告する。2016年7月現在、31観測点での広帯域MT観測を完了し、BIRRPコード（Chave and Thomson, 2004）を使用した時系列解析により、300Hzから1万秒の周期帯において良質なMT応答関数を推定した。MT応答の位相テンソルやインダクションベクトルの分布から、SSE発生領域を囲む比抵抗構造のコントラストが存在する可能性が示唆される。広帯域MT観測の概要や得られたMT応答の特徴、予察的な三次元構造解析結果などを報告する予定である。

Signature of the oceanic lithosphere asthenosphere system from seafloor electromagnetic and seismic observations

Hisashi Utada[1]
[1] ERI, Univ. Tokyo

In-situ geophysical observations provide key information to understand the signature of the oceanic lithosphere-asthenosphere system (LAS), although the relation between physical and mechanical properties of the mantle rocks is neither simple nor well understood. Recently magnetotelluric array studies have been carried out in different tectonic settings mostly in the Pacific Ocean with wide range of seafloor age (0-150 Ma). Results are inverted to either 1D, 2D or 3D model of electrical conductivity distribution in the upper mantle down to depths of several hundred km, and all available 1D profiles are compiled. Generally, thus estimated 1D profile consists of shallower low conductivity and deeper high conductivity layers (called as LCL and HCL, respectively). The LCL-HCL (LH)-transition occurs at depth of 50 km or deeper, and some results show a good correlation to the seismologically determined LID-LVZ transition. Below the LH-transition, electrical conductivity is almost constant or its variation is very gradual.

We examine the age dependence of the LH-transition depths and the typical HCL conductivity values based on thus compiled 1D profiles. The HCL conductivity is found to show little age dependence, taking value of about -1.4 in log scale (about 0.04 S/m). Only exception so far obtained is the result from the Cocos plate subduction zone (Naif et al., 2013), in which the typical conductivity value is as high as about 0.2 S/m (isotropic part). On the other hand, the age dependence of the LH-transition depth is apparently more complicated. However, if we exclude a few profiles near plate boundary such as the EPR (Evans et al, 2005) or the NW Pacific subduction zone (Baba et al., 2013), we found that the transition depth is mostly following the cooling of a plate, implying dominance of its thermal control. Of course available observation data are not enough to rule out other possible interpretation (e.g., compositional control). We definitely need more array observations (seismic and EM jointly) from different areas, as well as understanding the basic physics that relates physical to mechanical properties, for further elucidating the oceanic LAS.

沖縄トラフ伊平屋北海丘の3次元比抵抗構造

臼井 嘉哉 [1]; 笠谷 貴史 [2]; 小川 康雄 [3]; 岩本 久則 [4]
[1] 東工大・理・地惑; [2] JAMSTEC; [3] 東工大・火山流体; [4] 海洋研究開発機構

Three-dimensional resistivity structure around the Iheya North Knoll in the middle Okinawa trough

Yoshiya Usui[1]; Takafumi Kasaya[2]; Yasuo Ogawa[3]; Hisanori Iwamoto[4]
[1] Earth and Planetary sciences, Tokyo Tech.; [2] CEAT, JAMSTEC; [3] VFRC, Titech; [4] JAMSTEC

The Iheya North Knoll is located on the northern termination of the Iheya Graben, a depression in the middle Okinawa Trough extending around 100 km in an ENE-WSW strike. In the knoll, the volcanic body penetrates through a sedimentary sequence and rises about 500 m above the seafloor (Tsuji et al., 2012). On the eastern flank of the western peak of the knoll, hydrothermal field with about tens of active hydrothermal mounds were situated, facing the Central Valley (Ishibashi et al., 2015). In the middle Okinawa trough, Shimakawa and Honkura (1991) revealed the two-dimensional resistivity structure along a profile orthogonal to the Ryokyu trench-arc system by using the magnetic transfer function. Since, however, the minimum period of the data was 30 minute and the observation sites were sparsely distributed, detailed resistivity structure in the crust has not ever been obtained in the middle Okinawa Trough, including the area around the Iheya North Knoll.

In order to reveal the resistivity structure around the Iheya North Knoll, we performed three-dimensional inversions with the data obtained by marine magnetotelluric survey of Japan Agency for Marine-Earth Science and Technology (JAMSTEC). In the inversions, so as to prevent the misinterpretation of subsurface structure due to the bathymetric effects on the observed response functions, we utilized the scheme proposed by Usui (2015), which enabled us to incorporate precise bathymetry around the knoll into the computational mesh with the aid of the unstructured tetrahedral element. In the obtained resistivity structure, there was a conductive surface layer (lower than 3 Ohm-m) and an underlying resistive layer (higher than 100 Ohm-m). The former conductive layer is considered to be consistent with the pelagic/hemi-pelagic sediments and the highly permeable zones within the upper crust where hydrothermal fluid migration occurs (Tsuji et al., 2012).

R003-06 **会場: B** **時間: 11月23日 10:30-10:50**

One-dimensional resistivity structure of Iwo-yama, Kirishima Volcanoes

Kaori Tsukamoto[1]; Koki Aizawa[2]; Wataru Kanda[3]; Kaori Seki[4]; Takahiro Kishita[4]; Makoto Uyeshima[5]; Mitsuru Utsugi[6]; Takao Koyama[7]
[1] Grad.Sch.Sci.,Kyushu Univ.; [2] SEVO, Kyushu Univ.; [3] KSVO, Tokyo Inst. Tech.; [4] Earth and Planetary Sciences, Tokyo Tech.; [5] ERI, Univ. Tokyo; [6] Aso Vol. Lab., Kyoto Univ.; [7] ERI, University of Tokyo

Iwo-yama is located in Kirishima volcanic group, southern part of Kyushu Island, Japan. Around Iwo-yama and Karakuni-dake, tectonic earthquakes have increased since December 2013, and volcanic tremors have occasionally occurred since July 2015. In December 2015, fumarolic gases appeared at the southwest of the crater of the Iwo-yama for the first time in 12 years. Moreover the leveling survey detected the ground uplift more than 1 cm during June to December 2015 (Matsushima et al., 2015), while the interferometry observations detected the ground uplift at 4 cm (134th Coordinating Committee for prediction of volcanic eruption). These events suggest that volcanic activity has been increasing in Iwo-yama.

Previous magnetotelluric survey at the site 400 m northeast of Iwo-Yama imaged the electric conductive zone approximately at a depth of 0.1 to 0.7 km, and interpreted it as the low permeability altered clay layer (Aizawa et al., 2013). The upper level of the hypocenters of tectonic earthquakes corresponds to the bottom of the conductive zone. In addition, the pressure source by the leveling survey also corresponds to the bottom of the conductive zone. These spatial relationships suggest that the supply of high temperature fluids has increased beneath Iwo-yama, and causes the increase in pore pressure beneath clay layer, resulting in the increase of earthquakes and ground inflation. In order to examine this hypothesis, we conducted the broadband (0.005˜3000s) magnetotelluric (MT) measurements around the Iwo-yama. As compared to audio-magnetotellurics (AMT), broadband MT have advantage in that it can resolve a resistivity structure to a depth greater than the bottom of the shallow conductive zone. During 11 April 2016 to 30 April 2016, we recorded two components of electric fields at 20 observation sites and five components of electric and magnetic fields at 7 observation sites. In this presentation, we will show one-dimensional resistivity structure of each station, and discuss the association with the earthquakes and inflation source.

R003-07 **会場: B** **時間: 11月23日 11:10-11:25**

屈斜路カルデラ下の３次元比抵抗構造

本多 亮 [1]; 市原 寛 [2]; 山谷 祐介 [3]; 長谷 英彰 [4]; 茂木 透 [5]; 上嶋 誠 [6]; 中川 光弘 [7]
[1] 東濃地震研; [2] なし; [3] 産総研; [4] 東工大・火山流体; [5] 北大・工; [6] 東大・震研; [7] 北大・理・地惑システム

Three Dimensional Resistivity Structure under the Kutcharo Caldera

Ryo Honda[1]; Hiroshi Ichihara[2]; Yusuke Yamaya[3]; Hideaki Hase[4]; Toru Mogi[5]; Makoto Uyeshima[6]; Mitsuhiro Nakagawa[7]
[1] TRIES, ADEP; [2] KOBEC, Kobe Univ.; [3] FREA, AIST; [4] KSVO, Tokyo Tech; [5] Fac. Eng., Hokkaido Univ.; [6] ERI, Univ. Tokyo; [7] Hokkaido Univ.

Kutcharo caldera is the biggest caldera in Japan, which has been repeating large-scale eruption. It is very important to clarify the eruption mechanism of the Kutcharo volcano, which has potential to cause catastrophic eruption. The eruption history with its mechanisms has been investigated based on tephra stratigraphy (e. g. Katsui et al., 1975, J. Fac. Sci. Hokkaido Univ.; Hasegawa et al., 2008, Earth Monthly; Kishimoto et al., 2009, Kazan). There are some report for the caldera structure by gravity surveys and AMT explorations (e. g. Yokoyama, 1958, J. Phys. Earth; Honda et al., 2011, J. Fac. Sci. Hokkaido Univ.; Ichihara et al., 2009, EPS), however, no obvious structures which associate any volcanic activities has been reported. We report the result of the 3-Dimensional analysis of the resistivity structure in and around the Kutcharo caldera.

We already noted about the observations and the data in Honda et al. (2011, J. Fac. Sci. Hokkaido Univ.). Again, we compiled the wide-band MT data from Ichihara et al. (2009) and Ichihara et al. (2013, Tectonophysics), which are the observation data around the focal area of Teshikaga Earthquake. We adopted the remote reference analyses (Gamble et al., 1978, Geophysics) to those MT data. We used the reference magnetic data of Kakioka Magnetic Observatory and the Esashi station for the long wavelength and the wide-band data, respectively.

The summary of the characteristic resistivity structures assumed by 2-D analyses by Honda et al. (2011) was as follows: 1) Surface tephra layer which exhibits 100 ohm-m, 2) Tertiary under the tephra layer which exhibits more low resistivity, 3) Further deeper part shows high resistivity again, and the back-ark side exhibits lower values compared to the for-ark side, 4) The extraordinary low resistivity body is piercing the high resistivity layer towards the Atosanupri volcano from the deep layer. As "4)" is three dimensional structure, there was an importance for the three dimensional analyses. The three dimensional analysis is executed by WSINV3DMT (Siripunvaraporn et al., 2005, PEPI; Siripunvaraporn et al., 2009, PEPI). As a result, the conductor under the Kutcharo caldera became more sharpen. We also recognized the conductor under the Akan volcano, the western part of the research area. We will report the overview of the result.

