R004-01
D 会場 ： 11/25　PM1（13:45-15:45）
13:45～14:00:00

熱・組成拡散方程式モデルに基づく地球外核最上部の安定成層形成について：長時間磁場生成との共存条件

#中川 貴司 [1)]
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A condition for long-term geodynamo operation with a stable stratified layer at the top of outer core

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Seismic waveform analyses and fluid motion studies linked to geomagnetic fluctuations suggest that a stably stratified layer could be emerged at the top of the outer core. To test this possibility, Nakagawa et al. (2023) evaluated the kinetic energy production rate in a one-dimensional radial convective structure computation; a stable stratification was defined where this rate is negative (i.e., convection is suppressed). Their results indicate that sustaining both a long-lived geodynamo and a stable layer at the top of outer core requires a present-day core-mantle boundary (CMB) heat flow around 13 to 14 TW. In contrast, Nakagawa (2018) developed a formation model for the stable layer based on thermal and chemical diffusion, but did not assess whether such a layer can coexist with a long-term magnetic field. Here, I revisit the diffusion-based framework in Nakagawa (2018) to evaluate whether a stable layer at the outermost outer core can operate the geodynamo over ~4 billion years.

The analysis indicates that the dominant mechanism for stable stratification is compositional origin, driven by the injection of light elements from the silicate mantle into the outer core. A thermal stratification, by contrast, emerges only when the present-day CMB heat flow is lower than the isentropic heat flow. With respect to sustainability of geodynamo operation, the results suggest that long-term magnetic field generation - persisting over ~4 billion years - requires a present-day CMB heat flow of ~12 TW. Comparing these findings with conditions inferred from radial one-dimensional convective structure computation shows that the overlap between stable stratification and sustained magnetic field generation occurs at a present-day CMB heat flow of 12 to 14 TW. In this regime, a stable layer is primarily caused by the compositional effect, arising from the injection of light element from the silicate mantle associated with the core-mantle chemical coupling. This estimated range of CMB heat flow is consistent with constraints from geophysical observations, numerical modeling, and high-pressure material properties. Taken together, these results support the view that a stably stratified layer at the top of the outer core can coexist with long-term geodynamo operation.

R004-02
D 会場 ： 11/25　PM1（13:45-15:45）
14:00〜14:15:00

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Investigation of the thermal structure at the inner core boundary (ICB) in numerical dynamos including the latent heat at ICB

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[(1]Institute of Science Tokyo

Recent seismic observations suggest that inner the core has a seismic anisotropy. These studies suggest aspherical growth of the inner core, and that slow viscous deformation of the inner core and latent heat distribution are expected due to the aspherical growth of the inner core. To explain inner core anisotropy and aspherical growth of the inner core, a number of dynamo simulations have been performed with prescribed boundary conditions at ICB. In the present study, we perform thermally driven dynamo simulations with solving the heat equation throughout the inner and outer core, and investigate thermal structure at the inner and outer core boundaries which are generated by the flow motion in the outer core.

In the present model, we assume that the change of the topological change of the ICB is much smaller than the radial resolution, and that change of the position of ICB is proportional to the given radius of the average radius of the ICB. We also assume that the latent heat per volume is constant. Under the present condition, the latent heat at ICB makes the thermal diffusivity at ICB smaller than that in the other area. We implement and solve the present model into the heat equation throughout the center of the Earth to the core-mantle boundary in geodynamo simulations.

We perform /dynamo simulations with changing the thermal diffusivity at ICB to be from 1.0 (no latent heat) to 1x10^{-4} times of that in the other area and compare these results at the quasi-steady state to investigate the effects of the latent heat. The average amplitude of the $Y_2{}^0$ component in no latent heat case is approximately 0.78 times of that fixed heat flux cases. After introducing the latent heat, the $Y_2{}^0$ component of the temperature variation increases between 0.83 and 1.09 times of that of the fixed heat flux cases in the cases with less than 0.1 times of the thermal diffusivity at ICB.

