R004-01
Zoom meeting A ：11/4　AM1　(9:00-10:30)
09:00-09:15

富士山における紀元前 1000 年から西暦 1100 年にかけての地磁気永年変化曲線

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Paleomagnetic secular variation curve from BCE 1000 to CE 1100 at Fuji volcano, Japan

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As the paleomagnetic directions and intensities have changed incessantly, it can be and has been utilized for a dating tool. The paleomagnetic secular variation (PSV) records in Japan has been revealed by archaeomagnetic studies of old kilns and hearths (e.g. Hirooka,1977) and paleomagnetic studies of sediment cores (e.g. Ali et al.,1999). However, the archaeomagnetic results are restricted to the last 1600 years in Japan, and PSV records from sediment cores are inconsistent. So, we have carried out the paleomagnetic direction measurements of the volcanic products on Fuji volcano to present the PSV curve extending back to the pre-historic ages, up to BCE 1000. The PSV curve is drawn as a sequence of direction, minimizing the sum of fitness and roughness and the ratio of them is determined by Akaike's bayesian information criterion (ABIC).
Fuji volcano is one of the largest active volcanos in Japan, having erupted mostly basalt in chemistry. Takada et al., (2016) has been revised the geological map of Fuji volcano, and categorized the rock-stratigraphic units into 185, which were erupted during BCE 17000 to CE 1707. For the last 3500 years (Subashiri-d and -c stages), they added a significant amount of ^{14}C dates and utilizing stratigraphic relation with Iz-Kt (CE 838) and Kg (1210-1187 cal BCE) tephra layers (Yamamoto et al., 2005 ; Kobayashi et al., 2007 ; Tani et al.,2013), and established the stratigraphy on the age duration. Those developments enable us collecting paleomagnetic direction data in a sufficient frequency.
The samples were collected from 42 units of lava flows, pyroclastic flows and pyroclastic cones of mostly known eruption ages. We selected carefully several sites from each volcanic product and corrected 6 to 20 samples using an engine powered core picker. Samples were oriented by a sun compass to eliminate the influence of local magnetic anomalies. Magnetization of the samples are measured using a spinner magnetometer with alternating field demagnetization (AFD) and thermal demagnetization (ThD). Our criterion for the site mean direction is a95 less than 5.0 degrees, which gives less than 2.1 degrees of a95 for unit mean.
The dataset enable us to draw the PSV curve between BCE 1000 and CE 1100 at Fuji volcano. It is interesting that there seems to be a stagnant point in PSV at around ca.BCE 1000, whose direction is similar to a known stagnant point in PSV at around CE 800. A phase shift is observed from clockwise circularity (BCD 1000 to CE 600) to counterclockwise circularity (CE 700 to CE 1100), looping around the stagnant point in PSV at around CE 650. Comparing the PSV curve with those from the Korean archaeological sites (e.g. Sung and Hirooka,2000), there shows some disagreements in the age assignments before CE 400. It is necessary to reconsider smoothing and/or fitting parameters of ABIC, and the age of volcanic products (Takada et al., 2016). The PSV curve revealed here is a good tool for the correlating the ages in various discipline in the East Asia.

R004-02
Zoom meeting A ：11/4　AM1　(9:00-10:30)
09:15-09:30

タービダイトが挟在する海底堆積物コアを用いた過去 3 万 5000 年間の古地磁気永年変動と相対古地磁気強度の復元：南海トラフ熊野沖の例

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PSV and RPI over the past 35 kyrs using marine sediment cores with turbidite layers: An example of off Kumano in the Nankai Trough

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Paleomagnetic secular variation (PSV) has been studied widely using marine and lake sediments and archaeological samples. Ali et al. (1999) obtained PSV records for the past 10 kyrs from Lake Biwa sediments, and the PSV record has been used as the master curve for Holocene in Japan. However, their records have some problems including the accuracy of the age axis and consistency with previous studies. With the subsequent progresses of paleomagnetism, it is now possible to estimate relative paleomagnetic intensity (RPI)variations from sediments. However, few RPI record for the past tens of thousands of years was reported so far from sediments around Japan.
Marine sediments have the potential of providing continuous PSV records and　radiocarbon ages using foraminifera. For PSV studies using marine sediments, it is desirable that sediments are gently deposited and not disturbed by sediment inflow from land sources or submarine landslides after deposition. Studies for PSVs over the past tens of thousands of years need sediments with high enough sedimentation rates in continental slopes, in which turbidites are often intercalated. Recently, with the development of turbidite research, it has become possible to identify turbidites with greater accuracy than before mainly based on CT values, magnetic susceptibility, and chemical compositions using an XRF core scanner. The purpose of this study is to obtain PSV and RPI for the past several tens of thousands of years from marine sediments around Japan with intercalation of turbidites and tephras, by identifying and excluding these events layers.
In this study, piston core KH-17-2 PC04 (core length 701 cm, 0-35 ka) taken by the Hakuho-maru KH-17-2 cruise off Kumano in the Nankai Trough was used. The site is on a small knoll in a closed basin at a water depth of 2,255 m. This basin is not directly connected to submarine canyons, so it does not receive sediments from land originating from floodings or other events, and the basin topography makes it unlikely that incoming sediments go out again (Ashi et al., 2014). Okutsu (2019, Ph.D thesis) dated and identified turbidites of core KH-17-2 PC04. The uppermost part of the core was complemented by multi-core KH-17-2 MC08 (core length 34 cm) collected at the same site. Descrete samples of 7cc each (293 for KH-17-2 PC04, 14 for KH-17-2 MC08) were continuously collected. Natural remanent magnetization (NRM), anhysteretic remanent magnetization (ARM), and isothermal remanent magnetization (IRM) measurements were performed on these samples.
Stepwise alternating-field demagnetization of NRM indicates that the samples preserve primary magnetization throughout the core. The PSV record obtained is generally agrees with to those of previous studies (Ali et al., 1999; Ohno et al., 1993).
NRM intensity was normalized with ARM intensity to estimate RPI. The relatively small variability of kARM/SIRM and S-ratio and lack of correlation with the normalized intensity suggest that changes in the sedimentary environment are small and that fluctuations of magnetic properties do not influence significantly to the RPI estimations. The S-ratios of 0.9 and higher with small fluctuations suggest that the magnetic minerals responsible for the magnetization are mainly magnetite and that magnetite dissolution by reductive diagenesis did not occur. Our RPI record show an increasing trend since about 30 ka, which is similar to GLOPIS-75 (Laj et al., 2014). To investigate further the magnetic properties, we plan first-order-reversal-curve (FORC) measurements and transmission electron microscope (TEM) observations.

古地磁気永年変動（PSV：paleomagnetic secular variation）は，海底・湖沼堆積物や考古学試料を用いて世界的に研究が行われている．日本における PSV 研究の代表例として Ali et al.(1999)が挙げられる．Ali et al.(1999)では，琵琶湖の湖沼堆積物を用いて過去 1 万年間の PSV 記録が得られており，今日に至るまで日本における完新世の PSV 標準曲線として，古地磁気層序による年代決定や堆積物コア対比などに用いられてきた．しかし，Ali et al.(1999)には，年代軸の精度や先行研究との整合性など複数の問題点が指摘される．また，その後の古地磁気学の発展に伴い，堆積物を用いた相対古地磁気強度（RPI：relative paleomagnetic intensity）の変動が議論できるようになった．日本近海において，過去数万年間の RPI 変動についての先行研究はほとんどない．
海底堆積物を用いた PSV 研究には，①連続的な PSV 記録が得られること，②浮遊性有孔虫を用いた放射性炭素年代測定による詳細な年代決定が行えることの利点がある．海底堆積物を用いた PSV 研究では，磁化を担う磁性鉱物を含む堆積物が穏やかに堆積し，堆積後に陸源からの土砂の流入や海底地滑りなどにより乱されない堆積環境を有す

ることが望ましい．過去数万年間の PSV 記録を目的とした研究を行う場合は，堆積速度の大きな大陸斜面の堆積物を研究対象とする必要があり，このような場所はタービダイト層が挟在する堆積環境にある．しかし近年，タービダイト研究の発展に伴い，堆積層序や CT 値，磁化率に加え，XRF コアスキャナーITRAX による化学組成を総合的に検討して，従来よりも確度をもってタービダイト層の認定が可能となった．以上を踏まえ，本研究ではタービダイト層やテフラ層が挟在する海底堆積物コアを用いて，これらイベント層を考慮して，日本近海における過去数万年間程度の PSV 記録および RPI 変動記録を得ることを目的とした．

本研究ではまず，学術研究船「白鳳丸」KH-17-2 次研究航海によって南海トラフ熊野沖で得られたピストンコア KH-17-2 PC04（コア長 701 cm，現在～3 万 5000 年前）を用いた．KH-17-2 PC04 は，水深 2,255 m，閉鎖型小海盆内部の凸部から採取された．この海盆は，海底谷に直結していないため，洪水などによる陸からの土砂の供給を受けず，地形は周囲より大きく凹んでおり，外部から流入した土砂が再び流れ出すこともない環境下にある（Ashi et al., 2014）．また，KH-17-2 PC04 は，奥津（2019，博士論文）によってタービダイト層の認定および年代決定が行われている．ピストンコアでは最表層部が物理的に乱れることが多いため，同地点で採泥されたマルチコア KH-17-2 MC08（コア長 34 cm）で補完した．KH-17-2 PC04 と KH-17-2 MC08 から連続的に採取された個別試料（PC04：7 cc キューブ×293 試料，MC08：7 cc キューブ×14 試料）について，自然残留磁化（NRM）測定と非履歴性残留磁化（ARM）測定，等温残留磁化測定（IRM）測定を行った．