Acknowledgement

For this study, we have used the computer systems of the Earthquake and Volcano Information Center of the Earthquake Research Institute, the University of Tokyo. We are thankful for the magnetic data provided by the GSI and MAJ.

屈斜路カルデラは日本最大のカルデラであり，後カルデラ火山活動を含めて大規模な噴火活動を繰り返してきた．破局的噴火を引き起こすポテンシャルを持つ屈斜路火山についてその噴火メカニズムを解明することは非常に重要であるといえ，これまでにテフラ層序の調査等によりその噴火様式とともに噴火史が詳細にされてきている（たとえば Katsui et al., 1975，J. Fac. Sci. Hokkaido Univ.；長谷川・ほか，2008，月間地球；岸本・ほか，2009，火山）．一方で周辺地域を含めた地下構造については重力探査および AMT 探査などによるいくつかの報告があるものの（Yokoyama，1958，J. Phys. Earth；本多・ほか 2011，北大地物報告； Ichihara et al., 2009，EPS），火山活動との関連が示唆されるような詳細な構造は明らかにされていない．我々は屈斜路カルデラ周辺で行った MT 法比抵抗探査結果について，3 次元インバージョン解析を試みたので報告する．

観測の概要や使用した機材については既に本多・ほか（2011，北大地物報告）で報告したとおりで，本報告の解析も新規観測データと Ichihara et al.（2009，EPS）および Ichiara et al. (2013, tectonophysics）による弟子屈地域地震発生域周辺の広帯域 MT 調査データと併せて行った．広帯域データについては国土地理院水沢測地観測所・江刺観測場の磁場データを，長周期のデータについては気象庁柿岡磁気観測所の磁場データを用いてリモートリファレンス処理（Gamble et al., 1978，Geophysics）を行った．

2 次元解析の結果確認できていた特徴をまとめると，テフラに覆われる表層が数 100 Ω m の高抵抗域となっている，テフラよりも下層は低抵抗を示し，第三紀層に相当すると考えられる，さらに下層は再び高抵抗を示すが，背弧側の抵抗値は前弧側に比べて低い値を示す，地殻深部の高抵抗域中を貫く低抵抗領域が存在し，アトサヌプリ直下へ繋がっている，といったところで，特に 3 次元的な構造であるに関してその像の真偽を確かめるためにも 3 次元解析を行う必要性が高かった．3 次元インバージョン計算は WSINV3DMT（Siripunvaraporn et al., 2005, PEPI; Siripunvaraporn et al., 2009, PEPI）により行った．その結果２次元解析の結果に現れたものに比べてよりシャープに引き締まった低抵抗構造が屈斜路カルデラ直下に現れた．また，観測点網の中央域からはやや外れるが，阿寒カルデラ下にも低抵抗領域が確認できた．報告ではこれらについて詳しく述べる．

本研究のために東京大学地震研究所地震火山情報センターの計算機システムを利用しました．また，解析では気象庁および国土地理院の磁場連続観測データを使用しました．記して感謝いたします．

R003-08 **会場: B** **時間: 11月23日 11:25-11:40**

Wide range MT and GDS responses at Kakioka, Kanoya and Memambetsu

Ikuko Fujii[1]
[1] Meteorological College

An attempt to estimate the magnetotelluric (MT) response at periods ranging from 6 sec to 8 days is reported.

Geoelectric voltage differences have been continuously observed at Kakioka, Kanoya, and Memambetsu in Japan for more than 60 years by Kakioka Magnetic Observatory, Japan Meteorological Agency. Fujii et al. (2015) estimated the MT responses at the three sites by using the geoelectric and geomagnetic fields measured for a recent 11-year period (2000 to 2011); the responses were stably computed at the three sites at periods of 6 to 10^4 sec, and the period was extended to ~10^6 sec at Kakioka and Memambetsu. However, the responses at the longest period band have large error bars or show unreasonable behaviors.

In this study, I update the MT responses at all three sites at periods longer than 10^4 to complete a response data set at a very wide period range. Sq variations and a long-term trend caused by the instability of the observation system need to be removed before estimation of the response in this period band.

The least squares fit of the sinusoids over specific periods were used to remove the Sq and tidal influences from both the geoelectric and geomagnetic fields. Periods considered are 24 hours and their harmonics including seasonal variations of the Sq amplitude as well as major tides.

The robust Kalman filter procedure was applied to the geoelectric field to remove the long-term trend. A hyper parameter for the trend component was set for a flexible variation and estimated trends contains variations at periods longer than 2 days.

Then, I tried to estimate the MT response at periods from 10^4 to 10^6 sec at the three sites. Four tensor components of the response at periods shorter than about 10^5 sec are successfully obtained. The responses connect smoothly at the period of 10^4 sec to those at shorter periods. At periods longer than 10^5 sec, the MT responses related to the northward component of the geomagnetic field (Zxx and Zyx) are stably computed, while those related to the eastward component of the geomagnetic field (Zxy and Zyy) have large uncertainties. This is probably because of the source field geometry. The coherence between the geoelectric and geomagnetic fields starts decreasing at 10^4 and starts increasing at the period of 2 x10^5 sec.

The induction vectors and phase tensor parameters were also computed at the three sites. KAK and KNY have similar induction vectors and phase tensor. MMB shows three dimensional features.

R003-09 **会場: B** **時間: 11月23日 11:40-11:55**

2000年三宅島噴火における傾斜ステップに伴う地磁気変化の再検討(序報)

笹井 洋一[1]; 上嶋 誠[2]
[1] 東海大・海洋研・地震予知セ; [2] 東大・震研

Magnetic changes accompanying the tilt-step events during the 2000 eruption of Miyake-jima volcano

Yoichi Sasai[1]; Makoto Uyeshima[2]
[1] EPRC, IORD, Tokai Univ.; [2] ERI, Univ. Tokyo

The 2000 activity of Miyake-jima volcano, central Japan, began with magma intrusion, followed by the depression of the summit area along with some episodic eruptions from the new sink-hole. The sink-hole enlarged to form a new caldera. During the caldera formation, a rapid crustal deformation called ’tilt-step’ occurred once or twice a day, which was detected by bore-hole tiltmeters in Miyake-jima island (Ukawa et al., 2000): it is characterized by abrupt uplift toward the summit area followed by gradual subsidence with more than several hours duration. Electric and magnetic field variations associated with the tilt-step events were observed by the island-wide SP observation network using telephone cables and by proton magnetometers array (Sasai et al., 2002). As for the mechanical source for the tilt-step, they assumed the sudden inflation of a spherical pressure source (Mogi model), i.e. the magma chamber, and ascribed the SP variations to the electrokinetic effect due to the forced fluid injection from the magma chamber. They also ascribed the magnetic variations to the piezomagnetic effect due to stress changes associated with the inflation of the magma chamber.

However, the forced fluid injection model was rejected recently by Kuwano et al. (2015), in which they concluded that the uniform expansion source could not explain the spatial sign distribution of SP changes. They proposed the poroelastic electrokinetic model, which could reproduce the observed SP variations accompanying the fluid flow induced by sudden appearance of the mechanical pressure source. They adopted a vertical tensile crack for the mechanical source, which was originally proposed by Kumagai et al. (2001) with the aid of the moment tensor inversion for the velocity wave form of tilt-step events. Sasai et al. (2002) proposed the Mogi model as the source for magnetic variations associated with tilt-step events. Currenti et al. (2005) obtained the best-fit source parameters of the piezo-magnetic Mogi model using a genetic algorithm technique.

Moreover, new data for magnetic variations are provided by courtesy of NIED (National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan). Fig. 1 shows the location of proton magnetometers (ERI) and 3-components magnetometers (NIED) in Miyake-jima island. TMF (total magnetic field) changes associated with tilt-step events were observed at several points, which are reproduced in Fig. 2 (Sasai et al., 2002). The 3-component magnetometers (NIED) were installed at two sites, MKK and MKT, which are also shown in Fig. 1. The sampling interval of the 3-component magnetometers is 1 second (GPS-controlled) in contrast to 1 minute for proton magnetometers.

The largest tilt-step event took place on July 14, 2000. Fig. 3 shows X (north), Y (east) and Z (down) component magnetic changes observed at MKT and MKK, which are subtracted from simultaneous data at Kakioka (KAK). Two blue-colored bars in each component indicate the duration of the VLP (Very-Long-Period) seismic wave, during which the tilt-step event occurred (Ukawa et al., 2000). The electric field accompanies the fluid flow induced by an abrupt deformation of the volcano (Kuwano et al., 2015), which can produce the magnetic field by the piezomagnetic effect. Now we are to examine if the mechanical source for the tilt-step can explain the observed magnetic variations. New 3-component magnetic data should strongly constrain the mechanical source parameters. According to Kumagai et al. (2001), the first-order approximation to the source was a vertical tensile crack. It can be regarded as a far-field solution for the magma plumbing system. Further studies will be required on the piezomagnetic field due to an ellipsoidal source.

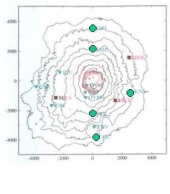


Fig. 1. Observation sites. Blue circle: F. Red square: 3 comp.

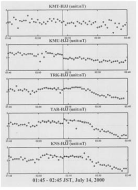


Fig. 2. TMF changes at the tilt-step event on July 14, 2000. Minutely plot.

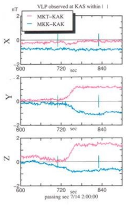


Fig. 3. 3 comp data at MKK (NE: Blue) and MKT (SE: Red).