R004-03
D 会場 ： 11/25　PM1（13:45-15:45）
14:15〜14:30:00

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Changes in core flow structures associated with polarity reversals in an MHD simulation

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The Earth's magnetic field is dominated by a dipole field which is nearly aligned with Earth's rotation axis. It is widely accepted that the geomagnetic field is sustained by fluid motions in the Earth's outer core through dynamo action. The secular variations of the geomagnetic field originating from the core have a wide range of time scales. The polarity reversal, one of the secular variations, occurs over a few thousand years and has taken place more than 400 times throughout geological history, as revealed by paleomagnetic records. Numerical geodynamo simulations have been conducted to understand the physical mechanisms underlying the polarity reversal, showing that during polarity reversals, equatorially antisymmetric flows become intensified and contribute significantly to reversals, despite being generally suppressed in rapidly rotating convection. This indicates that an enhancement of the equatorially antisymmetric flows is an important phenomenon for understanding the reversal mechanism. Our previous study has shown that the inertial force is responsible for energy transfer from symmetric to antisymmetric flows. This fact has been revealed by spectral analyses in terms of spherical harmonics. However, the specific flow structures in physical space that are responsible for such energy transfer remain unclear.

In this study, we investigate flow structures in cross-sections parallel to the equatorial plane as well as meridional cross-sections. Then, we show that energy transfer by inertial force occurs in regions where local vortices interact with large-scale zonal flow. This result is consistent with the results obtained from spectral analysis, which indicates that finer symmetric flow energy is transferred to the antisymmetric flows with a larger length scale. Furthermore, energy transfer by inertial force occurs only in either the northern or southern hemisphere, while energy input by buoyancy flux is found in the opposite hemisphere. The results suggested that the equatorially antisymmetric zonal flow consists of the flow induced by the Coriolis force from the upwelling flow in one hemisphere and that induced by inertia in the other hemisphere.

R004-04
D 会場 ： 11/25　PM1（13:45-15:45）
14:30～15:00:00

理論と太陽系物質から探る原始惑星系円盤の磁気的進化

#奥住 聡 [1)]
[(1] 東京科学大

Exploring the Magnetic Evolution of Protoplanetary Disks with Theory and Solar System Material Studies

#Satoshi Okuzumi[1)]
[(1]Institute of Science Tokyo

Planets and small bodies form in disks of gas and dust surrounding young stars, known as protoplanetary disks. Understanding disk evolution is essential for addressing the fundamental questions of when and where these bodies form. The dynamical evolution of disks is thought to be largely governed by magnetic fields threading them. Thanks to recent advances in disk magnetohydrodynamics, the long-term evolution of disks can now be predicted once the evolution of magnetic fields is understood. However, direct observational constraints on the strength of disk magnetic fields remain extremely limited. Recently, magnetic measurements of meteorites and asteroid return samples have attracted attention as an alternative approach to probing the evolution of disk magnetic fields. In this talk, I will present recent theoretical and paleomagnetic studies on disk magnetic fields and discuss future perspectives.

地球をはじめとする惑星や小天体は、若い星の周囲に存在する、ガスと固体からなる原始惑星系円盤で形成される。これらの天体がいつ・どこで形成されるのかを理解するためには、円盤進化に対する正確な理解が不可欠である。円盤の力学的進化は、円盤を貫く宇宙磁場によって支配されると考えられている。近年の円盤磁気流体力学の進展により、円盤磁場の分布の長期的進化が分かれば、円盤全体の進化もおおよそ予測できるようになってきた。しかし、円盤磁場の強度に対して天文観測が与える直接的な制約は極めて限られている。その代わりに、隕石や小惑星サンプルの磁気測定が、円盤磁場の進化に迫るアプローチとして注目されてきている。本発表では、円盤磁場およびその進化をめぐる近年の理論的・物質科学的研究を紹介し、今後の展望を議論する。

R004-05
D 会場 ： 11/25　PM1（13:45-15:45）
15:00〜15:15:00

#森田 里咲 [1), 佐藤 雅彦 [1)
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Reconstruction of protoplanetary disk magnetic field from chondrule measurements of the Aba Panu meteorite