NRM 測定による段階交流消磁の結果から，コア全体を通じて直線性の良い初生磁化成分が得られ，安定した残留磁化を保持しているサンプルであることがわかった．また，得られた PSV 記録は，当該年代における先行研究である Ali et al.(1999)や Ohno et al.(1993)などと概ね類似した傾向が確認された．

NRM 測定の結果を ARM 測定の結果で規格化し，RPI 変動の推定を行なった． kARM/SIRM や $S_{-0.3T}$ 比の変動が比較的小さく，また RPI 変動と相関するような変動を示していないことから，この海域では堆積環境の変化が小さく，堆積物の磁気特性の変動が相対古地磁気強度推定に大きな影響を与えていないと考えられる．また，$S_{-0.3T}$ 比が 0.9 以上であり変動が小さいことから，磁化を担う磁性鉱物は主としてマグネタイトであり，磁性鉱物の還元溶解を受けておらず，安定した残留磁化を保持していることがわかった．さらに First-Order-Reversal-Curve（FORC）測定や透過型電子顕微鏡（TEM）観察を行う予定である．得られた RPI 変動記録は， 過去 7 万 5000 年の RPI 変動のグローバルモデルとして用いられている GLOPIS-75（Laj et al., 2014）と類似の，約 3 万年前以降の増大傾向が見られる．

R004-03
Zoom meeting A ：11/4 AM1 (9:00-10:30)
09:30-09:45

Effects of thermal boundary conditions for cooling from the CMB on geodynamo with various Rayleigh numbers and inner core radii

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The Earth has been sustaining its intrinsic magnetic field for at least 3.5 billion years as revealed by paleomagnetic studies [e.g., Biggin et al., 2015]. The geomagnetic field is generated and maintained by dynamo action due to convection of liquid iron alloy in the outer core. Studies of the thermochemical evolution of the Earth's core suggest that the solid inner core has been growing up for approximately one billion years [e.g., O'Rourke and Stevenson, 2016]. Consequently, heat flow in the core has also been changing through the Earth's history [e.g., Driscoll and Bercovici, 2014]. Hence it is important to investigate effects of heat flux in relation to various inner core size on dynamo action to understand a physical state of the past Earth. Heimpel et al. (2005) evaluated dynamo onset conditions with various inner core size for a fixed temperature (FT) boundary condition. Hori et al. (2010) found that magnetic field is more dipolar on a fixed heat flux (FF) boundary condition, zero flux at the inner-core boundary (ICB) and outgoing flux at the core-mantle boundary (CMB), rather than on the fixed temperature boundary condition for the range of the inner to outer core radius ratio, r_i/r_o = 0.1 and 0.35. It is suggested that the fixed heat flux boundary condition to sustain a strong dipole field would be preferred to the fixed temperature boundary condition in $0.1 < r_i/r_o < 0.35$. Therefore, we carry out dynamo simulations with the fixed heat flux boundary condition for cooling from the CMB to understand geodynamo in the past Earth.

In the present study, we investigate the effects of cooling from the CMB on numerical dynamos with various inner core size using a numerical dynamo code Calypso [Matsui et al., 2014]. We fix the Ekman, Prandtl, and magnetic Prandtl numbers to be $E = 10^{-3}$, Pr = 1, and Pm = 5, respectively, and change the Rayleigh number and the radius ratio to be r_i/r_o = 0.15, 0.25, and 0.35. For boundary condition, we perform simulations with (i) FT, (ii) FF with balanced heat flow at ICB and CMB, and (iii) FF with taken into account of the cooling of the core. To compare these three conditions, we perform the simulations with the same flux Rayleigh number (Ra^F) at the CMB. First, we compare (i) FT cases and (ii) FF with balanced heat flow cases. The results show that the Ra^F range to sustain the intense dipole field in (ii) FF cases is smaller than that for the (i) FT cases. FF with balanced heat flow boundary is inappropriate to a strong dipolar dynamo for all r_i/r_o. We also compare the two FF cases. In r_i/r_o = 0.25, strong dynamo is sustained with balanced heat flow case (ii) with $Ra^F = 1.08*10^6$, while dynamo is failed with zero flux (iii). In the case (iii), kinetic energy density is approximately 1/4 times of that of heat balance case (ii). This result suggested that convection in case (ii) is not intense enough to sustain dynamo. We will discuss how heat flux condition is suitable to sustain the intense dipolar field by further simulations with various thermal boundary conditions.

R004-04
Zoom meeting A ：11/4 AM1 (9:00-10:30)
09:45-10:00

Study of the equatorial symmetry of flow and magnetic field in reversal and non-reversal dynamo models

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Paleomagnetic observations revealed that the geomagnetic field has reversed its polarity every hundreds of thousands to millions of years and each reversal typically takes 2000-12000 years to occur. Some numerical dynamo simulations represented dipole reversals and gain insight into physical processes that give rise to polarity reversals.These dynamo simulations revealed a strong inverse correlation between the stability and the equatorial symmetry of the simulated field (Coe and Glatzmaier, 2006). This result is consistent with the paleomagnetically inferred degree of the symmetry of the Earth's magnetic field during the past 150 Ma, which reversed polarity more frequently when the geomagnetic field was more symmetrical with respect to the equator (McFadden et al.,1991). From insight of the induction equation, anti-symmetric flow has an important role to generate the symmetric magnetic field from the dipolar magnetic field. Olson et al., (2004) proposed a process of magnetic polarity reversals in a dynamo model. In their model, the reversed magnetic field flux is produced locally in the convective plumes and transported from south to north by the meridional circulation. This result suggests that asymmetric flow with respect to the equator play a role in reversals. However, it is an open question how to generate anti-symmetric flow under the condition of the strong rotation because symmetric flows with respect to the equator is dominant under the strong rotation condition. In the present research, we investigate how asymmetric flow is growing and maintained in the dynamo in which reversals occur.
In the present study, we perform two dynamo simulations with reversals in order to compare the equatorial symmetry between the cases with and without reversals, using a geodynamo code Calypso [Matsui et al., 2014]. In Case A, we set the fixed temperature condition at the inner and outer boundaries, and set the Ekman, Prandtl, magnetic Prandtl and Rayleigh numbers to $E = 10^{-3}$, Pr = 1, Pm = 5 and Ra = 400, respectively. In Case B, we set the fixed heat flux condition at the inner and outer boundaries, and set the dimensionless numbers to $E = 6*10^{-4}$, Pr = 1, Pm = 5 and Ra = 1540, respectively. In Case B, Ra is derived from the time average of temperature difference between boundaries. For each case, we investigate the time series of dipole tilt angle, kinetic and magnetic energy for symmetrical and asymmetrical components. In Case A, the time average for the ratio of magnetic to kinetic energies is 0.05, and correlation between polarity reversals and amplitude of the energies are not found. Symmetric part and asymmetric part of the kinetic energy are anti-correlated, so both may have different energy source. For Case B, in which the time average for the ratio of magnetic to kinetic energies is 0.6, a clear relation between the tilt angle and the energies is observed. During the reveal and excursion, kinetic energy grows, and the asymmetric magnetic energy ceases more than symmetric part. Consequently, the symmetric and anti-symmetric energies become comparable. On the contrary, the kinetic energy decreases and the asymmetric magnetic field recovers when the dipole magnetic field sustains stably. We discuss a detailed analysis for the flow and magnetic field structure in these reversal cases and investigate more cases without reversal and stable dipole field.

R004-05
Zoom meeting A ：11/4　AM1　(9:00-10:30)
10:00-10:15

機械学習に基づく地球主磁場の経年揺動検出に適した長期毎月値データセットの構築

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Developing a historical monthly magnetic dataset to resolve the fast core field fluctuations based on a machine learning algorithm

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Earth's core magnetic field is known from observations to evolve on various timescales. Among them are the most rapid variations observed so far, interannual fluctuations (IFs), that have been recently revealed to exist by satellite magnetormetry missions enabling very dense sampling over the globe (Chulliat et al. 2010). The IFs are thought to arise from hydromagnetic waves consisting of different modes as theoretically predicted to prevail within the fluid core. Particularly, a mode called 'torsional oscillations (TOs)' seems most likely responsible for the IFs. Information on the magnetic field itself and dynamics within the fluid core can possibly be acquired by resolving the interannual TOs. However, their amplitudes are typically too small (fluctuations of as much as 2nT/yr in the secular variation at the Earth surface) to be clearly distinguished from those due to the field of the external origins. The precision of the internal-external field separation has been improved by the advent of the continual satellite missions, while it is much poorer before. Model variance of the TOs inversely estimated from imperfectly separated core field model downward continued is considerable (Asari & Wardinski 2018). Highly precise core field models are available for the last 20 years, but the time length is not sufficient for analyzing the interannual TOs.
In this work, we aim to improve the original monthly mean dataset (simple arithmetic mean of all hourly data for a month; Chulliat and Telali 2007), by creating an optimized monthly mean dataset back to 1957 based on a machine learning algorithm. These monthly means are derived from hourly means just as the original ones, while the contributions from the magnetosphere and ionosphere (external disturbances) are eliminated as much as possible. These monthly means are estimated by using a machine learning with the following procedure. (1) A gradient boosting framework called LightGBM is used to predict the external disturbances involved in Kakioka hourly means of a satellite field model from January 1999 to December 2015. We set the geomagnetic indices (Dst, AE, HMC, their time derivative, and ap index) and solar zenith distance as input parameters in the machine learning model, and set the external disturbances as output parameters. (2) The indices for 1957-1998 are applied to the machine learning model to predict the external disturbances at Kakioka for the same period. (3) The predicted external disturbances are subtracted from the original hourly data to obtain the hourly means data. (4) The monthly means are calculated by the weighted mean of hourly data. Such hourly data is downweighted as associated with predictions of large external disturbances or in the daytime when the Sq is dominant.
In the presentation, the results of the above procedure for three components (XYZ) of the Kakioka magnetic field will be reported. A significant improvement has been seen in the temporal smoothness of the optimized monthly means, particularly for X component which tends to be seriously affected by the ring current. Also, the standard deviations of the monthly X component means are significantly reduced. They are 10-15nT for the optimized ones irrespective of the solar activity cycle, whereas roughly over 50nT for the original ones around the solar maximum. Although the accuracy of the prediction of external disturbances degrades backwards in time as the geomagnetic indices get less reliable, the machine learning can be effectively applied to creating a historical dataset of the optimized monthly means. It is expected that a core field model optimized for describing IFs are eventually constructed, by using worldwide monthly mean datasets improved with the optimizing method presented.

