地震時地磁気変化の存在を示すための日本周辺の地磁気経年変化率分布の解析

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Analysis of geomagnetic secular variation anomalies in Japan to deduce existence of earthquake-related phenomena

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To find an evidence of earthquake-related geomagnetic changes is a challenging work. Some earlier studies have reported pre- or co-seismic changes in the geomagnetic field with sizable amplitudes (˜10 nT). However the rarity of large earthquakes, combined with the sparsity of continuous geomagnetic stations, means that there are few opportunities to reach a reliable conclusion on the existence of earthquake-related geomagnetic changes.

As an alternative approach, I focus on geomagnetic secular variation (SV) anomalies that are NOT related to earthquakes or other prominent events. SV anomalies up to few nT are reported in several areas in Japan. On the other hand, anomalies in absolute values of the geomagnetic field in the same area are up to 100 nT. If the reported SV anomalies are persistent during several decades, a contradiction arises unless there are "counter changes" which possibly related to earthquakes. Therefore precise analysis of the SV anomalies may provide an evidence of the existence of earthquake-related changes in the geomagnetic field, although indirect.

To determine SV anomalies, the 1st geomagnetic survey's data provided by the GeoSpatial Authority of Japan (GSI) during 1970-2000, together with observatories data provided by GSI and the Japan Meteorological Agency, are analized. Spatio-temporal variations in the geomagnetic field in the region are approximated by the Spherical Harmonic functions with low degrees, and the differences between the observed and approximated values are regarded as the SV anomalies.

In many sites, persistent small SV anomalies (˜0.1 nT/yr) are determined. Although they are smaller than those reported by an earlier study, it still suggest the SV cannot continue for several 1000 years unless "counter changes" in values exists, at least in each 100 years. To find generation mechanism(s) of the SV is a future challenge, which possibly leads to an insight on the relationship between the geomagnetic SV and tectonic processes.

古くから、地震に関連した地磁気変化があると言われているが、数 10nT 程度の大きな変化で信頼できるものは未だ見つかっていない。たとえそうした変化が本当にあるとしても、地磁気観測点の密度が低いことを考えると、信頼できる観測結果が得られる可能性はほとんどないとも言える。

そこで、地震時の変動そのものを捉える代わりに、地震がない時期の地磁気経年変化を調べる、という方法を著者は考えている。数 nT 程度の地磁気経年変化異常（広域的な経年変化パターンからの偏差）が日本列島で見られることは、すでにさまざまな先行研究で指摘されている。一方で、静的な地磁気異常の大きさは、高々数 100nT 程度である。もしも、数 nT の経年変化が例えば 100 年にわたって続くのだとしたら、これは静的磁気異常の大きさについての事実と矛盾する。つまり、どこかで逆向きの変化がおこらなければならない。したがって、少なくとも数十年続く数 nT 程度の経年変化が存在するならば、それは、地震時とは限らないが、地磁気経年変化の局所的な急変が存在することの間接証拠になる。

本研究では、日本の経年変化異常を検出するために、国土地理院により実施された一等磁気測量結果を解析した。気象庁および国土地理院の観測所で得られた連続観測データも合わせて利用した。まず低次の球面調和関数によって経年変化の広域パターンを決定し、そこからの残差として経年変化異常の分布を抽出した。

多くの観測点において、持続性の経年変化の大きさは、0.1nT/yr の桁であった。これは先行研究で報告されているものよりは小さい。しかしそれでも、同じ大きさの変化が数 100 年続くならば、上記の矛盾は、やはり生じる。

地震前兆電磁波パルスの検出に関する観測研究

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Observation of electromagnetic pulses prior to earthquakes

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In order to confirm electromagnetic (EM) waves which could be excited prior to earthquakes, we had been observing EM noises in boreholes. Since we could not detect any EM pulses related to earthquakes, we shifted down the monitoring frequency from the range around 5 kHz to a range below 25 Hz. As the result, we detected earthquake-excited EM pulses in the earth. We also found that the EM pulses were excited due to Piezo-electric effect by vibration of seismic waves in the earth's crust around the EM observation site.

Furthermore, in order to clarify behaviour of EM pulses in the earth and above the ground, we began simultaneous detections of EM pulses with another EM sensor system installed above the ground and an accelerometer installed on the ground surface. As the result, we confirmed that EM waves were excited by seismic P wave and amplified by S waves, respectively and that they can readily leak out of the ground surface [1].

Detailed analysis of EM pulse in the earth and above the ground when an earthquake occurred just beneath the EM observation site has resulted that polarizations of the EM pulse above the ground was elliptic whereas that in the earth was a linear one. This phenomenon means that the EM pulse was radiated from the deep earth.

Based on such behaviours of EM pulses, we proposed a hypothesis of EM pulse excitations prior to earthquakes as follows; when a pressure began to load to both sides of two large earth crusts in an active fault where a fragmentation layer exists between the two large crusts, small crusts in the fragmentation layer could be first fractured even by the pressure weaker than that further strong stress at earthquake rupture. By the stress impact at the fracture of the small crust, seismic P wave could spread in the earth's crusts, and by the vibration of the P wave in the earth's crust, EM pulses could be excited due to piezo-electric effect in the crust and radiated out of the ground surface. This process would proceed and after that an earthquake would occur. Therefore, this kind of EM pulses can be regarded as a precursor of the earthquake.

Figure 1 shows spectrograms of tri-axial magnetic components and vertical electric component detected above the ground. An earthquake occurred at 24 km west of the EM observation site at 21:02 JST, January 14, 2015, and spectral lines of magnetic components can be seen at that time in the spectrogram. On the other hand, four vertical spectral lines of EM components are seen at about 7 hours before (14:08 JST) the earthquake. Since the polarization of the EM pulse was elliptical, and the short axis of the ellipse was pointing to the direction of the epicentre of the earthquake, this EM pulse can be regarded as a precursor of the earthquake occurred 7 hour later.

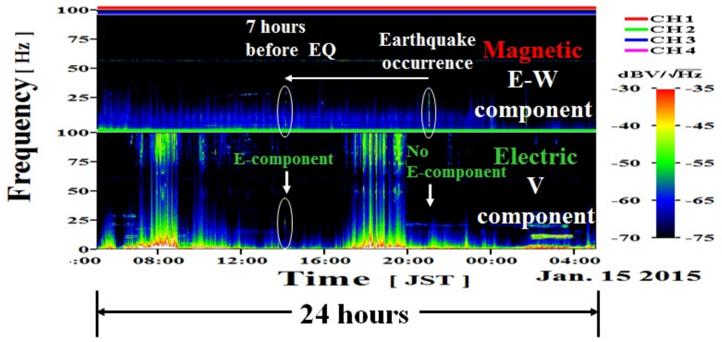
[1] Minoru Tsutsui, Behaviors of Electromagnetic waves Directly Excited by Earthquakes, IEEE Geoscience and Remote Sensing Letters, Vol. 11, No. 11, pp. 1961-1965, 2014. (DOI: 1109/LGRS.2014.2315208, Now Open Access)