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([1Tokyo University of Science

The planets of the solar system formed as a result of the dynamical evolution of a protoplanetary disk composed of nebular gas and dust. Therefore, understanding material dynamics within the protoplanetary disk is essential to understanding planet formation. Research on material transport in such disks has primarily been conducted through chemical and isotopic analyses of meteorites, as well as numerical simulations based on those findings. Recent magnetohydrodynamic (MHD) simulations suggest that the primary mechanism driving material transport (accretion) in disks is the interaction between ionized gas and magnetic fields present in the protoplanetary disk. Nevertheless, observational data on magnetic fields in protoplanetary disk remain scarce (Weiss et al., 2021). Several studies have investigated the nebular magnetic field based on the paleomagnetism of chondrules. Fu et al. (2014) and Borlina et al. (2021) reported magnetic fields on the order of tens of μT, while others argued that reconstruction is not feasible (Gattacceca et al., 2019), or suggested values of only a few μT (Fu et al., 2020). However, these estimates involve large uncertainties due to limitations in experimental and analytical methods. the nebular magnetic fields were derived from a very small number of chondrules—fewer than ten grains—resulting in significant variations in the reported values and raising concerns about their accuracy and reliability. To address these issues and place new constraints on the accretion rate of the early solar system, we conducted remanent magnetization measurements on the Aba Panu ordinary chondrite, which has undergone minimal aqueous alteration on its parent body and has experienced little terrestrial weathering due to its recent discovery in 2018. The fragment of Aba Panu meteorite was crushed, and then, the chondrules were collected under a stereoscopic microscope. Natural remanent magnetization (NRM) was measured for 216 chondrule grains using a 2G SQUID magnetometer at Tokyo University of Science. 90 out of 216 grains showed NRM intensity larger than the detection limit of the SQUID magnetometer. Stepwise alternating-field demagnetization (AFD) measurements were conducted for 19 chondrule grains with NRM intensity larger than 1 × 10-11 Am2. As the results, the part of grains showed the stable NRM components. This study plan to conduct the paleointensity measurements based on the anhysteretic remanent magnetization, saturation isothermal remanent magnetization, and thermoremanent magnetization. In this presentation, we will report the results of NRM and paleointensity measurements and will discuss the magnetic field and accretion rate conditions of early solar system.

R004-06
D 会場 ： 11/25 PM1（13:45-15:45）
15:15〜15:30:00

#佐藤 雅彦 [1), 潮田 雅司 [2), 中田 亮一 [3), 田村 裕二郎 [4), 山本 伸次 [4), 小澤 一仁 [5), 高橋 太 [6), 坂田 遼弥 [5), 関 華奈子 [5), YAN Chi[7)
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Reconstructing the Noachian Martian dynamo from crustal magnetic anomalies

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Magnetic field observations of Mars revealed that there are strong magnetic anomalies arising from the crustal remanences, which is estimated to be about 10 times as strong as the Earth's crustal magnetization. The strong crustal remanences require a particular origin such as the strong dynamo field of the ancient Mars, the high concentration of ferromagnetic mineral in the Martian crust, and so on. However, the exact mechanism responsible for this phenomenon remains unclear. Plagioclase, one of the common constituents of terrestrial crustal rocks, sometimes contain fine-grained magnetite crystals exsolved from Fe-bearing magmatic plagioclase at subsolidus condition. The natural remanent magnetization carried by exsolved magnetite in plagioclase is a likely candidate for the source of Martian magnetic anomalies: the crustal remanence must persist for over 4 Gyr to account for the observed anomalies, and exsolved magnetite satisfies this condition (Sato et al., 2018). In this study, a suite of experiments (magnetic measurements, synchrotron radiation study, and microscopic observation) and calculations (thermodynamic calculation with the rhyolite-MELTS program) were carried out to estimate the concentrations of exsolved magnetite in the Martian crust. The results indicate that Martian crustal rocks contain high concentrations of exsolved magnetite. Thermoremanent magnetization (TRM) acquisition experiments on plagioclase samples revealed that exsolved magnetite efficiently acquires TRM. These findings suggest that the Martian crust exhibits a high remanence acquisition efficiency. Based on this efficiency and the crustal remanence values derived from magnetic anomaly observations, the paleo-planetary magnetic field intensity on Mars during the Noachian period is estimated to have been 10 – 20 μT. Using dynamo scaling laws (Olson and Christensen, 2006; Christensen et al., 2009), this study estimates both the heat flux at the core – mantle boundary (CMB) and the morphology of the Martian magnetic field during the Noachian. The estimated CMB heat flux of 20 – 30 mW/m^2 is consistent with thermal evolution models based on 3D spherical simulations (Thiriet et al., 2019). This heat flux corresponds to a dynamo state characterized by a non-reversing dipole for both dynamos powered by bottom heating and internal heating (Yan et al. 2023). Based on the inferred state of Mars's magnetic field during the Noachian period, we examine the evolution of the planet's magnetic field and its implications for the history of atmospheric water loss, as inferred from oxygen escape rates.