地球コアを起源とする主磁場は様々な時間スケールで変化することが地磁気観測から知られている。近年の人工衛星を用いた稠密な全球観測では、その最も「速い」方の変化成分――経年揺動――の存在が特定されるようになった（Chulliat & Maus. 2014）。主磁場の経年揺動は、準静的に発展するコアの基本場に重なる電磁流体波に由来し、理論的に予言される多様な波動モードのうち特に「ねじれ振動」と呼ばれる波動を主要因とすると考えられている。ねじれ振動を詳細に解像できれば、コア内部の磁場や力学に関する情報が観測から得られる。しかし、この揺動の振幅はかなり小さいものであり（地表での永年変化が数年スケールで 2nT/年ほどふらつく程度）、外部起源成分との分離が容易ではない。主磁場モデリングにおける内外分離の精度は、継続的な衛星観測ミッションが登場した 1999 年以降に比してデータに限りのあった 1998 年以前で大きく低下する。分離の不完全な主磁場モデルに対して下方接続を適用し、逆推定により得たねじれ振動モデルの不確定性は大きい（Asari & Wardinski 2018）。衛星観測の運用された最近 20 年については高精度の分離を実現した主磁場モデルが得られているが、ねじれ振動の解析に要する期間としては十分に長いとは言えない。
そこで本研究ではこれまでの主磁場モデリングに用いられた「従来型」毎月値（各月の全毎時値の単純平均（Chulliat and Telali, 2007））データを見直し、経年揺動の検出に「最適化」された毎月値データセットの整備を 1957 年まで

遡って行う。この最適化毎月値は、従来のように毎時値から算出されるが、ノイズとなる磁気圏・電離層起源の寄与（外部擾乱）をできるだけ除外する。ここで外部擾乱の推定には機械学習を用い、次の手順に従って学習と毎月値を算出する。①主磁場モデルの内外分離の精度が格段に高い 1999 年 1 月から 2015 年 12 月において、地磁気擾乱指数（Dst, AE, HMC およびその時間微分と ap 指数）と太陽天頂角を入力データとし、 柿岡毎時値に含まれる外部擾乱を出力データとして学習させる。ここでは最も良好な予測結果を与えた勾配ブースティング（LightGBM）に基づく学習モデルを採用する。②得られた学習モデルに 1957 年から 1998 年の入力パラメータを利用し、同期間の柿岡毎時値に対する外部擾乱を予測させる。③毎時値データから外部擾乱の予測値を引く。④外部擾乱の予測値が大きい時刻の毎時値、および Sq の卓越する昼間の毎時値については加重を落として月平均値及び標準偏差を算出する。
本発表では、柿岡の地磁気 3 成分（XYZ）を例とし、以上の手順により算出された最適化毎月値を示す。外部擾乱の影響が軽減したことで、時間変化が滑らかさにおいて従来型毎時値に比べて有意な改善が見られる。特に赤道環電流の寄与を受ける X 成分で明瞭である。また、標準偏差に顕著な減少が見られる。従来型毎月値では太陽活動周期に伴って増減し、最大で 50nT にも及んでいたものが、最適化毎月値では太陽活動周期によらず 10-15nT ほどに抑えられている。Y と Z 成分については Sq の寄与が除外されたことで同様の効果が見られる。過去の擾乱指数自体の正確性が落ちることもあり、時代を遡るにつれ機械学習による外部擾乱の予測精度も低下するものの、本手法の最適化データセット作成における有用性は高い。同手法を世界各地の観測点データに拡大することで、経年揺動をより正確に記述する主磁場モデルの構築に繋がることが期待される。

R004-06
Zoom meeting A ：11/4 AM2 (10:45-12:30)
10:45-11:00

Contribution of biogenic magnetite on natural remanence magnetization in deep-sea sediments

#Kosuke Inoue[1)], Toshitsugu Yamazaki[2)]
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Intensity of ancient geomagnetic field, called paleointensity, has been widely studied to understand the variations of the geomagnetic field. Deep-sea sediments are expected to preserve continuous records, and their relative paleointensity (RPI) has been widely used for stratigraphic correlations and age estimations. RPI is the normalized intensity defined as natural remanent magnetization over artificial remanent magnetization like ARM and IRM. RPI estimations are based on the assumption that ARM correctly normalizes the acquisition efficiency of depositional remanent magnetization (DRM). Recent studies have shown the existence of biogenic magnetites in marine sediments, which are originated from magnetotactic bacteria (MTB). MTB have single domain magnetites aligned in chains in their membrane, and biogenic magnetites have higher ARM acquisition efficiency than terrigenous magnetites in general. However, differences of DRM acquisition efficiency between biogenic and terrigenous magnetites have not yet been understood well. Normalized intensity may depend not only on geomagnetic field intensity but also variations in the abundance of biogenic and terrigenous magnetites. In addition, the morphology of biogenic magnetite is expected to be an environmental indicator because it is reported that the morphology of biogenic magnetite varies with chemical conditions of sediments.
My study aims to understand the relation between the normalized intensity and magnetic mineral composition using some cores in which the average normalized intensities are significantly different. The differences of magnetic mineral constituents, in particular biogenic vs. terrigenous magnetites, could affect the normalized intensity, and ARM may not be an appropriate normalizer.
By measuring first-order reversal curves (FORCs), the contributions of biogenic and other detrital magnetic particles were estimated. Using principal component analysis, FORCs were statistically unmixed to the terrigenous and biogenic components with and without collapsed chains. The results suggest that the variations in magnetic properties of sediments can affect the normalized intensity.

R004-07
Zoom meeting A ：11/4 AM2 (10:45-12:30)
11:00-11:15

Paleomagnetism of sediment cores taken from the Ontong-Java plateau

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Abstract: We studied sediment cores taken from the Ontong-Java plateau and managed to extract the geomagnetic paleointensity variation from them. Relative paleointensity (RPI) variations are widely used to understand geomagnetic field behavior and to develop age models for sedimentary sequences. Biogenic and terrigenous magnetic components are considered as the two major components, but for RPI estimations it is conventionally assumed that these two contribute to the remanent magnetization acquisition in an identical manner. However our RPI estimation shows some intriguing results. Relative paleointensity normalized by ARM shows artificial downcore decreases, and it has an inverse correlation with the kARM/SIRM ratio, which suggests that as the proportion of biogenic to terrigenous magnetic components increases, the RPI record becomes weaker. So varying proportion of biogenic components may have considerable influence on RPI signal recording in the sediments. Moreover, NRM-ARM demagnetization diagrams show curvature, which can be interpreted as the coercivity distributions of NRM and ARM are different. Therefore, we tried to distinguish the different contributions of the biogenic and terrigenous components to the RPI record by recalculating NRM-ARM demagnetization slopes in relatively higher and lower alternating field intervals. If we assume that the higher coercivity component correspond to biogenic magnetites while the terrigenous component is in lower coercivity distributions as some previous studies did, NRM acquisition efficiency of the biogenic component may be lower than that of the terrigenous component. But our result contradicts with the previous studies using the similar method, and the reason remains to be studied. The purpose of our research is trying to figure out the mechanism how magnetic minerals derived from different sources contribute to the remanent magnetizations of sediments. Then, it is expected that influences on the relative paleointensity records brought by different proportions between the biogenic and terrigenous components in the sediments is able to be known.
Keywords: geomagnetic paleointensity; biogenic magnetite; coercivity distribution; Ontong-Java plateau

R004-08
Zoom meeting A ：11/4　AM2　(10:45-12:30)
11:15-11:30

ラハール堆積物の定置年代の推定とナノバブルを用いた還元化学消磁の試み

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Reductive chemical demagnetization with ultrafine bubbles technology for estimation of Lahar`s emplaced age