地震に伴って電磁波が励起されるだろうとの仮説の下、深さ 100 m の非導電性ボアホール内の底部に電磁界センサーを設置して、観測を続けてきたが、関連電磁波は全く検出できなかった。そこで、地中媒質の電気伝導度の大きさを考慮し、2011 年 12 月からは 25 Hz 以下の周波数範囲での観測を行った結果、電磁波観測点を中心に半径 40 km とする域内で発生したマグニチュードが 2 以上の地震において電磁波パルスが励起された事を確認した。これは電磁波観測点近傍の岩盤内で地震波の振動による圧電効果によって電磁波が励起された事と考えられた。このように地下岩盤から電磁波が励起されていることが明らかとなったので、発生した電磁波の影響が地上にも現れている事を検証するため、地上にも同じ電磁波センサーを、そして地表に地震計をも設置して、電磁波と地震波との同時観測を行った。この結果、岩盤内で地震 S 波の波頭では常に電磁波が増幅されており、それが容易に地上へも放射している事を示した [1]。さらに電磁波観測点直下で発生した地震の影響について、地中と地上での電磁波の同時観測を通して、両領域での電磁波の偏波状況を調べたところ、地中では直線偏波であったのに対して、地上では楕円偏波となっていた。これは屈折率の異なる媒質の境界面（地表面）を横切って直線偏波していた電磁波が通過した結果として生じる現象である。この事から「地上で検出した電磁波が楕円偏波をしておれば、それは地中から地上へ放射された電磁波である」と看做す事が出来る事が判った。

一方、地震発生に至るまでの過程において電磁波パルスが発生する可能性について、その励起機構を次のように考えた。即ち、活断層には大規模岩盤で挟まれた破砕帯という領域があり、そこには小岩石が存在する。地震発生に向けて大規模岩盤に圧力が掛かり始めるが、その圧力が弱い段階であっても小岩石が破壊する事がある。その破壊時の衝撃は、両側にある岩盤の内部に P 波を発生させる。この P 波の振動により、岩盤内では圧電効果により電磁波パルスが励起さ

れると考えている。岩盤に掛かる圧力が更に増加すると更なる小岩石の破壊と共に電磁波パルスが発生する。この圧力の増加が限界以上に達した段階で地震が発生すると考えている。以上のような機構で発生した電磁波パルスを地震前兆の現象として仮説として提唱している。そこでこの考え方に基づき観測データを調べていたところ、それに関連した電磁波パルスを見つけた。図 1 はその状況にある電磁波の磁界３軸方向成分および垂直電界成分のスペクトログラムを表している。図では 2015 年 1 月 14 日 21:02 JST に M3.9 の地震が電磁波観測点の西方 24 km 離れた地点で発生した事を示している。即ち、その地震波が電磁波観測点に達した時の電磁波パルスがスペクトル線として図に現れている。更に詳細に調べてみると、この地震発生の約 7 時間前 (14:08 JST) に興味ある電磁波パルスが検出されていた。そこで、その電磁波パルスの偏波を調べたところ、楕円偏波をしていた事から、それは地中から地上へと放射している事を示唆しており、電磁波の到来方位としての楕円の短軸方向はその震源に近い方向を示していた。故に、この電磁波パルスこそ地震前兆として発生したものと考えており、今後はこの種の電磁波パルスを集めて、その後に発生する地震との関係において何らかの傾向を見出す事により、地震前兆の電磁波パルスとして特定する事を目指す。

[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.



赤道域海洋島における津波起源磁場

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Tsunami-generated magnetic fields on oceani islands in equatorial regions

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Coupling between horizontal flows and the vertical component of the geomagnetic main field alone has been considered as source electromotive forces (emfs) in arguing motional induction in the ocean including tsunami-generated electromagnetic (EM) fields. Here we report significance of vertical particle motions in EM coupling with horizontal geomagnetic components especially around the sea surface in the equatorial regions.

Vertical velocities of the conductive seawater associated with ocean waves such as tsunamis are usually neglected in motional induction studies (e.g., Minami and Toh, 2013) because of its small magnitudes compared with those of horizontal velocities. On the other hand, horizontal geomagnetic components are also thought to produce negligible emfs since V x F forms a short circuit everywhere within vertical planes in the ocean (Larsen, 1971).

However, it has been found that vertical particle motions can be the only source of emfs in the equatorial regions by the analysis of the analytical solution of EM fields generated by linear dispersive tsunamis (Kawashima, 2015). The vertical velocities can couple with the horizontal geomagnetic component parallel to the direction of tsunami propagation. The coupling creates emfs tangential to tsunami wave fronts with different phases and depth dependence from the emfs by horizontal particle motions and the vertical geomagnetic component. Although they become nil on the seafloor, the emfs by the vertical particle motions can generate vertical magnetic components as large as 1nT for a 1m tsunami and a geomagnetic main field with a horizontal component of 35000nT at the sea surface.

This implies that tsunami-generated poloidal magnetic fields can still be observed on oceanic islands in the equatorial regions even in the absence of coupling of the horizontal particle motions with the vertical component of the geomagnetic main field. It is necessary for effective tsunami detection in the equatorial regions that tsunamis propagate in the north-south direction because the geomagnetic main field tends to be horizontal and along the north-south direction. This situation may be realized in the case of potential tsunami sources in the Solomon Islands and/or the eastern half of the Java Trench. In this presentation, results of data analysis of temporal geomagnetic variations on the Pohnpei Island at the time of significant past tsunami events as well as three-dimensional synthetic numerical simulations will be further discussed.

広域津波伝搬に伴う電磁場変動の時間領域三次元シミュレーション

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Time-domain three-dimensional simulations of the electromagnetic fields generated by wide-area propagation of tsunamis

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The reports of detectable electromagnetic (EM) fields generated by tsunami propagation attract interests of researchers because tsunami EM data allows us to infer propagation directions of tsunamis from a single observation alone. This feature may be able to improve the current tsunami early warning systems and tsunami analysis techniques. So far, Ichihara et al. (2013) inferred a new tsunami source location of the 2011 Tohoku earthquake tsunami by using a seafloor EM data, which is in the northern area compared to the tsunami sources obtained only by surface elevation data. However, almost all the preceding studies of tsunami EM phenomena, including Ichihara et al. (2013), used frequency-domain calculations to estimate the tsunami-generated magnetic fields. It is difficult to estimate accurate magnetic fields generated by tsunamis, since tsunamis are inherently transient so that most of the tsunami simulation are conducted in the time domain.

We, therefore, developed a new three-dimensional simulation code of tsunami-generated magnetic fields, adopting the time-domain finite element method (FEM) with unstructured tetrahedral elements, based on the technique of Minami and Toh (2013). Tetrahedral elements have an advantage in accurate expression of real bathymetry. In this simulation code, we first calculate the oceanic flow associated with tsunami propagation, solving the Laplace equation in terms of the velocity potential of the irrotational and incompressible seawater. Then, we conduct an EM simulation using the observed oceanic velocity field as a source. Use of the same tetrahedral mesh between hydrodynamic and EM simulations allows us to obtain the self-consistent results between them. Furthermore, we adopted MPI and MeTiS (http://glaros.dtc.umn.edu/gkhome/metis/metis/overview) to conduct parallel computations so that wide calculation areas up to 1500 km square are allowed in our simulations.