R004-07
D 会場 ： 11/25 PM1（13:45-15:45）
15:30〜15:45:00

マリーセレストトランスフォーム断層における海洋地殻の鉛直磁化構造の推定とその成因

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Estimation of the vertical magnetization structure of the oceanic crust and implications for its origin

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This study aims to reveal the structural characteristics and origin of the spreading axis during oceanic crust formation by examining its vertical magnetization structure through magnetic field observations along the transform fault scarp. In marine environments, magnetic field observations are generally conducted by towing a magnetometer at the sea surface or by mounting it on deep-sea platforms, such as autonomous underwater vehicles (AUVs). Most of the data obtained from these methods consist of horizontal magnetic anomaly profiles. One of the few previous studies focusing on vertical magnetization structures is Tivey (1996), which utilized the scarp topography of a transform fault to acquire vertical magnetic anomaly profiles and revealed that the uppermost lava layer of the oceanic crust is strongly magnetized, whereas the underlying dike layer is very weakly magnetized. In addition, Pariso and Johnson (1993) suggested from ocean drilling core samples that the gabbroic layer beneath the dike layer retains a partial remanent magnetization. Although these findings provided rare evidence for understanding the magnetic structure of the oceanic crust, they have not been verified in other regions, and a unified view has yet to be established. In this study, we conducted near-seafloor magnetic field observations from deep to shallow sections of a transform fault exposing lava, dike, and gabbro layers to determine the magnetization intensity and thickness of each layer. Furthermore, based on the estimated magnetization structure, we discuss the structural characteristics of the spreading axis at the time of crust formation and the factors that control them.

The observations were carried out during the KH-24-4 cruise of the R/V Hakuho Maru, targeting the scarp on the south side of the Marie Celeste Transform Fault in the Central Indian Ridge. The southern wall of the fault forms a slope with a maximum relief of approximately 4 km, extending for approximately 210 km, continuously exposing cross-sections of the oceanic crust formed over the past 11 million years. After dredging operations to collect deep fault rock samples, we simultaneously raised and towed a small three-component magnetometer mounted on the wire for dredging so that it passed close to the scarp. The observations were conducted at six different sites along the fault scarp. After correcting the magnetic data and referencing the standard magnetic field, we obtained magnetic anomalies caused by oceanic crustal magnetization as variations along the vertical cross-section. Strong magnetic anomalies were observed in both the shallow and deep parts of the scarp at each site.

Data analysis assumed a three-layer structure consisting of lava, dike, and gabbro layers, and two-dimensional forward modeling was performed based on Talwani and Heirtzler (1964). The magnetization intensities of the three layers and the thicknesses of the lava and dike layers were used as parameters in iterative calculations to determine the magnetization structure model that best explained the observed magnetic anomaly profiles. This procedure was applied to each observation site.

The results indicate the presence of a strongly magnetized layer (lava) about 300 m thick with magnetization exceeding 10 A/m, underlain by a weakly magnetized layer (dike) about 3,000 m thick with a magnetization of 1 – 2 A/m, and below that, a layer (gabbro) with variable magnetization intensity (2 – 8 A/m) among sites.