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Lahars are extremely destructive debris flow of mud-rock slurries, sometimes including boulders. In lahars, the presence of such boulders has well been known worldwide. Although such boulders had been difficult to date, Sato et al. (2014, 2016, 2019) proposed the method for dating such boulders using viscous remanent magnetization (VRM). The application of VRM dating to lahar boulders possesses the potential for reconstructing the occurrence of lahar events. We now focus on the andesite boulders in Sukawa lahars at the western foot of Adatara volcano, Northeast Japan. This is because radiocarbon dating of wood fragments within these lahar deposits has been already determined, indicating the occurrence of 18 lahar events during the last 14000 years although recent boulders-included lahars are not dated. These conditions give us a mutual check for dating with radiocarbon and VRM dating. However, some boulders have hydrothermally been altered in-situ or nearby the crater at the Adatara summit. The precipitation of hydrothermally iron-oxides would lead us to mislead unblocking temperatures of VRM components during thermal demagnetizations. Anai et al. (2018) proposed a new reductive chemical demagnetization (RCD) to dissolve ferric iron (Fe^{3+}) in secondary goethite and pigment hematite precipitated in voids and or cracks in samples using reductive liquid agents of ascorbic acid. Therefore, we preliminarily applied their method with ultrafine bubbles technology to our samples for chemical demagnetization, and also applied low-temperature demagnetization to prevent the effect of coarse-grained magnetite. These pre-treatments successfully removed the potential carrier minerals of hydrothermally precipitated iron-oxides along with voids and cracks in our andesites. Also, the RCD with ultrafine bubbles technology indicated the direction of remanent magnetization closer to the direction of the geomagnetic field, by dipping the samples in the container with ultrafine bubbles circulation with ascorbic acid hosted in two-layered cylindrical mu-metal magnetic shield in 2.5~3 hours.

ラハールは火山地域で発生する土石流の一種で，山麓において壊滅的な被害を引き起こす．ラハール堆積物中の古木の放射性炭素年代と層位学から，その地域の災害史を復元する研究が行われているが，いつでも古木が含まれるわけではない．一方，ラハール堆積物にはしばしば火口付近や斜面に定置していた巨礫が含まれることがある．近年，巨礫に対して粘性残留磁化を用いて年代を推定する方法が考えられている（Sato et al., 2014, 2016, 2019）．本調査地域である安達太良火山西麓酸川流域に広がるラハール堆積物中では安山岩起源の巨礫が多数見られ，木片や樹幹などの放射性炭素年代測定から過去 14000 年の間に 18 回のラハールが発生したと考えられている．また，本地域の直近数千年に関しては年代値が求められていないことから，粘性残留磁化による堆積年代の推定の有用性は高いと考えられる．しかしながら本地域の巨礫は安達太良火山の影響により熱水変質を被っており，このような場合鉄酸化物による二次化学残留磁化の影響で正しい推定を行えないことが多くある．そこで本研究では Anai et al. (2018)で提案された還元化学消磁(RCD)という新しい手法を用いて，二次磁性鉱物中の Fe^{3+}をアスコルビン酸により還元・溶解させることで取り除くことを試みた．このときコア試料を，超微細泡(ナノバブル)を発生させる装置にアスコルビン酸溶液とともに浸し，溶液を循環させた．この手法により 2.5~3 時間程度で試料中の鉄酸化物を溶解させ，RCD を施したサンプルとそうでないサンプルについて古地磁気測定を行ったところ，RCD を施したサンプルではより地磁気方向に近い新たな残留磁気成分が見られた．発表では実験と古地磁気測定の結果に関する詳細について報告する．

R004-09
Zoom meeting A ：11/4　AM2　(10:45-12:30)
11:30-11:45

本州中部，土岐花崗岩体の周辺に発達する接触変成岩の古地磁気学的研究

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Paleomagnetic study of contact metamorphic rocks around the Cretaceous Toki granite in central Japan

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This study presents rock magnetic and paleomagnetic results from a contact metamorphic aureole around the late Cretaceous (~70 Ma) Toki granite in central Japan. To investigate the relationship between rock magnetic and paleomagnetic characteristics and metamorphic grade, we collected oriented samples of metasedimentary (mainly pelitic and psammitic) rocks at 10 sites according to the distance from the intrusion contact. We performed progressive thermal demagnetization (PThD) of natural remanent magnetization, anisotropy of magnetic susceptibility (AMS) measurement, and PThD of three-axis isothermal remanent magnetization for the samples. The results suggest that characteristic remanent magnetizations (ChRMs) mainly reside in pyrrhotite and were acquired after tilting of strata as a secondary chemical remanent magnetization or thermoremanent magnetization. The ChRM directions have dual polarities, even at the same site, and they are almost antiparallel, indicating magnetization acquisition over a fairly long period of time. In addition, the ChRM directions are easterly deflected from the geocentric axial dipole field direction in geographic (in situ) coordinates, suggesting that they were acquired sometime between the granite intrusion and the Miocene clockwise rotation of southwest Japan. Possibly, the ChRMs were acquired during or immediately after contact metamorphism. The results of AMS and outcrop observations show that the metamorphic rocks in this area were not simply affected by heat from the Toki granite but were also affected by deformation during metamorphism.

本研究で筆者らは，本州中部の白亜紀後期(～70Ma)の土岐花崗岩体周辺の接触変成帯から得られた岩石磁気・古磁気学的結果を紹介する．岩石磁気・古磁気学的性質と変成度との関係を検討するために，筆者らは 10 サイトの変成岩（主に泥質と砂質）の定方位試料を土岐花崗岩体からの距離に応じて採取した．これらの試料に対して，自然残留磁化の段階熱消磁(PThD), 帯磁率異方性(AMS)の測定, 3 軸等温残留磁化の PThD などを行った. それらの結果は，特徴残留磁化（ChRM）は主にピロタイトが担い，地層傾動後に二次的な化学残留磁化または熱残留磁化として獲得されたことを示唆する．ChRM 方位は同一サイトであっても両極性を持ち，それらはほぼ反平行であることから，かなり長い時間をかけて磁化が獲得されたことを示す．また，ChRM 方位は地理的（in situ）座標において地心軸双極子磁場方位から東偏しており，このことは ChRM が花崗岩貫入と中新世の西南日本の時計回り回転との間に獲得されたことを示唆する．AMS や露頭での岩石観察の結果は，この地域の変成岩は土岐花崗岩による被熱の影響だけでなく変成時に変形の影響も受けたことを示す.

R004-10
Zoom meeting A ：11/4 AM2 (10:45-12:30)
11:45-12:00

Paleomagnetic study of volcanic rocks across the spreading axis in the Tendaho Graben in the Afar depression, Ethiopia

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The Afar depression is one of the unique areas for the study of the spreading centers. Magnetic anomaly observation and paleomagnetic measurements in Afar area are considered to be important to understand the magnetization structure of the spreading axis. In this study, paleomagnetic measurements were made on the samples from volcanic rocks of 43 sites across the spreading axis in the Tendaho Graben in Afar. For 72 specimens of the 43 sites, 16 specimens were measured by thermal demagnetization and 56 specimens were measured by alternating field demagnetization. Checking remanent magnetization directions for each site shows that four sites directions are less reliable. We adopt the other 59 results from 39 sites which give reliable paleomagnetic directions, and calculate the mean-site directions. Combining our preliminary data with the reported data of 21 sites, paleomagnetic directions are obtained for 60 sites across the spreading axis in the Tendaho Graben. For the 60 sites, 41 sites show normal polarity, 17 sites have reverse polarity, and 2 sites show intermediate directions. The paleomagnetic polarity shows a simple pattern along the line vertical to the spreading axis, which is reverse-normal-reverse polarity from southeast to northwest. The normal polarity zone is observed at the spreading axis with a width of about 40 km and the reverse polarity zones are recognized at both sides of the normal zone. These paleomagnetic data indicate the boundaries of Brunhes chron and Matuyama chron of both sides of the spreading axis, which gives age constraint on the formation of the fissure lavas erupted at the spreading axis.

R004-11
Zoom meeting A ：11/4　PM1　(13:45-15:30)
13:45-14:00

磁気探査における古地磁気学・岩石磁気学的情報

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Paleomagnetic and rock magentic information for magnetic surveys

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Archaeologists and exploration geophysicists have been undertaken a role of the main player of magnetic surveys to detect the buried magnetized materials in the archaeological sites. Here we consider the interpretation of the results of the observed magnetic anomalies from the paleomagnetic and rock magnetic point of views.
The target of this study are the undiscovered and uninvestigated buried kilns in Nakadake Sanroku Kiln Site Cluster in Kagoshima Pref., southwest Japan. In this kiln cluster, one kiln has been archaeologically investigated since five years ago and now we try to detect other kiln bodies in the neighborhood. We found five magnetic anomalies by scanning survey with using Overhauser magnetometer, and we reached a burned soil layer by explorative excavation after the magnetic survey. Above one of the other magnetic anomalies, we made an anomaly map by a 2-dimensional survey. There was an elongated magnetic anomaly with 6-7m length, 2-3m width and 250nT amplitude, which is characterized as a kiln body.
On the other hand, paleomagnetic and rock magnetic information from the floor samples of the investigating kiln shows that the magnetization of the kiln body (floor) is significantly high (~15A/m) and the main magnetic carrier may be fine magnetite. The observation of the anomaly is explainable in the model of a magnetized plate that the geometry is 6m long, 2m wide and 3.3cm thick, the magnetization is 15 A/m, and the burial depth is 0.4m.