R003-10 **会場: B** **時間: 11月23日 11:55-12:10**

地震波により励起された電磁波の放射と検出状況

筒井 稔 [1]
[1] 京産大

Detecting condition of electromagnetic pulses excited by earthquakes

Minoru Tsutsui[1]
[1] KSU

Since December, 2011, I have been detecting co-seismic electromagnetic (EM) pulses by an EM sensor system installed at the bottom of a borehole of 100 m in depth. The excitation mechanism of the EM pulse below 25 Hz was confirmed by a laboratory experiment as the piezo-electric effect in the earth's crust [1]. I am confident that EM pulses excited by seismic P waves are amplified by the large amplitude of the seismic S waves and that the EM pulses were decaying after short distant propagations in the earth [2]. Furthermore, I have been also observing EM noise above the ground for clarifying the behaviour of EM pulses after their radiations from the earth. As the result, it was confirmed that the excited EM pulses can be readily leaked out of the ground surface [1]. However, any EM pulses which would be exited at the hypocentre of earthquakes have never been detected at the EM observation site at its rupture time. The reason has remained unknown.

Recently, I found a new data which can explain the reason. An earthquake occurred in 11 km depth of a place 24.8 km west-north-west of the EM observation site at 21:1:38.8 JST on July 10, 2016. Figure 1(a) shows a waveform of the east-west component of an ELF magnetic field, and (b) shows that of seismic east-west component detected simultaneously at the EM observation site. Their pulses were detected at 21:13:47.66 JST. Although the waveform of the seismic S wave shows a peak amplitude at that time, that of EM wave shows an increasing trend in its amplitude until 21:13:48.35 JST.

On the other hand, the earth's surface at the EM observation site is formed by the sedimentary layer. Since the dielectric constant of the sedimentary layer is about 40, the critical angle of total internal reflection for the EM waves propagating from the earth becomes 9.1 degree. Therefore, EM waves can leak out of the ground surface from the earth in directions within the angle. Since the amplitude of EM waves become maximum at the vertical upward direction, The EM pulse at 21:13:48.35 JST was the vertical upward propagation. During the period of 0.69 second up to 21:13:48.35 JST, the seismic wave had propagated horizontally about 2.16 km. From this distance and the angle of 9.1 degree, the depth of the EM pulse excitation region was identified as 13.1 km. This result is consistent with the configuration of EM wave excitation in the earth.

As the result, we can understand that an EM pulse radiated vertically at the hypocentre of earthquake cannot be detected at the EM observation site fur from the epicentre of the earthquake.

[1] Minoru Tsutsui, Behaviors of Electromagnetic waves Directly Excited by Earthquakes, IEEE Geoscience and Remote Sensing Letters, Vol. 11, No. 11, pp. 1961-1965, 2014. (DOI: 1109/LGRS.2014.2315208, Now Open Access)

[2] Minoru Tsutsui, Derivation of Electrical Parameters of Earth's Medium from Electromagnetic Waves Excited by Earthquakes, IEEJ Transactions on Fundamentals and Materials, Vol. 136 No.5 pp.221-226, 2016. (DOI:10.1541/ieejfms.136.221) (in Japanese).

2011年12月以降、電磁波観測点にある深さ100 mの地中ボアホール内に設置した磁界センサーで、地震波の到来と同時に電磁波の磁界パルスをも検出できるようになった。25 Hz以下の周波数範囲を持つこの種の電磁波の励起機構は、地震により岩盤内に生じたP波（縦波）の振動による圧電効果によるものである事を、室内実験の結果により確かめた[1]。地震発生後、振動振幅の小さいP波は常に岩盤内に充満した状態の所に、振幅の大きなS波が到来すると、P波の振幅も大きく歪まされるために、励起される電磁波の振幅は大きなパルス状となる。ところが地中媒質の電気伝導度の大きさのため、電磁波振幅は距離と共に急激に減衰している事が判った[2]。一方、放射された電磁波の地上への振る舞いを調べるために、地中と地上での同時観測を行ったところ、地上では、地中での振幅よりも大きく検出される事が判った。即ち、電磁波観測点での震度が1程度の弱い地震波であっても、電磁波を検出できる事を確認している。このように検出感度が良いと思われるのに、地震発生時刻に震源で励起されたと思われる電磁波について、その検出が確認されておらず、大きな疑問として残されていた。ところが今回、新たなデータが得られ、その解析により、震源において励起された電磁波を十分には検出できない理由が判ったので、それについて報告する。

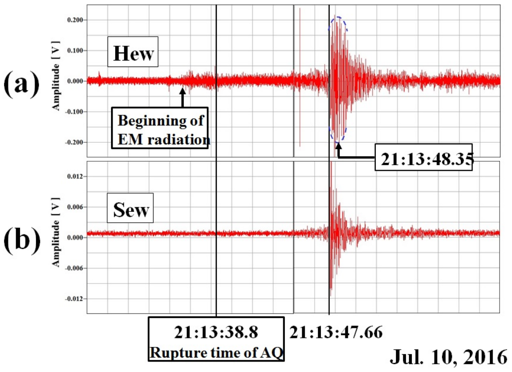
図は2016年7月10日の21:13:38.8 JSTに電磁波観測点の西北西24.8 kmの地点の深さ11 kmで起きたM3.0の地震に伴って検出された電磁波の磁界成分と地震波の波形データである。同図(a)は地震が電磁波観測点に到達して、地上のセンサーで検出した電磁波の磁界東西成分を表しており、(b)は同観測点で検出した地震波加速度の東西方向成分を示している。地震S波の電磁波観測点への到達時刻は21:13:47.66 JSTとなっており、電磁波磁界もほぼ同時刻に検出している。このため地震S波の平均伝搬速度は3.05 km/secである。

一方、電磁波観測点は堆積層から成っており、その比誘電率を約40とした場合、地中から地上への電磁波の放射を考えると、その臨界角は垂直上向きから9.1度である。即ち、その角度より大きくなると全反射を起こし、電磁波は地上には現れない。しかし、その角度以内の時のみ地上に放射される。特に地表に対して垂直上方への放射の場合は、電磁波振幅は最大となる。図(a)を見ると、21:13:47.66 JSTにおいて、電磁波の検出を開始した臨界角の状態で、その後に振幅

が増加し、0.69 秒後の 21:13:48.35 JST に平均的最大振幅（ピーク）を示しているので、この時 S 波の波頭部分が電磁波センサーの直下にあったと考えられる。この間に S 波が移動した距離は 2.10 km となるので、臨界角が 9.1 度とすると、この時の電磁波励起位置は地上センサーの直下 13.1 km にあった事が判る。

この解析結果から、半頂角 9.1 度で深さ 13.1 km の狭い円錐状内の領域を電磁波が上方に放射しており、地上に放射された後の水平方向への広がりは回折によるため、その成分は極めて弱くなっている事が考えられる。この理由により、電磁波観測点から離れた震源で放射された電磁波を殆ど検出できない事が理解できる。今後は M3 以上の規模の地震について、地震発生時刻に強い電磁波が励起されたとして、その回折波成分を検出できるかどうかを確認する予定である。

[1] Minoru Tsutsui, Behaviors of Electromagnetic waves Directly Excited by Earthquakes, IEEE Geoscience and Remote Sensing Letters, Vol. 11, No. 11, pp. 1961-1965, 2014.
(DOI: 1109/LGRS.2014.2315208, Now Open Access)
[2] 筒井稔, 地震波で励起された電磁波による地中媒質の電気的パラメータの算出,
電気学会論文誌 A, Vol. 136 No.5 pp.221-226, 2016. (DOI10.1541/ieejfms.136.221)



R003-11 **会場: B** **時間: 11月23日 12:10-12:25**

地磁気計測用 SQUID システムにおけるシールドノイズの評価と改善

河合 淳 [1]; 宮本 政和 [1]; 河端 美樹 [1]; 春田 康博 [1]; 上原 弦 [1]
[1] 金沢工大・電子研

Evaluation and improvement of shield noise in LTS-SQUID magnetometer system for geomagnetic field observation

Jun Kawai[1]; Masakazu Miyamoto[1]; MIKI KAWABATA[1]; YASUHIRO HARUTA[1]; GEN UEHARA[1]
[1] AEL, KIT

We have been developing and testing a low-Tc superconducting quantum interference device (LTS-SQUID) magnetometer system for highly sensitive observation of geomagnetic fields. In the previous study, we reported improvements in the performance of the system, by developing a low-noise flux-locked loop (FLL) circuits and using a 24-bit data logger. By observing the Earth fields with the system at Shiramine, Hakusan-city, we confirmed that the system could detect Schumann resonance and ionospheric Alfven resonance, which are smaller than 1 pT/rtHz.

However, the background noise in the observation was 0.2 pT/rtHz, which was not a smaller value than expected. In order to determine if the background noise is attributed to the system noise or not, we evaluated the thermal noise of the RF shield made of copper foil, which is covered around the SQUID magnetometers. As a result, we found that the low-frequency noise due to the RF shield was not negligible and possibly limited the system performance.

In this study, we will evaluate the noise generated from the RF shield. We will also show the performance in combination with an improved shield and new SQUID magnetometers, whose intrinsic noise is reduced by half compared to that of the SQUID used in the previous study.

我々は LTS-SQUID を用いた高感度地磁気計測システムの開発と検証を行っている。昨年の発表では、プリアンプのドリフトを低減した FLL 回路の開発と 24bit データロガーの採用によるシステム性能の改善について報告した。また改良システムを用いての石川県白山市白峰での観測試験の結果、1pT/√Hz 以下の信号である Schumann 共鳴および電離層 Alfv&#233;n 波共鳴が検出できる性能を有することが確認できた。

一方、背景ノイズは 0.2pT/√Hz@30Hz 程度であり、この値はシステム性能改善前の値と余り変わらなかった。この値が自然界由来なのか、それともシステム由来なのかを確認するため、SQUID の周りに施した銅箔製の電磁シールドについて再検討を行った。その結果、低周波における電磁シールドの雑音が大きく、背景ノイズと同等であることがわかった。

本発表では電磁シールドによるノイズの評価および改善についての報告を行い、これまで用いていた SQUID に比べ半分以下のノイズに低減した SQUID との組み合わせにおけるシステム性能を紹介する予定である。

R003-P01 **会場: Poster** **時間: 11月21日**

宮城県北部地震活動域における３次元比抵抗構造解析（2）

齋藤 全史郎 [1]; 小川 康雄 [2]; 市來 雅啓 [3]; 鈴木 惇史 [4]; 木下 雄介 [5]; Amatyakul Puwis[6]
[1] 東工大・地惑; [2] 東工大・火山流体; [3] 東北大・院理・地震噴火予知センター; [4] 東工大 理 地惑; [5] 東工大・理・地惑; [6] 東工大火山流体

3D magnetotelluric imaging of fluid distribution in a seismogenic region, Miyagi, NE Japan