We conducted a tsunami-generated EM simulation of the 2011 Tohoku earthquake tsunami with the tsunami source model presented by Satake et al. (2013). Approximately 5 minutes discrepancy in the tsunami arrival time at the DART observation sites (DART21418, 21401, 21419) between the observed data and calculation imply some problems in our simulation. However, the comparison between the simulation results and the magnetic data observed at the seafloor shows noticeable differences in the phase lag of the magnetic field to the sea surface elevation between on the eastern and western side of the Japan Trench, which is consistent with the implication by Minami et al. (2015). We plan to improve accuracy our simulation by comparing simulation results to analytical solutions of tsunami and tsunami-generated magnetic fields, and to reveal important features of tsunami-generate EM fields from our time-domain simulations.

In the presentation, we will report our new simulation technique in the time-domain and important features found from our tsunami EM simulations. Furthermore, we will discuss the comparison between the tsunami-generated magnetic data observed at the seafloor and the three-dimensional simulation results of the 2011 Tohoku earthquake tsunami.

津波伝搬に伴う電磁誘導現象が、陸上・海底において検出可能な電磁場変動を引き起こす事が近年注目されている。単点観測から津波の伝搬方向を推定できる点が、電磁場を用いた津波観測の大きな特長であり、従来の波高観測に加えることで、津波の早期予測、並びに、津波イベントの解析へ応用することが期待されている。これまで、例えば Ichihara et al. (2013) では、海底磁場データから津波の到来方位を推定し、2011 年東北地方太平洋沖地震津波 (Mw9.0) の波源が、波高データから推定された位置よりも北の緯度 39 度付近に存在する可能性が高い事を明らかにした。また一方で、Kawashima (2015) は、薄層導体近似を用いた津波電磁場シミュレーションを実施し、従来研究では推定が困難であった 2007 年千島地震の断層傾斜面が、南東傾斜である可能性が高い事を北西太平洋の海底磁場データを用いて示している。このように応用範囲が広がりつつある津波電磁場データの利用においては、時間領域の津波電磁場シミュレーションコードが存在しない事が、波高データを併せた解析において大きな障害になってきた。Ichihara et al. (2013) や Kawashima (2015) を含む従来の津波電磁場研究では、津波電磁場の理論/数値計算を周波数領域で行っており、時間領域で行われた津波シミュレーションの結果をフーリエ変換して利用している。しかし、過渡的な津波現象に起因する電磁場変動を周波数領域で再現するのは困難であり、時間領域で津波電磁場現象を扱える三次元シミュレーションコードの開発が期待されてきた。

これを受け本研究では、Minami and Toh (2013) が開発した二次元の時間領域シミュレーションコードの三次元への拡張を試みた。拡張されたシミュレーションコードでは、時間領域の有限要素法を非構造四面体要素と共に採用している。四面体要素は、直方体要素を用いる三次元数値計算手法に比べて、精度の高い地形表現が可能である点に特長がある。本シミュレーションでは、まず、渦なしの非圧縮流体を仮定し、速度ポテンシャルのラプラス方程式を線形境界条件と共に解くことで、津波伝搬を計算する。次に、得られた津波速度場を入力として磁場の誘導方程式を解き、津波伝搬に伴う電磁場変動を計算する。流体計算と電磁場計算において同じ四面体メッシュを用いることで、自己無撞着な結果が得られる点に本シミュレーションの利点がある。本研究ではこれまでに、MeTiS (http://glaros.dtc.umn.edu/gkhome/metis/metis/overview)

を利用した四面体メッシュの分割、並びに、MPI を用いたシミュレーションコードの並列化を行うことにより、約 1500km 四方の領域を伝搬する津波とそれに伴う鉛直磁場変動の計算に成功している。

このコードを用いて本研究では、Satake et al. (2013) の波源モデルを初期条件とした、2011 年東北地震津波の三次元シミュレーションを行った。その結果、NOAA による波高観測点 DART 21401, 21418, 21419 において、計算された津波の到来時刻が観測データに比べて約 5 分遅れること、また、系統的に計算波高が観測データよりも小さくなる、という本シミュレーションの問題点が明らかとなった。これらの問題が残るものの、本研究のシミュレーションからは、(1) 波源近傍では、Tyler (2005) 等の津波電磁場の理論解では説明できない波高と磁場鉛直成分の振幅比の時間変化がみられること、また、(2) Minami et al. (2015) で指摘される通り、水深が大きく異なる日本海溝の東西において、波高と電磁場変動の間の位相差が大きく変化していること、が明らかとなった。本研究では今後、津波波高・津波電磁場の計算結果を単純な場合の解析解と比較することによって計算精度の向上を図り、同時に、時間領域の広域シミュレーションによって得られる津波電磁場の性質を整理していく予定である。

本発表では、本研究の時間領域津波電磁場シミュレーションの計算手法と、広域シミュレーションから得られる津波電磁場変動の特性について、並びに、2011 年東北地方太平洋沖地震津波を対象とした計算結果と波高・海底磁場データの比較について併せて報告する予定である。

高感度地磁気計測 SQUID システムにおける性能の改良

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Improvements of the performance in a SQUID magnetometer system for highly sensitive observation of geomagnetic fields

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We have been developing a low-Tc superconducting quantum interference device magnetometer (LTS-SQUID) system for highly sensitive observation of geomagnetic fields. In our previous study, we reported the performance of the prototype system and the results of test measurements at our laboratory in a suburb of Kanazawa city. The system noise was about 0.15 pT/rtHz in the white region, which was limited by the resolution of a 14-bit data logger. The low-frequency noise, which was mainly attributed to the temperature drift of the preamplifier, was around 0.5 pT/rtHz at 0.1 Hz.

In this study, we have developed a low-drift FLL circuits to reduce the low-frequency noise, and have replaced the 14-bit data logger with a 24-bit one. We show improved performance of the system and some results of geomagnetic field measurements.

我々は LTS-SQUID を用いた高感度地磁気計測システムの開発を行っている。以前の発表では、試作システムの性能と金沢市郊外での地磁気計測実験のテスト結果の報告を行った。当時のシステムノイズは白色雑音領域で約 0.15pT/√ Hz であり、これは 14 ビットデータロガーで制限されていた。低周波ノイズは主として FLL 回路の初段アンプの温度ドリフトが原因であり、0.1Hz で約 0.5pT/√ Hz であった。

今回、プリアンプのドリフトを低減した FLL 回路を新たに開発し、また 14 ビットデータロガーを 24bit データロガーに変更することでシステムノイズの低減を図った。本発表では改善されたシステムの性能を報告するとともに、このシステムを用いて行った地磁気計測結果を報告する。

MT 法連続観測データの長期安定性について〜国土地理院 江刺・涌谷観測点データの解析

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Long-term stability of continuous MT monitoring — Analysis of GSI data measured at Esashi and Wakuya observatories

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The MT method has been recently applied to resistivity monitoring of seismic and volcanic activities and geothermal reservoir. These studies expect to derive a time-dependent resistivity change of target structures. In order to derive 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 February 2015. 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 this variation is not caused by only the variation of the electric field noise. Because such variations of ESA are larger than of WKY, the data can reflect variations of instrumental characteristics and electromagnetic noise. However, it is also possible that the seasonal variations of electromagnetic source intensity affect the MT responces, because a small change is also recognized in the data at WKY. Although we currently cannot detect a reason for these variations, we would advance the evaluation such as a comparative study with other time series data.