日本において、山中に埋没している被熱した考古遺構に関する磁気探査を担ってきたのは、主に遺構そのものについて知見をもった考古学者や探査手法に詳しい物理探査の専門家であった。我々も山中に埋没している被熱した考古遺構について磁気探査を行い、詳細な位置と大きさ・形などを推定する作業を続けてきたが、今回は埋没している物体のシグナル源である残留磁化について知見を持つ古地磁気学の立場からデータを解釈するとどうなるか考えてみた。
本研究では鹿児島県南さつま市の中岳山麓遺跡窯跡群を対象とした。ここでは数年前より 1 基の須恵器窯について発掘調査が行われ、付随して古地磁気学測定も行っている。我々は次に発掘調査する古窯を探索するため、オーバーハウザー磁力計を使用して、付近の山林の中から予め表採土器片が見つかっている数カ所において磁気探査を行った。その結果、5 カ所の磁気異常帯を発見し、そのうちの 1 ヶ所では試掘によって焼土が見つかった。また、別の磁気異常帯においてマッピングをしたところ、古窯と思われる 6〜7m の長さと 2〜3m の幅を持つ磁気異常（振幅は約 250nT）を特定した。
一方、発掘調査中の須恵器窯の床面試料について古地磁気測定を行ったところ、その残留磁化は極めて高い(〜15A/m)ことが分かった。また、岩石磁気測定より磁性鉱物は比較的細粒な磁鉄鉱の特徴を持つことがわかった。これらの結果を考慮して、観測された磁気異常を実現する磁化体に関するフォワードモデルを検討したところ、深度約 40cm にある幅 2m 長さ 6m の長円形の磁化体が適当であるとの結論に至った。
今回は対比可能な窯が近隣にあったため磁気探査の測定結果に対して古地磁気学的な考察を加えることができ、古地磁気学・岩石磁気学の情報が探査結果の解釈に有効であることが判った。今後は、似たような窯を見ることができなくても、土壌や粘土を焼くことなどで、類推可能か等について検討する。

R004-12
Zoom meeting A ：11/4　PM1　(13:45-15:30)
14:00-14:15

復元窯における窯体と土器片の考古地磁気学

#北原　優[1)],畠山　唯達[2)],山本　裕二[3)]
[1)]岡山理大・経営・経営,[2)]岡山理大・情報処理セ,[3)]高知大

Archaeomagnetism for kiln body and pottery fragments of reconstructed kilns

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Reconstruction of archaeointensity is one of the important research themes in archaeomagnetism. In Japan, archaeointensity research has stagnated since the 1980s due to the complexity of experimental techniques and the low success rate of experiments. We have been attempting to reconstruct the archaeointensity dataset in Japan from few years ago, based on the development of several new high-precision experimental techniques (for example the Tsunakawa-Shaw method and the IZZI-Thellier method) since 2000. The reconstructed intensity data of a lot of sites has little variation, but on several sites this variation was not uniform and was clustered. In order to obtain further suggestions for this result, the Tsunakawa-Shaw method was applied to the baked earth samples and pottery fragment samples collected from some reconstructed kilns built in the present time to reconstruct the archaeointensity and confirm the tendency of variations in the data. The following five characteristic results (from one of the reconstructed kilns) are obtained at the present; (1) The intensity reconstructed from the red kiln wall fragments indicate higher values (approximately 6-9 μT higher, n=4) than the observed magnetic field (47.5 μT). (2) The intensity reconstructed from the black kiln wall fragments indicate lower values (approximately 4-6 μT lower, n=4) than the observed magnetic field. (3) The result by heating in a vacuum systematically becomes larger than the result by heating in air (approximately 2-3 μT). (4) The results in a vacuum of the sample taken from the surface of kiln floor indicate a harmonic value with the observed magnetic field. (5) The result of the sample collected from the depth of 2 cm below the kiln surface indicates a value slightly lower than the observed magnetic field (approximately 1 μT). We will continue to study these causes together with the results of archaeodirection and rock magnetism.

考古地磁気強度の復元は、考古地磁気学における重要な研究テーマのひとつである。日本においては、1960 年代～80 年代（主としてオリジナル－テリエ法を用いた考古地磁気強度のデータセット構築が精力的に行われた時代）以降、実験技術の複雑さや実験合格率の低さなどに起因して研究が停滞していた。しかしながら、2000 年代以降にこれまでの強度実験手法の欠点を補った複数の新たな実験技術（綱川－ショー法や IZZI－テリエ法など）が開発されたことを受け、近年より、我々は日本における考古地磁気強度データセットを刷新し再構築する研究に取り組んでいる。新たな実験技術により推定された各サイト（遺跡）の強度データは基本的にばらつきが小さいが（変動係数が数%～十数%）、複数のサイトにおいて、そのばらつき方が均質でなく複数の強度値にクラスタ化するという特徴が見られた。
この原因についてさらなる示唆を得るため、現代の復元窯から採取された焼土試料や土器片試料に対して綱川－ショー法を適用して考古地磁気強度を推定し、そのデータのばらつきの傾向を観察する検証実験を行った。研究対象とした復元窯の一つである岡山県の「平川復元窯」（観測磁場値 47.5 μT）からは、現段階において、以下の 5 つの特徴的な結果が得られている。(1) 窯床表面から採取された試料からの推定結果は観測磁場値に一番近い、(2) 窯床表面から 2 cm 下の試料からの推定結果は観測磁場値よりも若干低めの値（4 μT 程度, n=2）を示す、(3) 赤色の窯壁片から復元された強度値は観測磁場値よりも高めの値（6~9 μT 程度, n=4）を示す、(4) 黒色の窯壁片から復元された強度値は観測磁場値よりも低めの値（4~6 μT, n=4）を示す、(5) 真空中加熱による推定結果は空気中加熱による結果よりも若干ではあるが系統的に値が大きい（2~3 μT 程度）。復元窯の部位や加熱環境（空気中あるいは真空中）に応じて強度推定値がクラスタ化している様子が分かるが、全試料の推定値の平均は 47.2 μT（変動係数 12%）であり、窯単位では観測磁場値とほぼ一致する推定結果が得られている。クラスタ化の原因に関しては、考古地磁気方位や岩石磁気学の結果と併せて引き続き考察を進めていく予定である。

R004-13
Zoom meeting A ：11/4　PM1　(13:45-15:30)
14:15-14:30

伊能忠敬の山島方位記から 19 世紀初頭の日本の地磁気偏角を解析し。NOAA の Historical Declination Viewer へデータ不足を改善する。

#辻本　元博
なし

Analyzing the early 19th century's geomagnetic declination in Japan from Inoh's Santou-Houi-Ki for Historical Declination Viewer.

#Motohiro Tsujimoto
none

The Santou-hou-iki is a national treasure of Japan,consist of 67 volumes ledger of approximately 200,000 magnetic compass
survey azimuth data by 0 deg 5 min unit in 1800 to 1816,cover from eastern Hokkaido to Yakushima recorded by map surveyor Tadataka Inoh. We excute interdiciplinary and simultaneous analysis of real azimuth,magnetic declination,precise position of the survey reference point and target points where the value of declination to any targets are similar or proximate.We analyzed the declination at 227 points in Japan including Nagano Prefecture the inland of Central Japan newly. NOAA's Historical Declination viewer according to Andrew Jackson's Gufm1 are lack of declination data in Japan from mid 17 century to mid 19 century equal to the term of national isolation of Japan. It is necessary to introduce the declination data analyzed from Santouhoui-ki to gufm1 or NOAA's Historical declination Viewer.

国宝山島方位記は地図測量家伊能忠敬により 1800 年から 1816 年に記録された北海道東部から屋久島迄の 67 巻の磁針測量方位角帳で測量対象地点及び測量実施地点の地名と 0 度 05 分単位の推計約 20 万件の磁針測量方位角が記録されている。測量対象地点緯度経度、測量実施基点緯度経度、真方位、地磁気偏角を同時解析する。測量実施基点からいずれの
測量対象地点への磁針測量方位角にも含まれる地磁気偏角が一定或いは近似になる精確な位置を逆算して中部日本の内陸部の長野県を含め日本の 227 地点で地磁気偏角を解析した。
欧米では日本が鎖国した 17 世紀中期から 1 9 世紀中期迄の日本の地磁気偏角のデータが不足している。その為山島方位記からの解析値をｱﾝﾄﾞﾘｭｰｼﾞｬｸｿﾝらの Gufm1 に基づくアメリカ海洋大気庁の Historical Declination Viewer に導入する必要がある。
両者の西偏の進行を対比表で示す。

R004-14
Zoom meeting A ：11/4　PM1　(13:45-15:30)
14:30-14:45

炻器中の ε-Fe_2O_3 (luogufengite)