The depth of the boundary between the dike and gabbro layers from the seafloor can be interpreted as the depth of the melt lens at the time of crust formation (Detrick et al., 1987). The depth of the melt lens is known to correlate with the spreading rate, and according to a typical model based on the thermal structure of spreading axes (Morgan and Chen, 1993), its depth at the Central Indian Ridge (full spreading rate of 40 mm/yr) is expected to be over 6,000 m. In contrast, the melt lens depth estimated in this study is 3,000 – 3,600 m, which is shallower than that predicted by the model. This finding indicates that the spreading axis exhibited a higher thermal structure than is typically observed. This elevated thermal state may have resulted from the thermal influence of a nearby hotspot.

本研究は、トランスフォーム断層の崖沿いの磁場観測による海洋地殻の鉛直方向の磁化構造の理解を通じて、地殻形成時の拡大軸の構造的特徴とその成因を解明することを目的とする。海域における磁場観測は、磁力計を海上で曳航したり AUV などの深海観測プラットフォームに搭載したりして行うことが一般的であり、得られるデータのほとんどが水平方向の地磁気異常プロファイルである。海洋地殻の鉛直方向の磁化構造に注目した数少ない先行研究として Tivey(1996) が挙げられる。この研究はトランスフォーム断層の崖地形を利用して鉛直方向の地磁気異常プロファイルを獲得することにより、海洋地殻最上部の溶岩層は強く磁化している一方、その下のダイク層の磁化は非常に弱いことを発見した。ま

た、Pariso and Johnson(1993) は深海底掘削で採取された岩石コアからダイク層の下のはんれい岩層も部分的に残留磁化を保持することを示した。これらの発見は海洋地殻の磁化構造の理解に関する稀有な証拠をもたらしたものの、他海域での観測に基づく検証がなされておらず、統一的な見解は未だ得られていない。そこで本研究では、溶岩・ダイク・はんれい岩が露出するトランスフォーム断層の深部から浅部にかけて海底近傍磁場観測を行うことにより、各層の磁化強度と厚さを特定する。また、推定される磁化構造より形成時の拡大軸の構造的特徴とその要因について考察する。

磁場観測は、白鳳丸 KH-24-4 航海において、中央インド洋海嶺のマリーセレストトランスフォーム断層の南側に存在する崖面をターゲットとして実施された。断層南側には最大高低差約 4km の斜面が約 210km にわたって続いており、現在から過去 1100 万年にかけて形成された海洋地殻の断面が連続的に露出している。断層深部の岩石採取を目標としたドレッジが終了した後、ワイヤーの巻き上げと曳航を同時に行なうことでワイヤーに取り付けた小型の 3 成分磁力計を崖面付近に通過させた。この観測は異なる崖面の 6 地点でそれぞれ実施された。磁場データの補正と標準磁場の参照により、海洋地殻起因の地磁気異常を鉛直断面による変化として観測した。いずれの地点でも崖面深部と浅部において強い地磁気異常が観測された。

データ解析では、溶岩層・ダイク層・はんれい岩層の 3 層構造を想定し、Talwani and Heirtzler(1964) をもとに 2 次元のフォワード計算を行った。岩相 3 層分の各磁化強度、溶岩層とダイク層の厚さ 2 層分をパラメータとして計算を繰り返し、取得した地磁気異常プロファイルを最もよく説明する磁化構造モデルを決定した。これをそれぞれの観測地点ごとに実施した。

解析の結果は、最上部 300m 程度に 10A/m を超える強磁化層（＝溶岩層）、その下約 3000m に 1-2A/m の弱い磁化層（＝ダイク層）、さらにその下に観測地点ごとに磁化強度にバリエーション（2-8A/m）を持つ磁化層（＝はんれい岩層）が存在することを示している。