地震や火山活動，地熱貯留層などのモニタリングの目的で，MT 法連続あるいは繰り返し観測による比抵抗モニタリングの適用例が報告されている．MT 法は人工ソースを用意する必要がなく，機器の電源が確保されれば比較的簡便に観測を行うことができる．しかしながら，MT 法により地下の微小な比抵抗の変化を捉えるには，電磁場ソースやノイズ環境，接地条件などの外的要因によるレスポンスの変化を排除する必要がある．そのため，本研究では長期電磁場連続観測データを使用して，MT データの長期安定性の検討，比抵抗モニタリングに適用する際の課題の抽出を行うことを目的とする．

国土地理院は，地殻比抵抗モニタリングのため，1996 年に水沢測地観測所（MIZ）と江刺観測場（ESA）において MT 法連続観測を開始した（佐藤ほか，2003）．その後，2003 年に機器の更新を行い，現在のシステムとなった（佐藤ほか，2004）．また，MIZ ではノイズ環境が悪化したため，2005 年に涌谷（WKY）に機器を移設して測定を開始した．これらのデータは，移設はあったものの同一観測点での 5 年以上にわたる連続観測データであり，欠測期間も比較的少なく，MT 法による長期モニタリングの例として利用価値が高い．本発表では，これらのデータを使用した，長期間にわたる MT レスポンスの変化について紹介し，その特徴について検討を行う．

解析には，サンプリングスケジュールが現行のものに変更された 2005 年 6 月以降のデータを使用した．観測期間は，ESA が 2005 年 6 月から 2015 年 2 月まで，WKY が同じく 2005 年 6 月から 2011 年 6 月までである．各日 18:00-08:00 (JST) の 14 時間のデータについて，BIRRP (Chave and Thomson, 2003) を使用して 1 日毎の MT レスポンスを算出した．ESA，WKY それぞれについてシングルサイト処理，また両観測点を相互にリモート点としたリモートリファレンス処理を行った．

代表的な周波数について 1 日毎のレスポンスを時系列として表示すると，1 Hz 以上の高周波数帯において，季節変動と考えられる明瞭な変化が毎年繰り返されていることが明らかとなった．これは，ESA の見かけ比抵抗，位相，磁場変換関数において顕著であり，11〜4 月の冬季において電場-予測電場のコヒーレンスも悪化する．磁場変換関数も冬季にエラーが大きくなるので，電場のみのノイズの変化ではないことが示唆される．WKY に比べ ESA の変動が非常に大きいことから，機器の特性やローカルな電磁場ノイズ環境の変化をとらえている可能性があるが，WKY でも小さいながらも変動が認められるため，電磁場ソースの変化を反映している可能性も排除できない．現時点ではこの原因が明らかにできていないが，今後他の時系列データと比較するなどして検討を行う予定である．

山田断層系郷村断層（京都府京丹後市）の電気伝導度構造モデルの再検討

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Reexamination of the conductivity structure of the Gomura fault of the Yamada fault system in Kyotango city, Kyoto, JAPAN

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Clear electrical conductivity variation is expected to be identifiable in the vicinity of an active fault as a result of enriched and interconnected fluid (meteoric waters and/or groundwater) in fractures and/or uneven fluid distribution across the fault because of impeded cross-fault fluid flow (e.g., Ritter et al., 2005). The electrical conductivity distribution can provide a new image of the subsurface structure of an active fault.

A clear surface earthquake fault appeared associated with the 1927 Kita-Tango Earthquake in the Tango Peninsula of the northwestern part of Kinki district, Japan. This fault is named the Gomura fault and is one of the fault segments of the Yamada fault system. Length of the Gomura fault is reported to be ~13 km on land, while it is ~43km or more when including a part on seabed (Headquarters for Earthquake Research Promotion, 2004). A general strike of the Gomura fault is N30W and its dip-angle is high. The mean slip rates are ~0.2-0.3m/1000yrs (horizontal component) and 0.07m/1000yrs (vertical component).

We made an audio-frequency magnetotelluric (AMT) survey at twelve stations along a transect across the Gomura fault. After dimensionality analysis using the Phase Tensor method (Caldwell et al., 2004), a two-dimensional inversions for the TE and TM modes were carried out (Ouchi et al., JpGU2014).

We reexamined the data and obtained the new conductivity model. The modified conductivity model (GMR_1) is characterized by four conductive regions.

(1) Shallow sub-horizontal conductive layer (C1) between 160m and 300m in depth.

(2) Deep sub-horizontal conductive layer (C2) between 750m and 1200m in depth.

These layers are located to the east of a surface trace of the Gomura fault.

(3) Sub-vertical conductive zone (C3) beneath a surface trace of the Gomura fault.

(4) Weak conductive zone (C4) beneath a surface trace of the Go-seihou fault.

In this presentation, we show the modified model and its interpretation with referring to the 1,300m-long borehole data. Finally, we discuss on parameters which determine special expanse and conductivity of the characteristic conductive zone beneath a surface trace of the active fault.

断層運動にともなって活断層の近傍に破砕が発達する．この破砕域に天水や地下水が浸入することによって，顕著な高電気伝導度領域が形成される場合がある．また，断層面に沿って発達する粘土層によって断層を横切る方向の地下水の流れが妨げられるために，断層の片側に顕著な高電気伝導度領域が形成される場合もある（e.g., Ritter et al., 2005）．これらの特徴を手がかりとして電気伝導度分布から活断層の地下構造を明らかにすることができる（e.g., Yamaguchi et al., 2010; Yoshimura et al., 2009: Goto et al., ; 1998, 2005). 電気伝導度構造に注目することによって，ほかの手法では探査が難しい条件の活断層についても，その構造を明らかにできることが期待される．また，既存の探査手法が有効な場合でも，新たに電気伝導度という物理量を加えて構造決定を行うことによって，活断層の構造に関して新たな制約を加えることができる．

京都府京丹後市に位置する郷村断層では，1927 年北丹後地震（M=7.3）に伴って地表地震断層が出現した．郷村断層の陸上部の長さは約 13km であるが，海底部まで含めた長さは約 43km もしくはそれ以上と報告されている（地震調査委員会, 2004）. この断層の一般走向は N30W で，傾斜は南西傾斜（地表付近）または高角度と報告されている．また，平均変位速度は概ね 0.2-0.3m/千年（左横ずれ成分）と 0.07m/千年（上下成分）であり，C 級活断層に分類される（地震調査委員会, 2004,　岡田・東郷，2000）．

我々は，2013 年に郷村断層の地表トレースとほぼ直交する測線（約 4km）を設け，この測線上の 12 地点で可聴周波数帯の自然磁場変動を信号源とする地磁気地電流法（Audio-frequency magnetotelluric ; AMT）探査を行った．そのデータを元に，2 次元電気伝導度モデルを示した（大内ほか，JpGU2014）．しかし，そのモデルの浅部には，やや不自然な高電気伝導層が認められていた．

本発表では，AMT 探査結果を再解析し，郷村断層を含み，深さ約 1.5km までの新しい電気伝導度構造モデルを示す．この結果を，本測線の近傍で行われたボーリング調査結果と対比させて電気伝導度構造の解釈を行う．さらに，西南日本を代表する横ずれ断層である山崎断層系の電気伝導度構造モデルと比較し，活断層下の特徴的な高電気伝導度領域の成因，空間的広がり，およびこの領域の電気伝導度を決める要因について議論する．

宮城県北部地震活動域の３次元比抵抗構造解析

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Three-Dimensional Magnetotelluric Imaging of a Seismogenic Region, Northern Miyagi

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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 granitic pluton at depth.