Zenshiro Saito[1]; Yasuo Ogawa[2]; Masahiro Ichiki[3]; Atsushi Suzuki[4]; Yusuke Kinoshita[5]; Puwis Amatyakul[6]
[1] Department of Earth and Planetary Sciences , Tokyo Institute of Technology; [2] VFRC, Titech; [3] RCPEV, Grad. School of Sci, Tohoku Univ.; [4] earth and planetary sciences, Tokyo institute of technology; [5] Earth and planetary Sciences, Tokyo Tech; [6] VFRC, Titech

Northern Miyagi is located in one of the strain concentration zones in NE Japan (Miura et al.,2004). This area is known to have high seismicity and experienced two large earthquakes, the 1962 Northern Miyagi Earthquake (M6.5) and the 2003 Northern Miyagi Earthquake (M6.2). The 2003 earthquake was well studied and its focal mechanism and aftershock distribution support that the earthquake was a high angle reversed fault, which is a reactivation of an originally normal fault, created in the Miocene during the Japan opening. The surface extension of the fault is recognized as a flexure. Geologically, the area is mostly simply covered with thick sediment and is surrounded by granitic rocks of Kitakami Mountains to the east and to the north. A high magnetic anomaly under the Izu-Numa area may represent the existence of relatively deep sediment. The objective of this study is to image the geofluid in three dimensions and relate them to earthquake activities in the region. The previous studies were by 2D modelings. We used MT data at 52 sites in total: 24 sites are new and are arranged in an approximately 2 km grid whereas two older dataset were along profiles, one NEE-SWW profile with 18 sites (Mitsuhata et al., 2001), and one NNE-SSW profile with 12 sites (Nagao, 1997). We inverted the data using WS3dMTINV (Siripunvaraporn and Egbert, 2009). Our preliminary model showed that shallow (less than 5km depth) and deep (deeper than 5km) conductors exist: Shallow conductors represent sedimentary layers. One of them runs along the edge of the Kitakami Mountains. Deep conductors may imply an anomalous body containing saline fluids originating from slab fluids. Two conductors are significant. One is located at south of Izu-numa at 5-10km depth, which is inclined downwards to the west with dip of 30 degrees. Another conductor exists to the south toward the hypocentral region of the 2003 Northern Miyagi earthquake at 10-km depth, which is nearly vertical. And, it seems the two is connected. We noticed that seismic activity is high around the deep conductors covered by high-resistivity. The may imply the episodic migration of fluid from the fluid reservoir to the upper brittle crust triggers high seismicity.

R003-P02 **会場: Poster** **時間: 11月21日**

山崎断層帯主部南東部の琵琶甲断層東セグメントの地磁気地電流調査

倉光 伸 [1]; 山口 覚 [2]; 小田 佑介 [1]; 三島 稔明 [3]; 伊東 修平 [1]; 三村 明 [3]; 村上 英記 [4]; 加藤 茂弘 [5]
[1] 大阪市大院・理・地球; [2] 大阪市大院・理・地球; [3] 大阪市大・理・地球; [4] 高知大・自然科学系・理学部門; [5] 人と自然博

Magnetotelluric survey of the eastern segment of the Biwako fault, the Yamasaki fault zone, southwest Japan

Shin Kuramitsu[1]; Satoru Yamaguchi[2]; Yusuke Oda[1]; Toshiaki Mishima[3]; Shuhei Ito[1]; Akira Mimura[3]; Hideki Murakami[4]; Shigehiro Katoh[5]
[1] Geosciences, Graduate school of Science, Osaka City University; [2] Geosciences, Graduate school of Science, Osaka City University; [3] Geosciences, Osaka City Univ; [4] Natural Sciences Cluster-Science Unit, Kochi Univ.; [5] Museum of Human and Nature Activities, Hyogo

Introduction

The Yamasaki fault zone (YFZ) consists of the Nagisen fault, the main part of the YFZ, and the Kusadani fault. The main part of the YFZ is further divided into a northwestern (NW) group (the Ohara, Hijima, Yasutomi, and Kuresakatouge faults) and a southeastern (SE) group (the Biwako and Miki faults) based on their latest faulting events and mean slip rates; AD 868 and 1.0 m/kyr for the NW group vs. AD400 - 600 and 0.8 m/kyr for the SE group (Okada, 1987; Earthquake Research Committee, 2013).

Audio-frequency Magnetotelluirc (AMT) surveys have made at 81 stations along seven survey lines across the faults of the NW group, while the survey has made at only 29 stations along two survey lines (BWK_W and MIKI lines) across the fault of the SE group.

The two 2-D resistivity models along the BWK_W (Ito *et al.,* JpGU2015) and the MIKI line (Katsumura *et al.,* JpGU2016) were already reported. The former model, named the BWK_W model is characterized by the clear resistivity boundaries beneath the surface trace of the western and the location corresponding to the eastern segments of Biwako fault. The latter model, named the MIKI model is characterized by (1) the shallow sub-horizontal conductive layer and (2) the broad conductive zone which is dominated on the north side of the fault.

We made additional AMT survey along the line between the BWK_W and MIKI lines, because it is important to make clear the subsurface structure of the whole nature of the SE group to know that of the YFZ and difference between the NE and SE groups of the main part of the YFZ.

Observation

AMT surveys were undertaken in February 2015 and March 2016 at 24 stations along the transect (BWK_E line) across the eastern segment of the Biwako fault where is located between the western segment of the Biwako fault and the MIKI fault. The remote station of the magnetic field was made ~18km north from the northeastern end of the transect to analyze the data using the Remote reference method (Gamble *et al.,* 1978). Two horizontal components of electrical field and three components of magnetic field were measured at the stations along the BWK_E line.

Analysis

After MT response functions were obtained, we adopted the phase tensor analysis (Caldwell *et al.,* 2004 ; Bibby *et al.,* 2005) to estimate the dimensionality of the resistivity structure below the study area and to determine the regional strike, if the structure is two-dimensional. Then the two-dimensional resistivity model was constructed using the code of Ogawa and Uchida (1996).

Result

This optimum model obtained (named BWK_E model) is characterized by the two conductive zones : (1) the shallow sub-horizontal conductive layer and (2) the broad conductive zone dominated on the north side of the fault. This feature is quite similar to the MIKI model.

In this presentation, we will show the outline of our observation, data analysis, modeling procedure, and feature of the BWK_E model. We, then, interpret the BWK_E model comparing to the BWK_E model with the BWK_W model and the MIKI model.

はじめに

山崎断層帯は，那岐山断層帯，山崎断層帯主部，草谷断層からなる．山崎断層帯主部は，ほぼ西北西―東南東方向に一連の断層が連なるように分布し，左横ずれが卓越する断層帯である．また，最新活動時期と平均変位速度の違いから北西部と南東部に分けられる．北西部は大原断層，土万断層，安富断層，暮坂峠断層からなり，南東部は琵琶甲断層

と三木断層からなる (地震調査研究推進本部地震調査委員会，2013).

これまでに，山崎断層帯主部での地磁気地電流調査は北西部で 7 測線，81 観測点で行われてきた．一方，南東部では琵琶甲断層西セグメントと三木断層の 2 測線，29 観測点で行われているのみである．

琵琶甲断層西セグメントの比抵抗モデル (BWK_W モデル) (伊東ほか，JpGU2015) は，琵琶甲断層の西セグメントの地表断層位置および東セグメントの延長位置の地下に存在する比抵抗境界で特徴づけられる．三木断層の比抵抗モデル (MIKI モデル) (勝村ほか，JpGU2016) は，(1) 深さ 300m 付近に位置し，ゆるやか (約 10 度) に北東に傾斜する低比抵抗領域層および，(2) 地表断層位置から北東に 1km の深さ 600 m˜1,000 mに位置する低比抵抗領域の 2 つで特徴づけられる．両者の比抵抗モデルを比較するとその特徴は異なる．そこで，琵琶甲断層西セグメントと三木断層の中間に位置する琵琶甲断層東セグメントで，2015 年 2 月と 2016 年 3 月に audio-frequency magnetotelluric (AMT) 観測を実施した．

観測

琵琶甲断層東セグメントと直交する長さ 6km の測線を設け，この測線上の 24 点で AMT 法調査を行った．MT 応答関数の算出に Remote reference 法 (Gamble *et al.,* 1978) を用いるため，測線北端から 18km 離れた点に磁場参照点を設置した．

解析

電場，磁場のそれぞれ水平 2 成分から，Remote reference 法に基づいて，MT 応答関数を算出した．そして，Phase tensor 法 (Caldwell *et al.,* 2004 ; Bibby *et al.,* 2005) を用いて比抵抗構造の次元と走向を求めて，そして，Akaike’s Bayesian Information Criterion (ABIC) による平滑化拘束付き 2 次元比抵抗インバージョンコード (Ogawa and Uchida, 1996) を用いて，2 次元比抵抗モデルを求めた．

結果

得られたモデル (BWK_E モデル) は，(1) 深さ 500m 付近に位置し，ほぼ水平で明瞭である低比抵抗領域層および (2) 地表断層位置から北東に 1˜2km の深さ 1˜1.5km の位置するやや低比抵抗な領域の 2 つで特徴づけられる．

BWK_E モデルおよび MIKI モデルは，いずれも (1) 浅部 (深さ約 300˜500m) のほぼ水平な低比抵抗領域層および (2) 地表断層位置から北東に 1˜2km に位置する低比抵抗領域の 2 つで特徴づけられる．これらの特徴は MIKI モデルの比抵抗モデルと共通している．

本発表では，琵琶甲断層東セグメントの観測・解析の概要および得られた 2 次元比抵抗モデル（BWK_E モデル）の特徴を述べる．そして，すでに得られている BWK_W モデルおよび MIKI モデルとの比較を行いながら，比抵抗構造の解釈を行う．

R003-P03 **会場: Poster** **時間: 11月21日**

紀伊半島のＭＴ法による３次元構造解析 (序報)

木下 雄介 [1]; 小川 康雄 [2]; 齋藤 全史郎 [3]; 市來 雅啓 [4]; 山口 覚 [5]; 藤田 清士 [6]; 梅田 浩司 [7]; 浅森 浩一 [8]
[1] 東工大・理・地惑; [2] 東工大・火山流体; [3] 東工大・地惑; [4] 東北大・院理・地震噴火予知センター; [5] 大阪市大院・理・地球; [6] 阪大・工; [7] 弘前大・理・地球環境; [8] 核燃料サイクル開発機構

Three-dimensional magnetoelluric imaging of Kii peninsula -preliminary results

Yusuke Kinoshita[1]; Yasuo Ogawa[2]; Zenshiro Saito[3]; Masahiro Ichiki[4]; Satoru Yamaguchi[5]; Kiyoshi Fujita[6]; Koji Umeda[7]; Koichi Asamori[8]
[1] Earth and planetary Sciences, Tokyo Tech; [2] VFRC, Titech; [3] Department of Earth and Planetary Sciences , Tokyo Institute of Technology; [4] RCPEV, Grad. School of Sci, Tohoku Univ.; [5] Geosciences, Graduate school of Science, Osaka City University; [6] Technology, Osaka Univ; [7] Earth and Emvironmental Sciences, Hirosaki Univ; [8] JNC

Although Kii peninsula is located in the forearc side of southwest Jpan, it has high temprature hot springs and fluids from mantle are inferred from the isotopic ratio of helium. Non-volcanic tremors underneath the Kii peninsula imply a rising fluid from slab.