#福間　浩司[1),]大賀　正博[2)]
[1)]同志社大・理工,[2)]同志社大・工

ε-Fe_2O_3 (luogufengite) in sekki potteries

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A variety of fired archeomagnetic materials have been known to contain high coercivity, stable and low unblocking temperature (HCSLT) magnetization in addition to characteristic magnetization carried by magnetite. Recently ε-Fe_2O_3 was confirmed to carry the HCSLT magnetization of potteries and found in nature to be called luogufengite. Sekki potteries, which were produced at many sites in medieval Japan, were fired at high temperature around 1000℃ in oxidative condition. HCSLT magnetization carried by ε-Fe_2O_3 (luogufengite) is ubiquitous in sekki potteries in contrast to sueki potteries fired in reduced condition.
We have studied 82 pottery sherds (72 sekki and 10 sueki) excavated at Doshisha University campus in downtown Kyoto. These pottery sherds were produced from 12th to 18th century at a variety of production sites in western Japan and then transported to Kyoto. For all the sherds we applied hysteresis measurements with a maximum field of 1 T, thermomagnetic analyses with 0.3 T and Thellier measurements. 78 percent of Sekki potteries exhibited highly constricted (wasp-waisted) hysteresis loops but no constricted loop was found for sueki potteries. Low unblocking temperature (100-200℃) components are common in sekki potteries along with high temperature (>500℃) components of magnetite. Low Curie temperature (Tc) of 210℃ is an unambiguous signature to identify ε-Fe_2O_3. However, only 15 percent of sekki potteries showed Tc around 200℃ through thermomagnetic analyses and lower Tc down to 140℃ were found for another 19 percent of sekki potteries.
To obtain further evidences of ε-Fe_2O_3, we performed 5 T hysteresis measurements, IRM acquisition up to 5 T and its DC demagnetization, low-temperature hysteresis measurement, thermal demagnetization of 2-axis IRM (0.4 and 5 T) and progressive cycling of thermomagnetic analyses for several selected sekki sherds. 2 or 3 T was required for saturating magnetization at room temperature. Temperature dependence of coercivity showed a broad peak at about 200 K as indicated for synthetic ε-Fe_2O_3. IRM imparted at 0.4-5 T have low unblocking temperature from 140 to 210℃ in accordance with variable Tc of sherds. Therefore lower Tc of sekki potteries compared to synthetic ε-Fe_2O_3 can be attributed to impurity (e.g., Ti) in ε-Fe_2O_3 as for magnetite. It is concluded that ε-Fe_2O_3 with variable content of impurity is prevailing in sekki potteries. Progressive cycling of thermomagnetic analyses exhibited magnetization enhancement after heating in air. ε-Fe_2O_3 is an end product of oxidation. Therefore laboratory heating induces magnetization enhancement and possibly contaminates characteristic magnetization carried by magnetite.

陶器などさまざまな加熱された考古遺物には，磁鉄鉱によって担われた特徴的な磁化に加えて，高い保磁力で，安定した，低いアンブロック温度(HCSLT)をもつ磁化が含まれていることが知られています．最近，ε-Fe_2O_3 が HCSLT の磁化を担っていることが確認され，自然界でも ε-Fe_2O_3 が発見され新たな磁性鉱物 luogufengite と認められました．中世の日本各地で生産された炻器は酸化状態で 1000℃程度の高温で焼成された陶器です． ε-Fe_2O_3 (luogufengite) によって担われた HCSLT の磁化は，還元状態で焼成された須恵器とは対照的に，炻器に頻繁に見いだされます．
京都の中心部の同志社大学キャンパスで発掘された 82 個の陶器のかけら（72 個の炻器と 10 個の須恵器）を調べました．これらの陶器は 12 世紀から 18 世紀にかけて西日本のさまざまな生産地で焼成され京都に運ばれたものです．すべての陶器のかけらに，最大磁場 1 T のヒステリシス測定，0.3 T での熱磁気分析，およびテリエ測定を適用しました．炻器の 78%は非常にくびれた（wasp-waisted）ヒステリシスループを示しましたが，須恵器ではくびれたループは見つかりませんでした．磁鉄鉱の高温(＞500℃)成分とともに，炻器ではアンブロック温度の低い(100～200℃)成分が一般的にみられます． 210℃の低いキュリー温度（Tc）は ε-Fe_2O_3 を識別するための明確な特徴ですが，15 パーセントの炻器のみが熱磁気分析により約 200℃の Tc を示し，さらに 19 パーセントの炻器で 140℃ までの低い Tc が見つかりました．
ε-Fe_2O_3 のさらなる証拠を得るために，最大磁場 5 T のヒステリシス測定，5 T までの IRM 獲得，およびその DC 消磁，低温ヒステリシス測定，2 軸 IRM の熱消磁（0.4 および 5 T）および熱磁気分析の漸進的サイクリングをいくつかの選択された陶器のかけらに適用しました．室温で磁化を飽和させるには 2~3 T が必要でした．保磁力の温度依存性は，合成 ε-Fe_2O_3 で示されているように，約 200 K で幅広いピークを示しました．0.4-5 T で付与された IRM は炻器の様々な Tc に応じて 140～210℃ の低いアンブロッキング温度を示しました．したがって，合成 ε-Fe_2O_3 と比較して炻器の Tc が低いのは，磁鉄鉱の場合と同様に，ε-Fe_2O_3 中の Ti などの不純物が原因だと考えられます． 炻器では不純物を含む ε-Fe_2O_3 が普遍的に存在すると結論づけられます．また，熱磁気分析のサイクリングは空気中での加熱後に磁化の増加を示しました． ε-Fe_2O_3 は酸化の最終生成物です．したがって，実験室の加熱は磁化の増加を伴い，磁鉄鉱によって担われた特徴的な磁化を汚染する可能性があります．

R004-15
Zoom meeting A ：11/4 PM1 (13:45-15:30)
14:45-15:00

Evolution of CV chondrite parent body inferred from magnetization of clasts in Yamato-86009 chodrite with SQUID microscope

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Chondritic meteorites have long been regarded as originated from undifferentiated asteroids based on their textures and chemical compositions. However, paleomagnetic studies of CV chondrites have shown that their natural remanent magnetization (NRM) was acquired after accretion of their parent asteroids suggesting that their parent body had molten core generating a dynamo magnetic field (e.g., Elkins-Tanton et al., 2011). There is an alternative explanation that an impact-generated field or nebula field was recorded during transient heating in the matrix of CV chondrite (Muxworthy et al., 2017). It is known that lithic clasts are contained in the matrix of CV chondrites as olivine-rich aggregates, which is considered as originated from the CV chondrite parent body. Jogo et al. (2019) suggested that the clasts experienced high-temperature metamorphism (>800 degrees C) in the interior of the CV parent body based on thermal modeling and the similarities of isotopic, chemical and mineralogical compositions between clasts and matrix of CV3 chondrites. Here, we present an ultra-high-sensitive paleomagnetic study of the individual clasts for the first time using the Yamato-86009 Chondrite with a scanning SQUID microscope in order to constrain the magnetic history of the CV chondrite parent body.
Rock magnetic and paleomagnetic analyses were made on oriented clast samples extracted from a thin section of the Chondrite as well as the matrix. Low temperature magnetometry on selected clast and matrix samples suggests that the magnetic minerals contained are magnetite and pyrrhotite.
Paleomagnetic intensities and directions of natural remanent magnetization (NRM) of the clast and matrix samples were calculated based on the scanning SQUID microscope measurements on the samples assuming that the magnetic field is dipolar. Progressive alternating field (AF) demagnetization experiments were conducted on the clast and matrix samples and three components of magnetizations were identified; i.e. low coercivity (LC; 0-1.5 mT), medium coercivity (MC; 1.5-20 mT), and high coercivity (HC; 20-60 mT) components. LC may correspond to viscous remanent magnetization acquired in the laboratory, in the repository and/or at the meteoritic strewn fields. Only three clast and two matrix samples provided stable MC and HC components. MC components of the clasts and matrix had identifiable stable paleomagnetic directions. The two clasts and two matrix samples retained up to about 90 % of its magnetization. Only the two MC components have a similar paleomagnetic directions; the rest of clast and matrix show a random magnetization distribution. HC components of the clasts and matrix are relatively unstable compared to MC components. Each clast and matrix have different HC component paleomagnetic directions.
Magnetic coercivity component identification based on decomposition of isothermal remanent
magnetization (IRM) at 20K and 40K across the low-temperature transition for pyrrhotite (Besnus point: about 34K) suggests that matrix contain considerable amount of PSD (vortex state) pyrrhotite (peak coercivies of about 40 mT) , whereas clast contain only minor amount of PSD pyrrhotite but considerable amount of PSD magnetite (peak coercivies of about 25 mT). HC corresponds to SD magnetite based on decomposition of IRM. Relative paleointensity will also be estimated using NRM and IRM experiments. We discuss possible scenarios on the meteorite parent body based on MC and HC paleomagnetic components and relative paleointensity.

R004-16
Zoom meeting A ：11/4　PM2　(15:45-17:30)
15:45-16:00

綱川ショー法の適用に対する「経年」熱残留磁化の更なる検討

#山本　裕二[1)],トークス　リサ[2)],安　鉉善[1)],サントス　クリスティーン[2)]
[1)]高知大学,[2)]スクリップス海洋研究所

Further investigation of “aged" thermoremanent magnetizations in response to application of the Tsunakawa-Shaw method