The objective of this study is to image the crustal conductor 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)

The 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 deep conductors are significant. One is located at south of Izu-numa, which is consistent with the previous result of Mitsuhata et al (2001), but the distribution is highly three dimensional and tit is rather elongated along the profile of Mitsuhata et al (2001). Another deep conductor exists to the south toward the hypocentral region of the 2003 Northern Miyagi earthquake. We noticed that seismic activity is high around the deep conductors. Mitsuhata et al(2001) pointed out that the high seismicity area is imaged as a resistive anomaly, and that it probably represents a granitic pluton. Our 3d model also confirmed their result.

岩手宮城内陸地震震源域周辺の３次元比抵抗構造解析ー低比抵抗体の存在とその意義

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3D MT Modeling Around the Focal Zones of Iwate-Miyagi Nairiku Earthquake- Crustal Conductors and Their Implications

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The 2008 Iwate-Miyagi Nairiku Earthquake (M 7.2) was an unusually large earthquake, which occurred near the volcanic regions. To understand the mechanism of inland earthquakes, it is important to study the structure around the area. Okada et al. (2012) observed aftershocks precisely and estimated the seismic velocity structure. Iinuma et al. (2009) detected coseismic and aseismic slips with GPS observations. Mishina (2009) and Ichihara et al. (2014) conducted 2-D and 3-D MT surveys respectively. However, the MT station distributions of the previous MT surveys were sparse. We carried out denser surveys and showed more precise resistivity structures around the area. We conducted MT surveys at 66 stations (59 stations from October until November in 2012 and 7 stations from October until November in 2014) around the area and estimated 3-D resistivity structures using inversion code of Siripunvaraporn and Egbert (2009) with full impedance tensor as response functions. The result of our final resistivity structures is similar to the one in Ichihara et al. (2014), but is more complex. We found a low resistivity zone to the northeast of Mt. Kurikoma below 3km depth. This anomaly is connected with a low resistivity zone located under Mt. Kurikoma below 10km depth. The locations of aseismic and co-seismic slips in Iinuma et al. (2009) correspond to the locations of low resistivity and high resistivity zones in our model respectively. This may represent that low resistivity zones are brittle and high resistivity zones are ductile.

磁場変換関数データの３次元比抵抗インバージョンによってイメージされる九州地方の比抵抗異常分布

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Anomaly Distribution for 3D-Inverted Resistivity Structure beneath the Kyushu District Revealed by Geomagnetic Transfer Functions

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We have performed three-dimensional (3-D) inversion analyses by using a data set of geomagnetic transfer functions whose period range is from 20 to 960 s to obtain a subsurface electrical resistivity model beneath the Kyushu district in the Southwest Japan Arc. Observations of original raw data sets for the geomagnetic transfer functions were carried out at the entire Kyushu island and several islands off the western coast of Kyushu from 1980's to 1990's [e.g., *Handa et al.*, 1992; *Shimoizumi et al.*, 1997; *Munekane et al.*, 1997]. The geomagnetic transfer functions were determined at 167 sites in the Kyushu district. The induction vectors, which are produced from the geomagnetic transfer functions and point to current concentration in conductive anomalies [*Parkinson*, 1962], on the Pacific seaboard of the Japanese arcs are known to point to the Pacific ocean of the deep sea in a large sense [e.g., *Yukutake et al.*, 1983]. On the other hand, the vectors on the northern and central Kyushu island do not point to the Pacific ocean off the eastern coast of the Kyushu island but point to the East China Sea of the shallow sea off the western coast of the Kyushu island [*Handa et al.*, 1992]. Additionally, the induction vectors on the southern Kyushu island point to the Pacific ocean in the eastern part and point to the East China Sea in the western part at short period, whereas the vectors are arranged along a direction parallel to a direction of the coast line at long period (>300 s) [*Shimoizumi et al.*, 1997; *Munekane*, 2000].

The complex behavior of the observed induction vectors remained unable to be expressed well by model calculations of the thin sheet analysis and the two-dimensional inversion analysis [e.g. *Handa et al.*, 1992; *Shimoizumi et al.*, 1997], although the behavior of the observed vectors suggested existence of highly conductive anomalies beneath the East China Sea. In this presentation, we will show a 3-D electrical resistivity model whose synthetic induction vectors are consistent with the observed ones. The 3-D resistivity model is obtained by using a DASOCC inversion code [*Siripunvaraporn and Egbert*, 2009]. We will also show results, which we try to verify structural cause of this anomalous behavior of the geomagnetic transfer functions in Kyushu and to verify previous discussions in 1990s.

Hikurangi 沈み込み帯における海底電磁気観測 (序報)

Hikurangi 沈み込み帯海底電磁気観測グループ 市原　寛 [1]
[1] -

A preliminary result of ocean bottom EM observations in the Hikurangi subduction margin (the HOBITSS experiment)

Ichihara Hiroshi Ocean bottom electromagnetic observation group for the Hikurangi subduction zone[1]
[1] -

The Hikurangi subduction margin, where the Pacific plate subducted beneath the Australian plate around the eastern coast of New Zealand's North Island, is an important research field for study of interplate coupling. Geodetic studies found the significant difference of interplate coupling rate between northeast and southwest sides of the margin (e.g. Wallace and Beavan, 2010; Wallace et al., 2012). In the northeast side, small plate coupling coefficient (i.e. weakly coupled plate interface) is estimated. Slow slip events (SSEs) frequently occur in this area. Because most portion of moment release in the plate interface is attributed to the SSEs (Wallace and Beavan, 2010) understanding of the SSE events are also important. On the other hand, high coupling coefficient (i.e. mostly locked plate interface) is estimated in the southwest side. Heise et al. (2013) found the low resistivity zone and high resistivity zone in the weakly coupled northeastern side and the strongly coupled southwestern side, respectively, based on land magnetotelluric (MT) observations. They imply that the low resistivity zone reflects fluid or clay mineral rich interface, which decreases interplate coupling. However, plate coupling, SSEs and physical properties in the interface is not well understood under the off-coast area. In particular, SSEs mostly occur in the off-shore in the northeastern side. In order to study SSEs in this area, the HOBITSS (Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip) experiment by the international research team deployed 15 ocean bottom seismometers (OBS), 24 absolute pressure gauges (APG) and 3 ocean bottom electromagnetometers (OBEM). RV Tangaroa (operated by NIWA, New Zealand) in May 2014. The instruments were recovered by RV Roger Revelle (operated by SCRIPPCS, US) in June 2015.

In this presentation, we will report preliminary result of the OBEM experiment. We used the single glass-sphere OBEMs developed by Tierra Tecnica and JAMSTEC (JM100 series) (Kasaya and Goto 2009). The data were recorded in the following locations: the intermediate point between coast and Hikurangi Trench (site OBEM-1) close to the IODP drilling target point, the point at 20 km landward from the trench (site OBEM-2), and the point at 10 km seaward from the trench (site OBEM-3). Although one OBEM settled at the site OBEM-2 was not recovered, the other two OBEM recorded high quality MT data. We preliminarily estimated MT impedances at the two MT sites based on the BIRRP program (Chave and Thomson, 2004). The horizontal magnetic field data of the other site were used for remote reference. The amplitude of estimated MT impedances in the diagonal components are comparable level with these of off-diagonal components at any rotation angles. It indicates strong 3-D effect due to bathymetry and/or underground resistivity distribution. They also show out of quadrant phase in the TE-mode. Because the phenomenon is observed when the resistivity in the underground is high (greater than 100 ohm-m in the case of Tohoku-oki area; Key and Constable, 2011), resistivity around the plate interface is possibly high in the slow slip area.