Previously, in the southern part of the Kii peninsula, wide band magnetotelluric measurements were carried out (Fujita et al.,1997;Umeda et al.,2004). These studies could image the existence of the conductivity anomaly in the shallow crust and in the deep crust. Long period observation using network MT data showed low resistivity on wedge mantle (Yamaguchi et al.,2009). These studies, however, used two dimensional iversions and three-dimensionally is not fully taken into consideration.

As part of the "Crustal Dynamics" project, we have measured 20 more stations so that the whole wide-band MT stations constitute grids to make three-dimensional modeling of the area.

As an first attempt, we have analyzed previous data (Fujita et al.,1997 and Umeda et al.,2004) by three-dimensional inversions. Preliminaly result showed the followings.

(1) The high resistivity in the eastern Kii peninsula at depths of 5-40km. It is located to the west of the exposed Kumano acidic igneous rocks.

(2) The western part of Kii peninsula has the shallow low resistivity in the upper crust.

(3) The western most part has a deeper conductor in the lower crust.

These features are qualitatively consistent with the previous 2d modeling results. Further modeling incorporating with new 20 sites will be presented.

海底マグネトテルリック観測による西ノ島火山のマグマ溜りイメージングへの挑戦

馬場 聖至 [1]; 多田 訓子 [2]; 市原 寛 [3]; 小山 崇夫 [4]; 杉岡 裕子 [5]; 浜野 洋三 [6]
[1] 東大・地震研; [2] 海洋研究開発機構・D-EARTH; [3] なし; [4] 東大・地震研; [5] 海洋研究開発機構・IFREE; [6] JAMSTEC

Challenge for imaging a magma chamber beneath Nishinoshima volcano by marine magnetotelluric observation

Kiyoshi Baba[1]; Noriko Tada[2]; Hiroshi Ichihara[3]; Takao Koyama[4]; Hiroko Sugioka[5]; Yozo Hamano[6]
[1] ERI, Univ. of Tokyo; [2] D-EARTH, JAMSTEC; [3] KOBEC, Kobe Univ.; [4] ERI, University of Tokyo; [5] IFREE, JAMSTEC; [6] JAMSTEC

Nishinoshima is an uninhabited island oceanic island generated as a volcano on oceanic island arc, which is located about 130 km west of Chichijima in Izu-Bonin islands. It has erupted intermittently since November, 2013 and has enlarged its area by filling in surrounding sea with lavas. It is an on-going process of development of an oceanic island arc and thus valuable target to study. Many kinds of observations have already been going on. Geophysical (seismic) studies, have not succeeded to image the magma chamber yet although a geochemical study of the lavas suggested that the magma chamber is in 3-6 km depth (Sano et al., 2016). Then, we planned to conduct an magnetotelluric (MT) observation using ocean bottom electromagnetometers aiming to image the magma chamber in terms of electrical conductivity anomaly. It is important to examine if the instrumentation and analysis methods at the present are useful to image the possible magma chamber reasonably in advance of designing the observation plan. We have studied the sensitivity of MT responses on the seafloor around Nishinoshima to the high conductivity anomaly presumed as the magma chamber by three-dimensional (3-D) forward modeling. We incorporated the latest and detailed bathymetry data around the Nishinoshima, which was provided by Japan Coast Guard, into the 3-D electrical conductivity structure. The conductivity of the crust and mantle is set as uniform 0.01 S/m, except for the shallowest part of the crust which changes from 0.316 to 0.01 from with depth. To this reference model, we superimposed 0.1 S/m conductive column with different diameters in different depth. We simulated the MT responses on the seafloor to the reference and modified models and calculated the difference in the responses between the two models. In case putting conductor of 3 km diameter and 3 km thickness in the top depth of 3 km, we observed the significant difference in the periods between 1 and 10 seconds at the location distant 3-6 km from the center of Nishinoshima. This result makes us expect that the real MT data can have significant sensitivity to the magma chamber if the true structure is similar to the presumed structure. We will show further detail of the sensitivity tests in the presentation. In addition, we are trying inversion tests using the synthetic data which were produced from the forward responses by adding noise to examine if the inversion can reproduce the presumed anomaly. We will show further detail of the sensitivity tests in the presentation.

西ノ島は、小笠原諸島父島の西方約 130 km に位置する海洋性島弧火山の無人島である。2013 年 11 月より噴火活動を活発化させて周囲を溶岩で埋め立て、島の面積を広げている。西ノ島の火山活動は、海洋性島弧の形成過程を理解する上で極めて貴重なサンプルであり、これまでにすでに様々観測が行われている。溶岩サンプルの地球化学的分析からは、マグマ溜りが深さが 3-6 km と見積もられている（Sano et al., 2016）が、地球物理学的（地震）観測からは、マグマ溜りの深さは未だ制約できていない。そこで、我々は海底電位磁力計を用いた電磁気観測により、電気伝導度構造としてマグマ溜りをイメージングすることを計画している。計画を実施するに当たり、既存の観測装置と解析技術でマグマ溜りが有意にイメージングできるかを検証することが重要となる。本研究では、3 次元電気伝導度構造のフォワードモデリングにより、西ノ島周辺海底での MT レスポンスが、想定されるマグマ溜りを模した高電気伝導度異常体に対して、有意な感度を持つかどうかを検証した。3 次元構造には、西ノ島周辺で 2013 年の活動以降に観測された最新・詳細な海底地形データ（海上保安庁提供）を組込んだ。海底下は 0.01 S/m の一様構造（ただし海底直下は 0.316 S/m から 0.01 S/m へ次第に遷移）を仮定した参照モデルに対し、西ノ島直下に深さ・大きさの異なるマグマ溜りを模した円柱状の高電気伝導度異常（10 Ohm-m）を加えたモデルを用意した。西ノ島の周囲の MT レスポンスを、異常体（上面の深さ 3 km、直径 3 km, 高さ 3 km）を加えたモデルと参照モデルについて計算し、両者の差をプロットしたところ、周期 1 秒から 10 秒において西ノ島の火口から 3-6 km の範囲で有意な差が生じることが分かった。したがって想定した構造が現実の構造に近ければ、実観測データはマグマ溜り対して感度を持つことが期待できる。本発表では、その他のモデルも含めたフォワード感度テストの詳細を議論する。また、現在フォワード計算値に誤差を与えた人工データを用いて、与えた異常体がインバージョンによって復元できるかについても検証中であるので、その結果についても報告する予定である。

日本の地磁気変換関数の長期変化

竹田 雅彦 [1]
[1] 京大・理・地磁気センター

Long-term variation of geomagnetic transfer function in Japan

Masahiko Takeda[1]
[1] Data Analysis Center for Geomagnetism and Space Magnetism, Kyoto Univ.

Geomagnetic transfer function at several pbservatories in Japan was studied in the period of since 1956. Some of the long-term variations areprobably caused by the solar activity variation, different behavior of the variation was found at some observatories, which may be caused by time variation of the local induced currents in the earth.

日本の観測所での地磁気変換関数の長期変化を調べた。特に柿岡についてはマイクロフィルムからディジタル化された1分値が利用できる1956年からの連続的な変化を得ることができた。各日夜間0h-4hLTのデータを用いて欠値の影響を小さくするために5点以上の連続欠値のある日を除外し、15日以上データがある月について計算し、それらの長期変化を算出した。その結果柿岡についてはYanagihara(1976)で指摘された短周期変化に着いてみられる1970年頃のAuの増加が比較的長周期で見いだされ、それがこの時期に特異な事象であったことが判明した。そのほか、いくつかの観測所では特異的に変化しているケースも見出され、地球内部電気伝導度変化に起因する誘導電流の変化を反映している可能性があり、詳しくは学会時に報告する予定である。

座標変換性に着目したMT応答に内在する異常位相の判別方法

岡崎 智久 [1]; 吉村 令慧 [2]; 大志万 直人 [2]
[1] 京大・理; [2] 京大・防災研

Discriminating Anomalous Phases in Magnetotelluric Responses

Tomohisa Okazaki[1]; Ryokei Yoshimura[2]; Naoto Oshiman[2]
[1] Kyoto Univ.; [2] DPRI, Kyoto Univ.

Magnetotelluric impedance phases are usually located in the first quadrant, which indeed holds for simple electrical structures such as 1D horizontal layers and TM mode of 2D structures. In some field data, however, phases largely deviate out of quadrant. Those phenomena are called anomalous phases. Since they make inverse analyses difficult, identifying the cause will improve the interpretation of MT data containing anomalous phases.

The appearance of anomalous phases changes depending on the observed coordinates. If the sounding curve is not anomalous in a certain coordinate system, it might be so by axis rotation. Therefore understanding the rotational properties is crucial to evaluate anomalous phases. In this direction, Lilley and Weaver (2010) used the Mohr circles of the impedance tensor to coordinate dependences. This enabled them to conclude that anomalous responses in their subject area are caused by galvanic distortion. However, their method requires geometrically depicting circles for each frequency, so it is difficult to analyze in a quantitative way.