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Absolute paleointensity (API) of the geomagnetic field can be estimated from a volcanic rock based on a comparison between an original thermoremanent magnetization (TRM) and a laboratory-induced TRM. The comparison can be made in a blocking temperature space using a Thellier-type method (Thellier and Thellier, 1959), a result of which is usually visualized as a so-called Arai plot (Nagata et al., 1963). It is known that an Arai plot often exhibits a curvature which is regarded as an indication of non-ideal behavior. Shaar and Tauxe (2015) investigated the curvature over time by applying the IZZI Thellier method (Tauxe and Staudigel, 2004) to specimens whose Arai plots were curved in the original studies. They compared the Arai plots obtained from the original studies, “fresh" laboratory TRMs, and “aged" laboratory TRMs for two years. They found that the curvature tended to increase according to age and the resultant APIs were also biased relative to the laboratory field according to age. Santos and Tauxe (2019) built on the results of Shaar and Tauxe (2015) by adding specimens whose original Arai plots were not significantly curved. They examined the curvatures of the Arai plots obtained from the original studies (NRMs) and the “fresh" laboratory TRMs, and categorized the curvatures into either “straight" or “curved". They concluded that the Arai plots resulted in four different types of behavior: “straight-straight" (SS), “straight-curved" (SC), “curved-straight" (CS), and “curved-curved" (CC) (NRM behavior - “fresh" laboratory TRM behavior).
Sister specimens from samples of Santos and Tauxe (2019), which were given “fresh" laboratory TRMs in a 70 uT field, were aged in laboratory for two years also in a 70 uT field but in a different direction. We chose the specimens of the four types which were recategorized based on recalculated curvature values of k (Paterson, 2011). The Tsunakawa-Shaw (TS) method (Tsunakawa and Shaw, 1994; Yamamoto et al., 2003) was applied to the specimens in order to investigate behavior of “aged" TRMs in a coercivity space. First analytical results were already presented in the JpGU-AGU 2020 joint meeting, and we have conducted further analyses in the present study.
For estimation of APIs, we developed a python code to analyze a series of remanence data obtained by the TS method. The analytical procedure is as follows: (1) find a coercivity interval of a primary component (H_1-H_2); (2) calculate API statistics for all possible coercivity intervals between H_1 and H_{max} for first heating plots and 0 mT and H_{max} for second heating plots; (2) discard the statistics not satisfying the usual selection criteria (e.g. Yamamoto et al., 2010); (3) sort the statistics by a fraction of NRM ($frac_n$) and select the best one. Overall, the TS method resulted in a median API of 69.0 uT with a standard deviation of 4.5 uT (N=17). This coincide with the expected filed value of 70.0 uT, and is consistent with the IZZI Thellier results of a median API of 69.8 uT with a standard deviation of 3.3 uT (N=20) for the “fresh" laboratory TRMs. Among the successful API results by the TS method, one API result of 54.2 uT, which was obtained from the CC type specimen, is significantly deviated from the other 16 API results. If we excluded this result as an outlier, a median API is improved to 69.6 uT with a standard deviation of 2.7 uT (N=16). Except the CC type, there are no differences in median APIs according to the types (SS=70.8 uT, N=5; SC=69.6 uT, N=4; CS=69.4 uT, N=6).
Some characteristic remanence behaviors are observed during the TS method according to the types. Percentage fractions of anhysteretic remanent magnetizations (ARMs) erased by low-temperature demagnetization (LTD) were larger in the order of CC (median of 14.5 %), CS (8.7 %), SC (5.1 %) and SS (4.3 %). Curvatures (k) of the NRM-TRM1 plots were also larger in the order of CC (median of 0.29), CS (0.23), SC (0.11) and SS (0.10). Similar tendency was observed for curvatures (k) of the ARM0-ARM1 plots. It is implied that multi-domain (MD) like components are larger in the order of CC, CS, SC and SS, and that ARM corrections work efficiently to give good API results because the curvatures are similar between the NRM-TRM1 plots and the ARM0-ARM1 plots for each type.
When compared the results by the TS method with those by the IZZI Thellier method, positive correlation is found between the percentage fractions of ARMs erased by LTD during the TS method and the curvatures of the Arai plots in the IZZI Thellier method (both NRMs and the “fresh" TRMs). Similar positive correlation is observed between curvatures of the NRM-TRM1 plots of the TS method and the curvatures of the Arai plots in the IZZI Thellier method, and also between curvatures of the ARM0-ARM1 plots of the TS method and curvatures of the Arai plots in the IZZI Thellier method. It is suggested that certain amount of non-ideality in the IZZI Thellier method can be reduced by a combination of LTD and ARM correction in the TS method.

R004-17
Zoom meeting A ：11/4 PM2 (15:45-17:30)
16:00-16:15

Preliminary report on the U-Pb geochronology and paleomagnetism of Miocene sediments from the Tanabe Group, Southwest Japan

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There are two end-member hypotheses for the mode of migration of Southwest Japan (the southwestern half of the Japanese island arc in front of the Japan Sea) during Miocene major back-arc opening of the Japan Sea. One is that Southwest Japan split and then migrated southward from the eastern margin of the Asian continent with clockwise rotation around a pivot located near its western end. In this hypothesis, Miocene and older remanent magnetization directions clockwise deflected from an expected direction, which were reported from the inner zone (the area to the north of an E-W-trending fault called the Median Tectonic Line; MTL), are interpreted to be the unequivocal evidence of the clockwise rotation of Southwest Japan. This has been incorporated into the famous double-door opening model of the Japan Sea. On the other hand, another hypothesis is that Southwest Japan split and then migrated southward from the continental margin without pivotal rotation; the clockwise deflection of remanent magnetization directions are interpreted to be due to block rotations in the inner zone. This has been accepted by the pull-apart opening model of the Japan Sea. To determine which of the two hypotheses is correct, an effective approach is to obtain paleomagnetic data from the outer zone (the area to the south of the MTL) because regional geologic structures suggest that the outer zone has not suffered block rotation. Here we will present preliminary geochronological and paleomagnetic results from Miocene sediments of the Tanabe Group on the outer zone. Our new U-Pb zircon dates indicate that the lower part of the group is of late early Miocene age. Samples for paleomagnetic study were collected at eight sites in the lower part, and site-mean directions of characteristic remanent magnetization (ChRM) were determined for five sites through detailed stepwise demagnetization experiments. Thermal or 'hybrid' demagnetization methods were effective to isolate ChRM. A positive tilting test demonstrates ChRM acquisition before tilting. Importantly, tilt-corrected directions are almost parallel to the directions of the same age reported from the inner zone, indicating no relative rotation between the inner and outer zones. Comparison of the tilt-corrected directions with an early Miocene reference direction suggests clockwise rotation in the study area with respect to the Asian continent. Therefore, our preliminary results are more compatible with the hypothesis of clockwise rotation of Southwest Japan and cast serious doubt on the drift migration hypothesis.

R004-18
Zoom meeting A ：11/4　PM2　(15:45-17:30)
16:15-16:30

古地磁気・岩石磁気学的手法を用いた被熱温度推定：第四紀後期以降の溶岩の数値年代決定への貢献

#安　鉉善[1)],Kim　Jin Cheul[2)],Lee　Jin Young[2)],Hong　Sei Sun[2)],Lim　Jaesoo[2)],Sohn　Young Kwan[3)],Cho Hyeongseong[3)]
[1)]高知大,[2)]韓国地質資源研究院,[3)]慶尚大

Application of paleo-and rock-magnetic determination of heating temperature: A contribution to late Quaternary lava chronologies

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Precisely dating Late Pleistocene-Holocene volcanic eruptions is essential for disclosing spatio-temporal frequency distribution of ancient volcanism and assessing volcanic eruptions probability in a volcanic field. However, such precise dating in volcanic fields is often difficult due to the lack of appropriate chronological approach. Such difficulty is being encountered in the Jeju volcanic field, where there are sedimentary deposits that are intercalated with volcanic units. For an aim to provide and examine a new alternative technique for numerical age determination of lavas and other volcanic products that were emplaced at high temperatures, we have carried out Ar radioisotopic dating, radiocarbon (14C) dating, optically stimulated luminescence (OSL) dating and a suite of paleo-and rock-magnetic analyses on a pair of a lava bed (a candidate of “young-aged" eruptions) and underlying unconsolidated sediments in Jeju Island. The Ar isotopic dating was performed with the step heating technique by using groundmass separates of lava rock samples, the 14C dating was performed with accelerator mass spectrometry by using humic acid extracts of bulk sediments, and the OSL dating was performed with the single-aliquot regenerative-dose procedure by using fine (4?11 micro m) quartz separates of bulk sediments. The paleo-and rock-magnetic analyses that were performed on both of the lava and sediment beds were designed in order to detect the occurrence of paleo-heating by the lava emplacement in the sediments and provide quantitative estimations of the heating temperatures, which are based mainly on progressive thermal demagnetization experiments of natural remanent magnetization and repeated magnetic susceptibility vs. temperature measurements with increasing peak temperatures.
The lava Ar isotopic dating could yield a plateau age of 15 +/- 5 (1 sigma) ka, which has a relatively large uncertainty. On one hand, the 14C and OSL dating show distinct differences in age-position profile for the sediments from each other, of which particularly the OSL ages clearly exhibit a concentration at around 15 ka, independent of the sample positions. The paleo-and rock-magnetic results reveal that the sediment samples at positions where the OSL ages were determined had experienced heating by the upper lava leading to reaching temperatures of 200?250 degree C and higher, which could result in the zeroing of OSL signals at the time of the lava emplacement. From these OSL ages, we could obtain a weighted mean age of 14.8 +/- 0.8 (1 sigma) ka, which is in good agreement with but clearly indicate a high-precision determination with respective to the lava Ar plateau age. Consequently, we suggest that the lava-heated sediment OSL dating with such magnetic analyses herein shown can be a feasible, new dating approach for improving chronology of the late Quaternary volcanism.