The ocean bottom electromagnetic observation group for the Hikurangi subduction zone:
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Five years of the Normal Oceanic Mantle (NOMan) Project

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The Normal Oceanic Mantle (NOMan) project was carried out for 5 years from 2010, aiming to solve two fundamental questions on the normal oceanic mantle from observational approach, which are: (a) Cause of asthenosphere lubrication, and (b) Amount of water in the mantle transition zone. We selected two study areas (A and B) of similar seafloor age (about 130 and 140 Ma, respectively) in the northwestern Pacific Ocean where the mantle below is supposed to be normal. This presentation will give an overview of five years of the NOMan project, especially of its observational activities and a summary of preliminary results so far obtained.

In June 2010, we deployed a small array consisting of 5 (both seismic and EM) sites and started data acquisition from area A, which we call the NOMan pilot experiment. The main observation by long-term seafloor arrays in areas A and B was started by two installation cruises carried out in November 2011 and in August 2012, deploying state-of-the-art ocean bottom seismic and electromagnetic instruments (BBOBS-NXs and EFOSs) in area A that are handled by ROV for installation and recovery. Conventional instruments (BBOBS and OBEM of free-fall/self-pop-up type) were also deployed both in areas A and B. Most of instruments of the pilot experiment were recovered by the cruise in August 2012. So-called advanced instruments (BBOBS-NXs and EFOSs) were equipped with batteries sufficient for 2 years of deployment, but conventional instruments (BBOBSs and OBEMs) only for one year or so. Therefore, we conducted a cruise by W/V Kaiyu in August 2013 to maintain the observation array by retrieving and re-deploying respective instruments. In June 2014, we conducted another W/V Kaiyu cruise, in which we recovered most of conventional instruments in area A after conducting a controlled source seismic experiment by using explosive sources. In September 2014, we completed a recovery cruise by R/V Kairei with ROV Kaiko-7000II. By these two cruises conducted in 2014, we have recovered instruments from all sites except only one site (NM03) where a few EM instruments were left and are to be retrieved in September, 2015.

The seafloor age difference between study areas A and B is only about 10 Ma, which was thought small enough for the temperature difference between two areas to be ignored at the first order approximation. So we originally expected that corresponding results in area B show close similarity to those in are A. However, a result of 1-D array analysis of the surface waves indicated significant difference in the lithosphere-asthenosphere structure between areas A and B. 1-D inversion results of multi-station seafloor magnetotelluric (MT) data also show a certain difference between these two areas. Furthermore, MT results in surrounding areas obtained by previous projects imply the presence of further significant heterogeneity in the old oceanic mantle in the northwestern Pacific toward the subduction zone. For the moment, we are trying to invert each of NOMan geophysical dataset as accurately as possible so as to characterize the mantle structure and its lateral variation. Later we try to clarify the cause for these lateral variabilities, as it can be one of the key issues to understand the lithosphere-asthenosphere system in the old oceanic mantle.

For the key question (b), high-quality data obtained by the long-term seafloor observations are used to investigate the MTZ structure. In particular, electric field data obtained by EFOS (with 2 km electrode separation) provide longer period MT responses sensitive to the MTZ. Resulting MT and GDS (Geomagnetic Deep sounding) responses are almost consistent with the NW Pacific semi-global 1-D model (Shimizu et al., 2010). This indicates that the MTZ conductivity below the study region has weak lateral variation (well approximated by a 1-D model) and is also consistent with the conductivity of MTZ minerals containing at most 0.1-0.5 wt.% water.

Temperature and melt anomalies of hotspot inferred from electrical conductivity

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The mantle upwellings are one of the most important features for understanding the mantle dynamics. A large-scale mantle upwelling beneath the French Polynesia region in the South Pacific has been suggested from seismic studies, which is called the South Pacific superplume. Nolasco et al. (1998) carried out magnetotelluric (MT) survey around the Society hotspot, which is one of the hotspots in the French Polynesia region, in order to estimate electrical conductivity structure beneath and the vicinity of the Society hotspot. This previous study is not enough to understand the geometry of the hotspot, because they estimated resistivity distribution based on two-dimensional inversion although the outline of the hotspot showed tubed like shape according to the results from the seismic study. Moreover, Suetsugu et al. (2009) suggested that the slow velocity anomaly continues from the lower mantle to the uppermost upper mantle just beneath the Society hotspot. The geometry, temperature, and composition of the Society hotspot remain controversial, however, due to still insufficient accumulation of the geophysical data.

Then, we carried out the TIARES project that composed of multi-sensor stations that include broadband ocean bottom seismometers, ocean bottom electromagnetometers (OBEMs), and differential pressure gauges from 2009 to 2010. To obtain three-dimensional (3-D) image of the upwelling of the Society hotspot in terms of electrical conductivity, we newly settled eleven OBEMs and obtained MT responses at 20 sites totally. A 3-D marine MT inversion program, which can treat topographic change distorting EM data, was applied to these MT responses to estimate 3-D electrical conductivity image. The result detected a conductive anomaly elongating from the mantle transition zone to the uppermost upper mantle just below the Society hotspot. This feature is consistent with the slow velocity anomaly obtained from the surface wave tomography (Suetsugu et al., 2009). High conductivity of this anomaly implies higher temperature and the existence of high fraction of volatiles (H_2O and CO_2) compare to the surrounding area.

地殻内部流体移動 に伴う重力・地球電磁気変化 1 :2 次元問題の定式化

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The gravity and geoelectromagnetic field changes caused by crustal fluid flow 1: formulation of a 2-D problem

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Tanaka et al. (2010) suggests a possibility of detecting gravity change due to fluid flow on plate boundaries accompanying slow slip events (SSEs). Since the fluid flow can cause geoelectromagnetic field changes due to the electrokinetic effect, simultaneous excitation of gravity and geoelectromagnetic field changes due to fluid flow accompanying SSEs is expected.

Although the theoretical formulation of the static change of the geoelectromagnetic fields due to a homogeneous fluid flow on a rectangle fault is derived by Murakami (1989), it does not express the temporal evolution of the fluid flow. The present study aims to theoretically derive the mathematical formulation of the changes of both the gravity and the geoelectromagnetic fields due to time-evolving fluid flow accompanying SSEs.

As the first step, the formulation of the gravity and electromagnetic field changes due to the fluid flow on a fault with infinite length and finite width in a 2-D homogeneous half space is discussed. Approximating the electrically conductive half space as a rigid body, based on a simple model that the compressible fluid flows satisfying the law of Darcy on the fault plane in the half space, the mathematical expressions of the field changes are analytically derived by deriving the expressions of the temporal and spatial changes of the density and the filtration velocity of the fluid diffusion with the boundary and initial conditions of the compression and the filtration velocity.