We constructed rotationally invariant functions distinguishing anomalous phases by combining geometric quantities of the Mohr circles. A value less than unity indicates that an anomalous phase appears in some coordinates, and a negative value indicates anomalous phases in any coordinates. In addition, we proposed a criterion judging to which quadrant impedance phases belong under axis rotation. It shows full coordinate dependence of phases without rotating the impedance tensor angle by angle.

We apply the obtained criterion to field data to confirm the efficiency. In particular, some data whose sounding curve is normal in the measured coordinates are judged as anomalous. Our criterion tells the angle of axis rotation for anomalous phases to appear, and by rotating the impedance tensor by that angle, the sounding curve indeed becomes anomalous. We also plan dense MT measurements where anomalous responses are observed in a previous observation so as to increase the number of anomalous data and discuss the spatial change of responses in the criterion we proposed.

MT応答のインピーダンス・テンソルにおいて、非対角成分の位相は通常第1象限に属する。特に水平成層構造や2次元構造のTMモードでは常に成立することが理論的に知られている。ところが観測では稀に、この範囲を大きく逸脱する位相が見られることがあり、異常位相と呼ばれている。その原因としては、特殊なノイズや地下の複雑な電気伝導度構造などいくつかのモデルが提案されている。しかし、個々の観測結果に対してモデルの有効性を議論するのが現状で、モデル相互の比較検討が十分にはなされていない。

異常位相は座標系によって様相が変化する。特に、測定した座標系では通常の位相でも、座標を回転すると異常位相が見られる可能性がある。観測に現れる異常位相の性質をもれなく把握するためには、座標変換性を理解する必要がある。Lilley and Weaver (2010) では、インピーダンスのモール円を周期毎に描き、ある座標で異常位相が現れるような応答関数を見分ける方法を提案した。これを用いて、対象地域の異常位相は galvanic distortion によると結論している。ただしこの方法は、モール円を多数描く必要があり、図形的で定量的に扱いづらいという欠点がある。

そこで本研究では、Lilley and Weaver (2010) を参考に、モール円の幾何学量を組み合わせて異常位相の有無を判定する回転不変な関数を構成した。関数の値によって、ある座標で異常位相が現れる場合や、どの異常位相が見られる場合を周期ごとに判別できる。さらに、座標回転に伴う位相の象限の変化を表示する方法を考案した。これによりインピーダンス・テンソルを実際に回転変換しなくても、座標による位相応答の全体像を把握することができる。

以上の定式化を観測データに適用し、正しく判別することを確かめた。特に、測定座標系の位相は正常でも判定関数の異常位相の存在を示す観測点があり、回転特性の表示をもとにインピーダンスを変換すると、探査曲線が異常位相を示すことを確認した。また本年9月に、過去に異常位相が見られた観測点周辺で高密度のMT観測を実施する予定である。異常位相データのサンプル数を増やすとともに、本研究の提案する判別方法により記述される応答の空間変化について議論する。

MT 法連続観測データの長期安定性について（２）

山谷 祐介 [1]; 茂木 透 [2]; 浅沼 宏 [1]
[1] 産総研; [2] 北大・工

Long-term stability of continuous MT monitoring, Part 2

Yusuke Yamaya[1]; Toru Mogi[2]; Hiroshi Asanuma[1]
[1] FREA, AIST; [2] Fac. Eng., Hokkaido Univ.

The magnetotelluric method has been recently applied to resistivity monitoring of a fault zone and volcano and geothermal reservoir. These studies expect to detect a time-dependent resistivity change of target structures. In order to detect such a small change, it is needed to remove any other variations, which are caused by variations of electromagnetic source, noise and contact conditions. This study aims to evaluate the long-term stability of MT data and to present a way for an application of resistivity monitoring. We analyzed the MT data continuously measured by GSI at Esashi (ESA) and Wakuya (WKY) observatories from June 2005 to June 2011. The 'BIRRP' time series processing code (Chave, and Thomson, 2003) estimated the MT responses by using 30-day-long data every 10 days. The 30-day-long data brought much better quality of the MT responses, which showed small error bars, compared to the ones from one-night data. The apparent resistivity, phase and magnetic transfer function at the ESA station obviously shows seasonal variations at a high frequency band above 1 Hz. The coherence between the electric field and predicted electric field shows poor quality in winter season (November to April). Large error bars of the magnetic transfer function in winter season imply that the variations are not caused by only the variation of the electric field noise. The phase tensor (Caldwell et al., 2004) can avoid an effect of the electric field distortions. Because the phase tensor parameters at the ESA vary with over 10 % range, the variation of the MT responses is not the effect due to the distortion. Additionally, because such variations of ESA are larger than of WKY, the data can reflect variations of instrumental characteristics and electromagnetic noise. These results show that an external factor can bring notable changes of the MT responses even if at the site where any structural temporary change is not expected. In order to apply the MT method to a detailed resistivity monitoring, it is required to previously know a background variation for the term without structural change, using continuous measuring at multiple stations.

2013 年野島注水実験で自然電位変動が観測されなかった原因について

村上 英記 [1]
[1] 高知大・自然科学系・理学部門

Possible causes of observing no self-potential changes during 2013 Nojima water injection experiment

Hideki Murakami[1]
[1] Natural Sciences Cluster-Science Unit, Kochi Univ.

Water injection experiments have been conducted in a borehole of 1800m depth at the Nojima fault to investigate healing processes of the Nojima fault, which is a surface earthquake fault of the 1995 Hyogoken-nanbu earthquake(Mw6.9). During the 2013 water injection experiment water was injected into the fault system through the open hole part of the borehole (1800m depth). Self-potential variations around the 1800m borehole were not observed or very smaller than those in the previous water injection experiments (1997, 2000, 2003, 2004, 2006, and 2008) at 540m depth and did not appear clearly to synchronize with the operation of the water injection. The previous observed self-potential variations were explained by the streaming potenital. however, no observation of self-potential variations durring 2013 water injection experiment was not explained by the streaming potential. Zeta potential depends on ph, salinity, aluminum ion of the fluid. If zeta potential is zero or very small, no observation of self-potential is explained due to the same model. In this study, we discuss effects of clay minerals, carbonate minerals, and sea water on zeta potential.

1995 年兵庫県南部地震（Mw=6.9）の地表地震断層である野島断層の回復過程を調べるために 1997 年，2000 年，2003 年，2004 年，2006 年，2008 年，2013 年と野島断層を貫く 1800m のボーリング孔への注水実験が実施されている。地震発生直後には，断層近傍は断層運動により破砕された状態のために，断層破砕帯への注水を行うと水は比較的速やかに流れてゆくが，断層の固着過程が進行してくると水は流れにくくなると予想される。1997 年から 2008 年までの注水実験は，実際には地下 1800m 深の断層破砕帯への注水ではなく，深さ 550m のボーリング孔の継ぎ手から周囲への注水という実験結果になったが，地震発生直後の 1997 年に比べ年々水が流れにくくなり，地震後数年でほぼ一定値に収束し始めていることを確認した。この結論は，1800m 孔近傍にある 800m 孔の湧水量変化や，坑内歪計，そして地表における自然電位変動の計測といった独立な測定により導き出されたそれぞれの結論が位置している。

注水実験により地下で水の流動が起きれば，流動電位が発生することが期待できる。1997 年から 2008 年の実験では，注水に同期した自然電位変動が地表において観測された。この自然電位変動は，1800m 孔のケーシングパイプが流電電極として作用しているというモデルで解釈をすることができた。しかし，2013 年の注水実験では注水に同期した自然電位変動を観測することができなかった。2013 年の注水実験では，従来の注水実験で漏水をしていた 540m 深さでの漏水対策を実施し注水を実施した。坑内温度計の不良のため，1800m 深さからの流出であったことが確認できてはいないが，断層破砕帯への注水になっていたものと考えられている。しかし，従来の注水実験と同様の条件（圧力，流量）で実施したにもかかわらず自然電位変動が観測されなかったことを従来のモデルでは説明ができない。

流動電位の大きさを決定する ζ 電位は，流体の pH，塩分，アルミイオンなどに依存していることが知られている。なんらかの要因により ζ 電位が非常に小さくなっていれば，従来の注水時の条件（圧力，流量）が同じであっても自然電位変動が観測されないことが説明できる。ここでは，断層破砕帯を構成する粘土鉱物，炭酸塩鉱物，そして海水の ζ 電位への影響を考察する。

ディープラーニングを利用した複数地点間の高精度地磁気推定方法の比較

香取 勇太 [1]; 大久保 寛 [1]; 竹内 伸直 [2]
[1] 首都大東京・院・シスデザ; [2] 東北大・院理・予知観測セ

Comparison of Deep Learning-based Estimation Methods of GeomagneticField Variation

Yuta Katori[1]; Kan Okubo[1]; Nobunao Takeuchi[2]
[1] Graduate School of System Design, Tokyo Met. University; [2] Res Cent Predict Earthq Volcan, Tohoku Univ.

We have reported successful observations of co-faulting Earth's magnetic field changes[1]. To develop a new system for a super-early warning of destructive earthquakes, these observation results are very important. On the other hand, these observation results suggested that the geomagnetic variation signals are very small. In the result at Iwate-Miyagi Nairiku Earthquake, the magnetic fields began to increase almost simultaneously with the onset of the earthquake rupture. This amount of change was approximately some hundreds pT. As another observation result, at the Iwaki-observation site in Fukushima, we also successfully observed a similar signal by our high-resolution geomagnetic observation system using HTS-SQUID magnetometer. This amount of change was approximately 50 pT.

To detect small co-faulting Earth's magnetic signals for developing new system for a super-early warning of destructive earthquakes, a signal processing method is very meaningful. Then we presented a nonlinear processing method of geomagnetic estimation by the deep neural network (DNN) using stacked-autoencoder[2]. In this study to improve the precision of estimation, we employ some estimation methods using the deep-learning technology to solve our problem. We perform an evaluation and report an effective estimation method using deep learning in this presentation.

[1] Okubo et al., EPSL,2011.
[2] Katori et al., JpGU Meeting, 2016.