R004-19
Zoom meeting A ：11/4　PM2　(15:45-17:30)
16:30-16:45

深海底層厚タービダイトの堆積残留磁化

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Detrital remenent magnetization of thick-deep-sea turbidite

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Sediment particles carried by a turbidity flow to deep sea-floor are aligned by hydrodynamic force when the deposition starts on the deep sea-floor. For this reason, remanent magnetization of turbidite has been traditionally excluded from studies from sediment paleomagnetic study (e.g. Tantyy. et al., 2016). After the 2011 Tohoku-ok earthquake, a few-meter-thick turbidites corresponding to huge past earthquakes were discovered in the Japan Trench. Paleomagnetic and rock magnetic data of those thick turbidites show characteristic in remanet magnetic directions changes within turbidite intervals. A sudden declination shift at the bottom of turbidites are recognized. It is considered that the magnetic particles are aligned reflecting the fluid motion at the bottom. The deflection angle gradually changes toward the top of the turbidite, returning to the magnetic direction of pre turbidite-deposition. On the other hand, the change in inclination angle tends to become shallower in the lower part of the turbidite layer as reported in previous studies. It also goes back to the magnetic direction of pre turbidite deposition. Therefor it is considered that those direction change is caused interaction between hydrodynamics of turbidity current and the earth's magnetic field controls. Because a geomagnetic field can be considered to be constant during instant deposition of turbidite, information of detrital remanent magnetization (DRN) can be extracted, which could be clues for better understanding of DRM.

乱泥流により深海底に運搬され堆積するタービダイトの粒子は、流体の影響を受け粒子配列が起こる。このためタービダイトの磁化方位はこの定向配列に大きく支配され、また時間解像度が極端に異なるため一般的に堆積試料の古地磁気研究から除外されてきた(e.g.Tanty et al., 2016)。一方堆積メカニズムと地球磁場情報を併せ持つ残留磁化は両者の特性を知る上でユニークな研究対象となる。2011 年の東北地方太平洋沖地震以降の海底調査により水深 7,500m を超える日本海溝に歴史時代の超巨大海溝型地震に対応する数 m 規模の厚層シルト質のタービダイトが保存されている事が報告された。この層厚細粒タービダイトの古地磁気・岩石磁気学的を計測したところ特徴的な方位変化が見られたので、これについて考察した。海溝に堆積した層厚タービダイトはその層厚である事と粒度が細粒である事で特徴付けられる。古地磁気方位はタービダイトの下底面で急激な偏角のシフトを示す。これは磁性粒子が着底時に流体作用に起因して配列する事が考えられる。タービダイト層の上位に向かって粒度が細粒化するが偏角は徐々にタービダイト堆積前の磁場方位に方向に戻るように変化をする。一方、伏角の変化はこれまで報告されているようにタービダイト層の下位で浅くなる傾向が見られるが偏角のシフトのタイミングと比べると遅いタイミングで出現していて、非常に小さい伏角のインターバルは短い。偏角と同様に上方に向かい堆積前の伏角の地球磁場方向へ復帰が起こる。この地球磁場方向へ復帰は偏角とほぼ同じ層準で起こっている。このタービダイト内の磁化方位の変化は、流体粒子配列作用に起源を持つ磁化（Dm）と地球磁場粒子配列作用による磁化（Gm）の相互作用で考えられる。タービダイトの最下位では Dm＞Gm であるが上方に向かい Dm＜Gm となる状況がある事を示している。タービダイトの堆積は一瞬と考えると地球磁場強度と方位は一定と考えられ主に流体による粒子配列作用の変化を見ていると考えられ、堆積残留磁化メカニズムに関する情報取得が期待できる。

R004-20
Zoom meeting A ：11/4　PM2　(15:45-17:30)
16:45-17:00

太平洋の赤色粘土中に見つかった低い残留保磁力（<10 mT）を持つ生物源磁鉄鉱

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Low remanence coercivity (<10 mT) biogenic magnetite in pelagic clays in the Pacific

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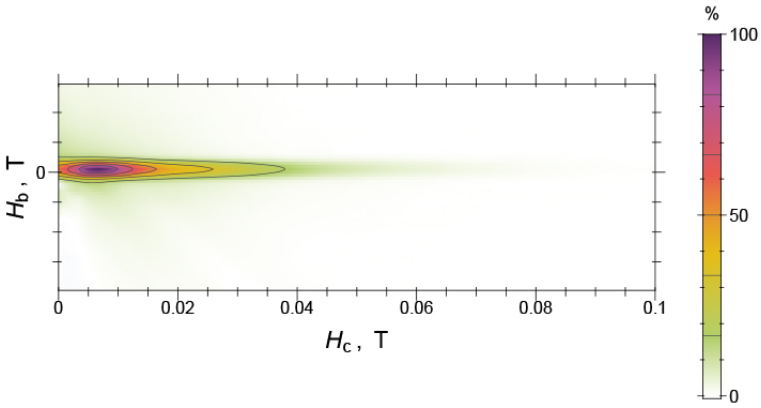
Biogenic magnetite has been commonly reported from fully oxic pelagic red clays from multiple sites. There are different morphologies of biogenic magnetite in red clays; the majority is equant (similar to cuboctahedra), but bullet-shaped crystals were abundant in a layer in the western North Pacific around Minamirotishima Island. It has been suggested that environmental magnetism can provide information on the past biogeochemistry in the deep-sea. However, we have only limited data about the variety of biogenic magnetite in red clays. Here we report a new type of biogenic magnetite from Ocean Drilling Program Site 777. The site is also in the western North Pacific (~900 km southwest from Minamitorishima Island). Lithostratigraphy is overall similar to that around Minamitorishima Island; from the top, siliceous clay (~3.5 m; Unit IA), hemipelagic clay (~30 m; Unit IB), a hiatus, and pelagic clay (Unit II). Unit II is a light brown clay interbedded with dark brown clay. This lithology was also observed around Minamitorishima Island. Rock magnetic data suggested that Unit IA and II are dominated by terrigenous and biogenic component, respectively, and Unit IB is a mixture. By isothermal remanence (IRM) acquisition analyses, we discovered that Unit II contains a component with very low coercivity (<10 mT). Some specimens showed bulk remanence coercivity as low as 14 mT, so this component is one of the major components at the Site. FORC diagrams showed clear central ridges suggestive of minimal magnetostatic interactions, but the peak coercivity was at <10 mT. The coercivity of this component was similar to the so-called EX component, which had been originally attributed to authigenic extracellular magnetite. However, it is not clear if authigenic magnetite formation is active in those fully oxic sediment. On the other hand, ferromagnetic resonance (FMR) spectra of specimens dominated by the low coercivity component were highly asymmetric, indicating strong magnetic anisotropy. Together with the minimal magnetostatic interactions shown by the FORC diagrams, it is likely that this low coercivity component is also derived from intracellular biogenic magnetite of magnetotactic bacteria. Moreover, the FMR spectra were indistinguishable from that of the specimens dominated by equant biogenic magnetite. These observations suggest that the newly discovered low coercivity biogenic magnetite is closely related to the equant biogenic magnetite. Interestingly, this low coercivity biogenic magnetite has not been observed around Minamitorishima Island, even though the lithology is similar. We will discuss possible mechanisms for the low remanence coercivity and its implication for environmental magnetism.

酸化的な赤色粘土中からも生物源磁鉄鉱が普遍的に見つかっている。その多くは等方的（立方八面体的）だが、北太平洋西部の南鳥島周辺では、弾丸状の生物源磁鉄鉱に富む層も見つかっている。これらより、環境磁気学により過去の深海底の生物地球化学に関する情報が読み取れると提案されている。しかし、赤色粘土中にどのような生物源磁鉄鉱が存在するのかについての全貌は未だよくわかっていない。本発表では、国際深海掘削計画サイト 777 から新たな性質の生物源磁鉄鉱を見出したことを報告する。 このサイトも北太平洋西部にあり、南鳥島から約 900 km 南西に位置する。岩相層序は概ね南鳥島周辺と類似する。すなわち上部より、約 3.5 m の珪質粘土（ユニット IA）、約 30 m の半遠洋性粘土（ユニット IB）、ハイエイタスを挟んで遠洋性粘土（ユニット II）である。 ユニット II は明褐色の粘土と暗褐色の粘土の互層であり、この岩相は南鳥島周辺でも見られた。 岩石磁気分析から、ユニット IA と II はそれぞれ陸源と生物源の磁鉄鉱が主であり、ユニット IB は混合であることがわかった。ユニット II について、等温残留磁化（IRM）の着磁分析から、10 mT 以下の低い残留保磁力を持つ成分が見つかった。バルクの残留保磁力が 14 mT の試料もあり、この成分はサイト 777 で主要なものの一つであると考えられる。FORC 図は、静磁的相互作用が小さい明瞭なセントラル・リッジを示すが、そのピーク保磁力も 10 mT 以下であった。これらの保磁力の値はいわゆる EX 成分に類似しているが、EX 成分は鉄還元菌により細胞外で生成された磁鉄鉱に担われると考えられており、酸化的な赤色泥で同様のプロセスが起きるかは不明である。一方、低い残留保磁力を持つ試料の強磁性共鳴（FMR）スペクトルは非対称的であり、強い磁気異方性を示す。FORC 図で示された小さな静磁的相互作用と合わせ、この低保磁力成分も磁性細菌由来の生物源磁鉄鉱であると考えられる。また、FMR スペクトルは等方的な生物源磁鉄鉱に富む試料のそれとよく似ていた。したがって、今回見つかった低保磁力の生物源磁鉄鉱は、等方的な生物源磁鉄鉱と密接な関係にあることが推定される。興味深いことに、南鳥島周辺では岩相が類似しているにもかかわらず、同様の低保磁力な成分はこれまで見つかっていない。発表では、低い保磁力の原因と、環境磁気学への示唆について議論する。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H_b, T
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