ダイク層とはんれい岩層の境界の海底面からの深さは、その地殻が拡大軸で形成された時のメルトレンズの深さと解釈することができる（Detrick et al., 1987）。メルトレンズの深さは拡大速度と相関関係があることが知られており、拡大軸の熱構造に基づく典型的なモデル（Morgan and Chen, 1993）によれば、中央インド洋海嶺（両側拡大速度 40mm/yr）においてその深さは 6000m 以上となることが見込まれる。一方、本研究で推定した形成時のメルトレンズの深さは 3000-3600m であり、これはモデルによる予想よりも浅い。この結果は、拡大軸が通常より高温の熱構造を有していたことを示唆している。高温の熱構造をもたらした原因として、海嶺に対するホットスポットの熱的関与が考えられる。

R004-08
D 会場 ： 11/26　AM1（9:15-10:45）
9:15〜9:30:00

シャツキーライズ南方のピストンコアの岩相変化と古地磁気強度推定

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The effect of lithological changes on paleointensity estimates based on the piston cores from Shatsky Rise

#Yoichi USUI[1)]
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Sediments provide continuous paleomagnetic intensity information, making them an excellent target for reconstructing variations in the geodynamo. On the other hand, it is known that the efficiency of natural remanent magnetization acquisition depends on lithology. There are virtually no sediments with constant lithology for tens of millions of years. Thus, it is important to examine whether it is possible to quantitatively estimate the effects of lithological changes and diagenesis on the acquisition of natural remanent magnetization. In this presentation, we discuss the results of paleointensity and rock magnetic measurements of four piston cores obtained from different water depths on the southern slope of Shatsky Rise. The core obtained from the shallowest water depth (PC01) consists of carbonate ooze, while the deepest core (PC03) consists of pelagic clay with diatoms. The other cores (PC02 and PC04) show variations in carbonate content, possibly reflecting changes in productivity and CCD. All cores show positive polarity. The relatively homogeneous pelagic clay core (PC03) showed variations comparable to the standard paleointensity curve. In contrast, the other cores showed variations of about 5-7 times in the paleointensity proxy at intervals of about 1 m. In layers where the paleomagnetic intensity proxy is relatively high, both the anhysteretic remanent magnetization (ARM) and the isothermal remanent magnetization (IRM) are low. In addition, the ARM/IRM ratios and S ratios also tend to decrease. However, even in PC03, where relatively good data was obtained, the overall range of variation in the ARM/IRM ratio and S ratio is similar to that of the other cores. The main difference between the data from PC03 and other cores is that PC03 shows a nearly single linear correlation between the S ratio and IRM intensity or ARM/IRM ratio. In contrast, in other cores, the S ratio deviates from the trend and decreases in layers where the paleomagnetic intensity proxy is relatively high. So, the large changes in the paleomagnetic intensity proxy were caused by a temporary process, which is different from the process that determines the overall range of variation in rock magnetic parameters. From the fragmentary paleointensity changes, the layers where the paleointensity proxy is relatively high generally correspond to glacial periods, and they contain a higher amount of carbonate. The fact that ARM decreases more rapidly than IRM and that the S ratio decreases can be explained by the dissolution of fine-grained magnetite due to diagenesis in these layers. The presentation will also discuss the variation in paleointensity proxies due to lithological changes.