我々の研究グループではこれまでの研究成果により，地震発生時に生じる微小な地磁気信号変化を観測することに成功している [1]。これらの観測結果は，地磁気信号を用いたより高速な地震検知システム実現の可能性を秘めたものである。しかしながら，得られる信号は非常に小さな信号である。例えば，岩手・宮城内陸地震発生時の近郊における地磁気観測結果では，３成分観測において磁場が地震発生から地震波が到達するまでの数秒間に，数 100pT 程度の大きさの微小な地磁気信号を得ることができた。また，いわき観測点では，HTS-SQUID 磁力計を用いた高感度地磁気観測において，2013 年 9 月 20 日に観測点近くを震源とする M5.9 の地震が発生した際，数秒間に 50pT 程度の同様な微小な地磁気信号を観測することに成功した。これらの結果から，多くの場合に，地震発生時に生じる地磁気信号変化は微小であることが予想される。ロバストな地震検知を行うためには，地震発生時に生じる微小な地磁気信号をリアルタイムに検知するための信号処理方法が必要であるが，現在，微小な地磁気信号を検出するための技術は確立していない。そこで我々はディープラーニング技術に着目し，その技術の一つである Stacked-Autoencoder を用いた非線形信号処理による地磁気信号の推定方法を提案し，その推定結果を利用した地磁気のローカルな異常信号検知を検討した [2]。本研究では推定精度の向上を目指し，ディープラーニング技術に基づく複数の手法を本課題に対して適用・比較し，リアルタイム地磁気変動推定のための有効なディープラーニング手法を示す。

[1] Okubo et al., EPSL,2011.
[2] Katori et al., JpGU Meeting, 2016.

高次モードの外部磁場ソースに対する 3 次元不均質球体電磁誘導モデリング

小山 崇夫 [1]; 清水 久芳 [1]
[1] 東大・地震研

3-D EM induction modelling in a spherical heterogeneous Earth by external sources of higher degree modes

Takao Koyama[1]; Hisayoshi Shimizu[1]
[1] ERI, University of Tokyo

For aiming to investigate an electrical conductivity structure in the Earth’s mantle by the EM induction method, it is essential to properly consider a source distribution in low frequency ranges unlike a common MT method. A simple P10 distribution assumption is valid in a period range over 5 days (e.g. Semenov and Kuvshinov, 2012), and most of conventional global EM induction studies have performed under this assumption (e.g. Kelbert, 2009). Recent studies, however, revealed that it’s invalid in a period range between 10,000 sec and 5 days even if well-known Sq field effects are separated and removed (e.g. Shimizu et al., 2011, Semenov and Kuvshinov, 2012). Observed EM field data at the surface in a period range described above are sensitive to the electrical conductivity structure in a lower part of upper mantle and a upper part of mantle transition zone, and thus it is inevitable to analyze the EM field data in those periods to fill in our understanding for a missing region. We’ve developed a 3-D modelling code of EM global induction mainly by P10 excitation so far (Shimizu et al., 2010, Koyama et al., 2014), and need to modify it further to be able to adapt in a period range mentioned above.

In this study, we’ll show how to modify our original code to be able to input source fields of mixed higher degree modes than P10. Our code is based on an integral equation method, and non-ohmic electric current source distributions are required to input as source terms in our code. Now we’re just considering the source effects of electric currents in ionosphere and magnetosphere as source terms. These current systems actually include both toroidal and poloidal components, but the effects of poloidal current components are vanished in the air, and thus only toroidal current components are needed for EM soundings in the Earth. So it turns that it is just required to know equivalent source distribution at an arbitrary radius above the surface. In our original code, Green’s functions are expressed as spherical harmonic expansions which are core parts of our code. Thus, it is convenient and suitable that external source current densities are also expressed by using spherical harmonic coefficients. Supposing that we’ve just already known Gauss coefficients of external magnetic field in those periods by geomagnetic data analysis, we can know the input source datasets which are expressed as spherical harmonic coefficients, because a conversion to external Gauss coefficients into spherical harmonic coefficients of equivalent electrical currents are easily derived (e.g. Koch and Kuvshinov, 2015).

In our presentation, details of modification of our original code are discussed and some numerical results of 3-D forward EM induction modelling will be shown due to, for examples, supposed Sq field excitations.

グローバルなマントルの構造のような深部電気伝導度構造を調べるために電磁探査法を利用する場合、数時間〜年単位の長周期帯の電磁場データが必要なのに加え、外部ソースは通常の MT 法のように平面波近似を適用することはできず、ソース形状を正しく考慮する必要がある。従来の磁場観測データ解析の研究から数日周期以上のソース分布に対しては、非常に簡単な P10 分布でよく近似できることが知られており（e.g. Semenov and Kuvshinov, 2012）、これまでのグローバルインダクションの研究のほとんどでは、ソース分布にはこの近似を適用して電気伝導度分布が推定されてきた (e.g. Kelbert et al., 2009)。しかし、一方で周期 10,000 秒〜数日の周期帯では Sq 場の影響を取り除いたとしてもこの近似がなりたたないことが最近の研究からわかってきた（e.g. Shimizu et al. 2011、Semenov and Kuvshionv, 2012）。上記の周波数帯は、上部マントル〜マントル遷移層上部に感度があるため、電気伝導度の深度分布を推定し、さらにマントルテクトニクス／ダイナミクスの情報を知る上で、この周期帯の解析が極めて重要である。著者らはこれまで（セミ）グローバルな 3 次元電気伝導度構造推定を従来の P10 ソース近似のもとで進めてきた (e.g. Shimizu et al., 2010, Koyama et al., 2014) が、上記の周期帯ではそのまま適用することはできず修正を施す必要がでてきた。

そこで本研究では、これまでに開発してきた積分方程式法による 3 次元グローバルインダクションのフォワードコードについて (Koyama et al., 2014)、P10 よりも高次の球関数モードを持ち、かつ、複数のモードが重畳するような複雑な外部ソース入力に対しても適用できるよう、コードを改良した。ここでは、電離圏・磁気圏での電磁場変動ソース分布を non Ohmic な電流密度ソースであるとして、積分方程式法の電流密度ソース項に与えることにする。電離圏・磁気圏での電流密度ソース分布にはポロイダル電流場とトロイダル電流場の両方が含まれるが地下の電磁誘導を考える上では、トロイダル電流場ソースだけを考えればよい。つまり、より単純化して、地表より上でのある任意の半径におけるトロイダルな等価電流場分布を求めればよいことになる。従来のコードは積分方程式法で必要となるグリーン関数をそれぞれの球関数モードによる重ね合わせとして表してきたので、本研究ではその方針を踏襲し、外部ソースを球関数モードに展開した各係数で与えることにする。将来的な実データへの適用を視野にいれ、たとえば地磁気データ解析等から外部磁場に対するガウス係数が既知であるものとしてコードに入力することに相応する。なお、既知の外部磁場のガウス係数からトロイダル電流場を球関数展開したときの係数への変換は容易に求まり（e.g. Koch and Kuvshinov, 2015）、本研究のコードへの入力が可能になる。

本発表では、コード改良の詳細とともに、今後の Sq 場解析を想定したフォワード計算結果を示す。

ドローンを用いた空中磁気観測システムの開発

宇津木 充 [1]; 橋本 武志 [2]
[1] 京大・理・火山研究センター; [2] 北大・理・地震火山セ

Development of the aeromagnetic survey system using drone multicopter

Mitsuru Utsugi[1]; Takeshi Hashimoto[2]
[1] Aso Vol. Lab., Kyoto Univ.; [2] ISV, Hokkaido Univ.

Aso Volcanological Laboratory and Neoscience Inc. has developed an aeromagnetic survey system using drone and multicopter to use near the active area of the volcanic region. This system consists DJI S1000 multicopter and Bartington Mag566 fluxgate magnetic sensor and it can be measured magnetic 3-component data at very high sampling in the specified area fully automatically. Using this system, it is expected that we can acquire the magnetic field data on the active volcano even while eruption is occurring.

To test our survey system, we conducted an aeromagnetic survey on Komezuka volcano, located in the northwestern part of the post-caldera central cones of Aso volcano, central Kyushu Island, Japan, on Aug. 2016. Komezuka is a basaltic monogenetic volcano comprising a scoria cone. On this volcano, Hasimoto et al. (2009) measured dense magnetic total field anomaly by ground-based observation. Applying procedure of the magnetic upward continuation to this data, we can estimate the magnetic anomaly on the arbitoraly point above the Komezuka volcano. Comparing this estimated anomaly and observed data acquired by our test survey, we will verify the accuracy of our survey system.

京都大学火山研究センターでは、有限会社ネオサイエンス社（大阪府泉南市男里 5 丁目 11-22）への委託事業として小型無人機（ドローン）を用いた火山活動域近傍における磁場観測システムの開発を行い、実フィールドでのテストフライトとして阿蘇米塚火山での空中磁気観測を行った。尚、本事業は文部科学省「災害の軽減に貢献するための地震火山観測研究計画」の一環として行った。

平成 26 年 11 月に、御嶽火山において水蒸気噴火が発生し多くの犠牲者を出した。この事態を受け、文部科学省「災害の軽減に貢献するための地震火山観測研究計画」の事業の一環として、水蒸気噴火後の地下浅部の熱的状態把握を目的とした空中磁気観測、即ち有人ヘリコプターを用いた空中からの地磁気観測を行う事を計画した。しかし現在も当該地域が飛行規制領域に設定されているため調査を実施することが出来ない状況である。地磁気観測は地下浅部の温度が空間的にどのような分布を持つかを知るうえで非常に効率の良い方法であることが知られている。さらに測定デバイスの安定性から、航空機を用い地磁気観測を空中から高密度で行う事が可能であるという利点も併せ持つ。こうした手法を用い火山の活動域地下の熱的状態を高分解能で把握することは、噴火のメカニズム解明、今後の噴火予測を行う上で非常に重要な情報となる。しかしこれまで、こうした調査の実施には有人の飛行機やヘリコプターを用いてきた。従って今回の御嶽火山の場合のように噴火直後には、そのタイミングこそメカニズム解明、噴火予測を行う上で最も重要であるにも拘わらず、安全性の観点から調査が不可能な状況が殆どである。こうした事から、今回の御嶽火山の事例を教訓として、近年様々な用途で盛んに用いられるようになった小型無人機（ドローン）による空中磁気観測システムの開発を行う事とした。

観測システムの開発は（有）ネオサイエンス社に委託した。このシステムで使用するマルチコプターは DJI S1000、磁力計センサは Bartington Mag566 フラックスゲート 3 成分センサである。磁気サーベイでは全磁力を計測する事が一般的だが、既存の全磁力型磁力計は S1000 のペイロードをわずかに超えてしまう事から今回は軽量、省電力の 3 成分センサを用いた。観測から得られる 3 成分データを元に全磁力値を求め、対象地域の全磁力異常分布を求める。この観測システムの実証試験として、2016 年 8 月に阿蘇米塚火山周辺で空中磁気観測を行った。米塚火山では橋本他 (2009) により詳細な全磁力異常の地上観測が実施されている。このデータに上方接続を施したものとの比較から本観測システムの精度の検証を行う。本発表では米塚での観測のデータ及びその精度検証の結果について報告する。

円筒形岩石試料に対する比抵抗トモグラフィーの試み

鈴木 健士 [1]; 吉村 令慧 [2]; 山崎 健一 [2]; 大志万 直人 [2]
[1] 京大院理・地球惑星; [2] 京大・防災研

Resistivity Tomography Applied to Cylindrical Rock Samples

Takeshi Suzuki[1]; Ryokei Yoshimura[2]; Ken’ichi Yamazaki[2]; Naoto Oshiman[2]
[1] Earth and Planetary Sciences, Kyoto Univ.; [2] DPRI, Kyoto Univ.