The static electromagnetic fields are separated to TE and TM modes under the 2-D condition. TE mode is excited by the fluid flow along the strike of the fault. Only the magnetic field is excited and the electrostatic potential filed and the gravity field change are not excited accompanying the fluid flow. TM mode is excited due to the fluid flow perpendicular to the fault strike. Though both the electrostatic potential and the magnetic fields are excited, the excited magnetic field cannot reach the boundary of the half space under an approximation that the domain outside the half space is insulating. The electrostatic potential field and the gravity change are observable on the boundary. Under the 2-D condition, it is qualitatively concluded that on the boundary of the spaces, the gravity change and the magnetic field are complementary and that the gravity change and the electrostatic potential field correlate with one another.

The quantitative discussion will be shown.

スロースリップイベント (SSE) に伴ってプレート境界に生じる流体移動が観測可能な量の重力変化をもたらす可能性が示唆されている (Tanaka et al., 2010)。流体移動は界面動電現象を通じて地球電磁気変化をもたらしえるため、重力場と地球電磁場の変化が SSE に伴う流体移動により同時に励起されることが予期される。

断層面上の流体移動に伴う地球電磁気変化は、Murakami(1989) が矩形断層面上に一様な流体移動を仮定して静電磁場の定式化を導いたが、流体移動の開始から終了までを表現するものとなってはいない。SSE に伴って時間発展する流体移動に伴う重力と地球電磁気の両方の変化を統一的に表現する理論的定式化が、本研究の目的である。

本発表ではこの最初の到達として、半無限一様な 2 次元空間中の無限長・有限幅の断層面上の流体移動がもたらす静的な重力変化・電磁気変化の定式化について報告する。剛体近似した半無限導体内部に仮定した断層面上にはダルシー則で圧縮性流体の移動が生じるとの簡単なモデルに基づき、流体圧と流速の境界条件及び初期条件から求められる流体の拡散によってもたらされる流体の密度と流速の時空間変化をまず求め、これによって静的にもたらされる重力場と電磁場の変化の表現を解析的に導出した。

2 次元問題を解くため、静電磁場は TE・TM モードに分離される。TE モードでは断層走向方向の流体移動によって静磁場が励起されるが、電位場と重力場は励起されない。一方、TM モードでは断層走向に直交する流体移動によって電位場と静磁場が励起されるが、半無限空間の外部を絶縁体と近似した場合、半無限空間表面においては励起された磁場は到達せず、電位場変化のみが観測される。この場合、重力変化も半無限空間表面では観測されるため、2 次元問題において半無限空間表面で観測される場は、定性的には、重力場変化と静磁場とは相補的であり、重力場変化と電位場とは相関があることが示される。

発表ではこの定量的議論を行う。

構造変化モニタリングを目指した四国西部での長周期 MT 連続観測

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Long-term Magnetotelluric Monitoring in the Western Part of Shikoku for Temporal Changes Detection of Resistivity Structure

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Recent geodetic observations detect recurrent slow slip events (SSE), 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 three-dimensional resistivity structure around SSE region, we are carrying out wide-band 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. In January 2015, we installed a long-term MT instrument as a pilot observation at Sukumo Observatory of DPRI, Kyoto University located above the eastern edge of Bungo SSE. In this pilot observation, we obtain three magnetic and two telluric data with sampling rate of 10Hz using a fluxgate magnetometer. Observed magnetotelluric data show quite low artificial noise level and is stably transferred in quasi-real-time.

In this presentation, we will introduce our pilot observation at Sukumo Observatory and show the result of stability check for estimating MT responses. Additionally, we will make a progress report on wide-band MT surveys.

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 30 点の広帯域 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、長周期 MT 連続観測による比抵抗構造の時間変化のモニタリングも計画している。モニタリングの可能性評価や最適配置を考える上で、バックグラウンドの三次元構造の推定は必要不可欠であるが、MT 応答推定の安定性などの事前評価のために、2015 年 1 月より京都大学防災研究所宿毛観測室において長周期 MT 連続観測を開始した。宿毛観測室は、豊後水道 SSE のすべり域の東縁に位置している。連続観測では、フラックスゲート磁力計による 3 成分磁場測定と 2 成分電位差測定を 10Hz サンプリングで行っている。人工ノイズの低い非常に良質な電磁場データが記録されており、安定した逐次データ転送がなされている。

本発表では、宿毛観測室での連続観測の詳細を報告するとともに、これまで収録した長期間の電磁場データを用いて、MT 応答推定の安定性の評価結果を報告する。加えて、三次元構造推定のための広帯域 MT 観測の進捗状況を紹介する。

活動的火山のイメージングとモニタリング：草津白根火山への適用の提案

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Electromagnetic Imaging and Monitoring of Active Volcanoes: Proposal for Kusatsu-Shirane Volcano

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Diagnostic understanding of active volcanoes is one of the targets of strong social demands, as indicated by the recent phreatic eruption of Ontake volcano on 27 September 2014 and also by many other volcanic activities in Japanese Islands. Kusatsu-Shirane Volcano, in particular, is the most important target for the volcanologists at Tokyo Institute of Technology.

In the last decade, we have had successfully imaged the edifice of the volcano in three dimensions with 200m horizontal resolutions to a depth of 2km by measuring impedances using natural electromagnetic fields in the frequency range between 0.1Hz and 10kHz (Nurhasan 2006). We have found that the peak of the volcano has a bell-shaped electrical conductor, consisting of clay minerals (smectite), which works as an impermeable cap to trap underlying vapor and fluids. The micro-seismic hypocenters of the volcano are consistently located under the bell-shape conductor. The pressure source location for the recent expansion of the volcanic edifice since March 2014, is also located inside the bell-shaped conductor. We think that the increase in the resistivity under the clay cap and the breakdown of the bell-shaped cap itself will lead to a phreatic eruption.

The continuous imaging of the cap structure by the electromagnetic method will thus be a key to successfully monitor the potential phreatic eruption. We now propose a controlled source electromagnetic imaging and monitoring system, consisting of multiple current loops sources and magnetic impedance (MI) sensor receiver arrays to be installed around the peak of Kusatsu-Shirane volcano. Following the concept of ACROSS (Accurately Controlled Routinely Operated Signal System) (Ogawa and Kumazawa 1996), transmitting signals consist of frequency combs and receiving the signal by a large number of stacking will enable detections of small magnetic signals and their temporal changes originating from the deep geothermal system prior to future phreatic eruptions.

References:

K.Ogawa, M.Kumazawa (1996)Towards the continuous remote monitoring of tectonic stress, H2O and physical states in the Earth curst by means of acoustic and electromagnetic ACROSS, Annual Meeting of Seismological Society, Japan.

Nurhasan (2006) Electromagnetic Imaging of Kusatsu-Shirane Volcano and its Implications for Hydrothermal System, PhD Thesis, Tokyo Institute of Technology, 169pp.

円筒形模擬試料を用いた高密度電気探査の試み

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High-density electrical measurement of a cylindrical simulated sample

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We plan to establish a method of high-density electrical prospecting for rock samples in order to image a high-resolution electrical structure and detect a cluster of microcracks generated by compression experiments. In future, we will contrast resistivity images and X-ray images so as to verify the applicability and scalability of several mixing lows which used interpret resistivity images.