We are designing a high-resolution resistivity tomography method for rock samples. Such measurements possibly give detailed information about microstructure of rocks and determine the mixing model that expresses geometric distributions of matrix and fluid. Whereas many works have been carried out for imaging heterogeneities with a field-scale around seismogenic zones, very few attempts have been made at applying high-density electrical measurements for rock samples because of difficulties in measurement. On the other hand, at the core-sample scale, the structures including microcracks are measurable by the other methods. Several works have observed clusters of microcracks in rock samples with the aim of detecting fracture nucleation and understand the process of faulting (e.g., Kawakata *et al*., 1999). Such studies allow a comparison of the distribution of microcracks with resistivity images at the core-sample scale.

As the first step in resistivity tomography imaging, we demonstrate direct-current methods using a high-density electrode arrangement for a resistive intact rock sample in the present study. We use cylindrical granite samples with 50 mm diameter and 100 mm long for present experiments. Conductive epoxies are used as electrodes. In order to measure voltage of high resistance samples, we use an electrometer with a high input impedance (>200 Tohm). In addition, we use both floating and guard measurements to prevent leakage current. In floating measurements, ground link between the negative terminal and chassis is disconnected. In guard measurements, an input positive terminal, an inner shield of the coaxial cable, and a metal mounting plate are set to a same voltage. Therefore, there is no current path except through the rock sample.

In the present work, we obtained a voltage distribution on the surface of the rock sample. The obtained voltage distribution roughly correlates with numerical predictions, but there are major differences between observed and calculated values. We will verify the validity of obtained data and report the problems in this presentation.

電気・電磁探査による地下の電気比抵抗イメージングは広く実施されているが、実験の難しさから、岩石試料に対する比抵抗イメージングの適用例は少ない。電気的手法以外ならば、岩石試料に含まれる微小クラック群の非破壊計測はすでに実施されており、X 線 CT スキャンによる内部構造の詳細な 3 次元イメージングが報告されている (例えば、Kawakata *et a*l., 1999 など)。微小クラック群を含む岩石試料に対する高解像度比抵抗イメージングが実現できれば、微小クラック分布と比抵抗イメージの対比により母岩中の流体のつながりを表現する混合則が決定できると期待される。

著者らは、岩石試料の高解像度比抵抗イメージングを試みている。その目的は、比抵抗イメージを他の物性データの対比することである。詳細なイメージングが困難なフィールドスケールでの対比の前段階として、我々はコアサンプルスケールでの対比を考えた。

これまでの研究では、無垢で高抵抗な岩石試料に対する高密度な電極配置での直流比抵抗法を進めてきた。実験には直径が約 50mm で高さが約 100mm の円筒形花崗岩試料を用いた。試料に接着する電極には導電性エポキシ樹脂を使用し、高抵抗な試料の電圧を測定するために高入力インピーダンス (> 200 Tohm) のエレクトロメーターを使用した。また、非常に高抵抗な試料に対して比抵抗法を適用する際、測定回路の絶縁抵抗が試料の抵抗と同程度の値になり、その結果アース線などを介した意図せぬ漏えい電流が生じることがある。これを防ぐため、フローティング測定とガード測定を適用した。フローティング測定は、シグナルグランドとアースを切断する測定法である。ガード測定は、同軸ケーブルの内側のシールド部と試料を固定する絶縁体の下に配置された金属プレートを同軸ケーブルの芯線と同電位に保つ測定法であり、測定回路中で試料以外の経路に生じる電位勾配をなくすことができる。これらによって、試料以外に取り得る電流経路を少なくし、漏えい電流の発生を防ぐことができる。

本研究では、無垢な岩石試料に対し高密度の比抵抗法を実施し、試料側面の電位分布を測定した。本発表では、この結果について報告する。得られた結果は、試料を均質媒質と仮定して行った数値計算結果とおおよその傾向の一致を示したが、一方で、数値計算結果と実測値の間に無視できない差異も確認された。これら結果についての妥当性と現時点での未解決な課題についても報告する。

「磁気図 2015.0 年値」の公表について

高橋 伸也 [1]; 菅原 安宏 [2]; 阿部 聡 [1]
[1] 国土地理院; [2] 地理院

Publish the Geomagnetic Charts of Japan for the Epoch 2015.0

Shinya Takahashi[1]; Yasuhiro Sugawara[2]; Satoshi Abe[1]
[1] GSI of Japan; [2] GSI

http://vldb.gsi.go.jp/sokuchi/geomag/index.html

The Geospatial Information Authority of Japan (GSI) has conducted geomagnetic surveys all over Japan since about 1950. In addition, we established 3 geodetic observatories in a sequential order from 1952 and nationwide 11 observation sites in 1997 which are collecting both total force and vector components of geomagnetic field at each site continuously. Those data have been not only opened in public but also used for making the "Geomagnetic Charts of Japan" which describe a normal state of a geomagnetic field over Japan. GSI published the charts every 10 years so far and the newest one was done in 2011 for the epoch 2010.0. On the other hand, there are also some requests for shortening its period to every 5 years which is same interval as world models such as the International Geomagnetic Reference Field (IGRF) and the World Magnetic Model (WMM). In order to live up to this demand, we develop a new method based on the principal component analysis to reproduce the fully reliable magnetic field with less data. GSI is now preparing for publishing a new chart for the epoch 2015.0 in this December. We will present the detail of both our new method and the upcoming product.

国土地理院では，日本全国の地磁気の地理的分布と永年変化を把握するため，1950 年頃から日本全国を網羅する地磁気測量を実施してきた．1952 年以降順次開設された 3 か所の測地観測所に加え，1990 年代の後半からは，全国 11 か所の連続観測施設においても地磁気ベクトルの連続観測を実施している．それらの観測データは，HP 等から一般に公開されているほか，日本全国の詳細な磁場分布として 1970 年から 10 年ごとに公表している磁気図への反映，地図上における真北と磁北のずれの補正量としての地形図等への掲載など，幅広く活用されている．現在公表している最新の磁気図は，2011 年に公表した「磁気図 2010.0 年値」であり，従前どおりであれば次回の磁気図は 2021 年公表となるが，ユーザへのニーズ調査の結果，地磁気世界モデル（IGRF，WMM）の更新間隔（5 年）に合わせた磁気図作成への要望が高かったことから，連続観測データを活用した主成分分析による新たな地磁気変化モデル作成手法を開発し（阿部ほか, 2015），今後は 5 年ごとに公表することとした．その最新の「磁気図 2015.0 年値」を，本年 12 月に公表する予定である．

今回使用したモデルは,「磁気図 2010.0 年値」作成時に採用した手法を拡張し，より細かな時間分解能を持つものとなっている．また，データをグリッド化する際の空間補間の方法を最適なものに見直したことで，従前より観測値の再現性が高い磁気図となっている．本講演では，今回使用したモデルの内容及び公表予定の「磁気図 2015.0 年値」について報告する．

球面調和関数の緯度経度冪級数展開を用いた日本周辺の地磁気の表現 (1)

小河 勉 [1]
[1] 東大・地震研

A geomagnetic field expression around Japan with the latitudinal and longitudinal power series of the spherical harmonics (1)

Tsutomu OGAWA[1]
[1] ERI, Univ. Tokyo

The present study aims to improve the geomagnetic variation model around Japan for identifying anomalous geomagnetic field variation. The geomagnetic variation model around Japan by Abe and Miyahara (2015) using natural orthogonal component method does not require its magnetic scalar potential expressed as a power series of longitude and latitude to satisfy the Laplace equation. In the model by Ji et al. (2006) using SCH, while the potential satisfies the Laplace equation, the major part of the analysis domain is above the sea surface. In the present study, the expression of the magnetic scalar potential is obtained as a latitudinal and longitudinal power series of the spherical harmonics with the maximum order of 4 and the number of expansion coefficient of 29. For expressing the geomagnetic field around Japan with the expression, a spherical coordinate system is defined of which its equator runs along the major part of the land of Japan which thus ranges in +/- 0.3 radians in longitude and +/- 0.075 radians in latitude in the present coordinate system. The geomagnetic variation model around Japan with the expression of the magnetic scalar potential in the present coordinate system and the geomagnetic data obtained by continuous stations of JMA and GSI is discussed.

本研究は、日本周辺の地磁気変化モデルの向上による地磁気変化異常場の同定を企図している。阿部・宮原 (2015) による主成分分析を用いた日本周辺の地磁気変化モデルにおいては、磁気スカラーポテンシャルが緯度経度の多項式で表現されるが、これにラプラス方程式の解となるための拘束はかけられていない。また Ji et al. (2006) による SCH を用いた日本周辺の地磁気変化モデルでは、磁気スカラーポテンシャルがラプラス方程式の解となるが、解析領域の大半が海洋上となる。本研究では、球面調和関数を緯度経度の冪級数で展開し、打ち切り次数 4、29 個の展開係数による磁気スカラーポテンシャルの表現を得た。これを用いて日本周辺の地磁気変化を表現するために、日本の陸地の大半が赤道に沿い、経度+/-0.6 ラジアン、緯度+/-0.15 ラジアンの範囲に収まる球座標系を定義した。この座標系において表現された磁気スカラーポテンシャルと、気象庁及び国土地理院の地磁気連続観測データを用いて得られる日本周辺の地磁気変化モデルについて議論する。