In our previous studies, we have developed a numerical simulation code of DC resistivity method for cylindrical shape samples and carried out feasibility studies by numerical simulation as the first step of laboratory experiments. Also, the results of numerical simulation were compared with results of electrical measurement to simulated sample (conductive plastic).

In this presentation, we will report results of electrical measurements for cylindrical simulated samples using several arrangements of electrodes. In particular, we will discuss reproduction precision by numerical calculation and evaluate an effect of electrode arrangement. Additionally, we will show the future plans of a measurement of rock sample.

本研究では、圧縮試験後の岩石試料内に局在化する微小クラック群を比抵抗構造の不均質として検出することを目的に、岩石試料を対象とした高密度電気探査の実現を目指している。高精度の比抵抗構造が求められれば、空隙率や連結性について解釈が可能となるが、そこに用いる混合則（例えば、Archie, 1942）によって解釈に幅が生じる。面状配列したクラックを含む岩石試料に対しては、X 線 CT スキャン（例えば、Kawabata et al., 1999）等による内部構造の把握が可能であり、フィールドでは困難な比抵抗構造と実構造の対比が容易であるため、種々の混合則の適用範囲の評価につなげたいと考えている。

我々はこれまで岩石試料での高密度電気探査の実現に向け、円筒形状をモデリングできる数値計算コードを新たに開発し、実験のフィジビリティ・スタディや、模擬試料（導電性プラスチックや導電性エポキシ樹脂）を用いたアナログ実験を並行して進めてきた。アナログ実験を通して層状の不均質構造を電位差変化として検出することができ、開発したコードによるフォワードモデリングによって不均質構造の比抵抗値もある程度の幅をもって推定することができた。一方、電極の位置や電極のもつ面積が、数値計算とアナログ実験結果の対比に大きな影響を及ぼすことも明らかになり、高精度の比抵抗構造を推定するためにはこれらの影響を評価した上で、高密度な電極配置による実験が可能か検討する必要があることが分かった。

本発表では、模擬試料に対していくつかの電極配置による電気探査を行い、どの程度数値計算による再現が可能か、また、電極の設定が対比精度に与える影響を評価した結果を報告する予定である。あわせて、実岩石試料を用いた実験についても、今後の岩石実験の計画を含めて進捗状況を紹介する。

R003-P05 **会場: Poster** **時間: 11月3日**

非構造四面体要素を使用したインバーバージョンの海洋MT探査への適用性評価

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Evaluation of the applicability of the inversion method using unstructured tetrahedral elements to the marine MT method

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The author applied a 3-D inversion scheme using unstructured tetrahedral mesh to a synthetic data of the marine magnetotelluric method and verified its effectiveness. Topographical effects have been a critical issue in marine MT (magnetotelluric) modelling and interpretation. Observation sites of marine MT surveys are located on undulating surfaces. Those undulations make anomalous electromagnetic field at the sites. If those effects are ignored, it is, therefore, possible to misinterpret resistivity structures. The finite element method using unstructured tetrahedral elements is one of the most effective methods to correct topographic distortions in the marine magnetotelluric data since it can precisely incorporate the bathymetry into computational grids without using too many elements, and a number of robust meshing algorithms have been proposed such as Delaunay triangulation method and the advancing front method. Schwarzbach & Haber (2013) has shown the applicability of the element to the marine controlled source electromagnetics. In addition, in relation to land MT problems, Usui (2015) has shown that the influence of topography can be sufficiently reduced by representing topography with the element. However, when used in marine MT problems, the unstructured tetrahedral element has been limited to forward calculations. Therefore, the author applied the 3-D inversion scheme of Usui (2015) to marine MT problem and confirmed that that the inversion using unstructured tetrahedral elements can properly estimate subsurface resistivity structure instead of the undulations of the sea floor.

AMT 稠密観測による中央構造線断層帯の浅部比抵抗構造（２）

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Shallow Resistivity Structure around MTL Fault Zone deduced from the dense AMT observations (2)

Yuhei Ouchi[1]; Ryokei Yoshimura[2]; Daisuke Tanaka[3]; Itaru Yoneda[2]; Tomoya Yamazaki[2]
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Izumi segment fault zone of the Japan Median Tectonic Line Fault Zone (MTL) consists of Gojyodani and Shobudani faults, etc. Wideband MT soundings were carried out across these faults (DPRI, Kyoto Univ., 2014). The obtained resistivity model was characterized by a contrast around MTL. However, the shallow resistivity structure was not so clear.

In order to delineate fine subsurface electrical structure of the fault, we carried out audio-frequency magnetotellurics (AMT) measurements at 38 sites along a 5km profile across the Gojyodani and Shobudani faults in November 2014. As the result of remote reference processing using local and far remote sites, we obtained superior quality MT responses at almost all of the AMT sites. Pseudo-sections of responses showed north dipping resistive zone from the surface trace of Shobudani fault.

In this presentation, we will show the outline of our research and report the result of 2D inversion.

中央構造線断層帯の和泉山脈南縁セグメントでは，北側に五条谷断層，南側に菖蒲谷断層が東西方向に並走している．前者は右横ずれ型の活断層で，後者は第四紀中～後期まで活動していた逆断層である（岡田，1986）．この２つの断層を横切るように，京都大学防災研究所（2014）によって広帯域 Magnetotelluric（MT）観測が行われ，地下数 10km を対象とする比抵抗構造の推定がなされている．推定された比抵抗構造では，断層帯を境に比抵抗コントラストが確認できるが，測点間隔が数 km であるため地下浅部の解像度は十分とは言えず，五条谷断層と菖蒲谷断層がもたらす比抵抗構造の差異を区別することが出来ない．高密度な観測が実現できれば，先行研究よりも詳細な構造を推定できると考え，2014 年 11 月に稠密な Audio-frequency MT （AMT）観測を実施した．

五条谷断層と菖蒲谷断層を横切るように，38 観測点で構成される南北方向約 5km の測線を設定した結果，測点間距離が平均 140m の高密度探査を実現することができた． 38 観測点の内，14 点は昼間の数時間分のデータを，残りの 24 点は昼間から翌朝にかけてのデータを収録した．昼間の観測点は複数の観測点で測定時間の重複する時間帯を，夜間の観測点はノイズレベルの低下する 4 時間（JST 01:00-05:00）のデータを切り出し， MT 応答関数を算出した．各観測点では，相対的にノイズの少ない観測点を用いリモートリファレンス処理（Gamble et al., 1979）を行っている．リファレンス距離は少なくとも 500m 以上離れている測点を選択した．33Hz より長周期側の周波数帯で，岩手県の国土地理院江刺観測場の MT 連続観測データを参照点として処理を行った．その結果，夜間の 8Hz より長周期側において見かけ比抵抗と位相の両者に改善が確認できた．しかし昼間のデータでは，このような改善は確認できなかった．したがって昼間にしかデータ収録をしていない観測点については，この帯域を解析対象から外している．疑似断面を確認すると，菖蒲谷断層の地表トレースから北に低比抵抗体が傾斜している．菖蒲谷断層が北に 40 度から 50 度で傾斜している（松田，1986）ことから，この低比抵抗体は菖蒲谷断層に沿って現れている可能性がある．しかし，五条谷断層の地表トレース下には，著しい応答関数の変化は確認できなかった．

本発表では，観測概要ならびに Ogawa and Uchida (1996) のコードを用いた 2 次元解析結果を報告する予定である．