堆積物からは連続的な古地磁気強度情報が得られるため、地磁気ダイナモの変動を読み解く対象として優れている。一方、自然残留磁化の獲得効率は岩相に大きく依存することが知られている。残念ながら数千万年間岩相が一定である堆積物はほとんど存在しない。そこで、岩相変化や続成作用が自然残留磁化獲得効率に与える影響を定量的に見積もれるかどうかの検討が、堆積物による長期的な地磁気変化の推定可能性を知るうえで重要である。本発表では、シャツキーライズの南方斜面で異なる水深から得られた 4 本のピストンコアについて古地磁気強度および岩石磁気測定を行った結果をもとに、磁化獲得効率について議論を行う。最も浅い水深から得られたコア（PC01）は炭酸塩軟泥、最も深いコア（PC03）は珪藻を含む遠洋性粘土からなる。中間の PC02, 04 では炭酸塩含有量が変動しており、生物生産性や CCD の変化を反映して岩相が変化していると考えられる。どのコアもすべて正極性を示し、ブリュンヌ正磁極期の堆積物である。比較的均質な遠洋性粘土コア（PC03）は、古地磁気強度標準曲線と対比可能な変動を示した一方で、その他のコアでは 1 m 程度の単位で、古地磁気強度プロキシの値が 5-7 倍程度変化した。古地磁気強度プロキシが相対的に高くなる層準では、非履歴性残留磁化 (ARM)・等温残留磁化 (IRM) は共に低い。また、ARM/IRM 比と S 比も下がる傾向にある。ただし、比較的良好なデータが得られた PC03 でも、 ARM/IRM 比や S 比の全体的な変動幅はその他のコアと同程度である。PC03 とその他のコアのデータとの主な違いは、PC03 は S 比が IRM 強度や ARM/IRM 比 などに対しほぼ単一の線型相関を示すのに対し、その他のコアでは古地磁気強度プロキシが相対的に高くなる層準で、S 比がトレンドから外れて下がっていることである。これは、岩石磁気パラメータの全体的な変動幅を決めるプロセスとは別に、一時的に働いたプロセスによって古地磁気強度プロキシの大きな変化がもたらされていると解釈できる。断片的な古地磁気強度変化から、古地磁気強度プロキシが相対的に高くなる層準はおおむね氷期に対応し、岩相的には炭酸塩含有量の多い層準に相当する。ARM が IRM より優先的に減少していること、 S 比が減少していることは、これらの層準では続成作用により、特に細粒な磁鉄鉱が溶解しているとすると説明できる。発表ではさらに、岩相変化による古地磁気強度プロキシの変動についての検討を合わせて紹介する。

R004-09
D 会場 ： 11/26　 AM1（9:15-10:45）
9:30〜9:45:00

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Paleointensity-assisted chronostratigraphy of a sediment core from the Southern Ocean

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Information of variations in the geomagnetic field intensity in the past (relative paleointensity, RPI) is important for better understanding of the geodynamo. As an application, RPI can be used as a tool for age estimation of sediments by correlating to templates such as stacked RPI curves and/or geomagnetic-field models. We present RPI estimations of a sediment core KH-19-6-PC7 of about 12.6 m long taken from the east of the South Sandwich arc-trench system. The water depth of the coring site, about 4400 m, is deeper than the CCD, and hence oxygen-isotope stratigraphy is difficult to be applied. It is known that in the Southern Ocean magnetic susceptibility variations often mimic the variation patterns of eolian dust flux recorded in the Antarctic ice cores, and this has been utilized for age estimations of sediments. This coincidence suggests that eolian dust is the main source of magnetic minerals in Southern Ocean sediments. Osanai (2024, Master Thesis) conducted a paleoceanographic study of the core, and proposed increased productivity associated with a southward shift of the Antarctic Circumpolar Current at the Antarctic Isotope Maximum (AIM) 2 (~24 ka). The age model of the studied core was constructed based mainly on magnetic susceptibility and Fe content derived from an XRF core scanner, which were correlated to the EDML ice core dust record through correlation with the magnetic susceptibility record of core MD073134 in the Scotia Sea. The age model shows that the core covers the last ~26 k.y. and that the sedimentation rate suddenly decreased at ~16 ka. The correlation to the EDML dust record was, however, not straightforward in the studied core; some spikes of magnetic susceptibility uncorrelatable to the EDML record hampered confident correlation. The susceptibility "noises" probably reflect volcanic ashes because the site is located leeward of the Sandwich volcanic arc. When this age model is used, on the other hand, RPI variations obtained from best-fit slopes on NRM-ARM demagnetization diagrams are consistent with the predictions from the geomagnetic models SHA.DIF.14 for the last 14 ka and GGFSS70 for an older period. This observation supports the age model. This is a good case for successful application of PRI-assisted chronostratigraphy. The paleomagnetic record of this core will also be useful for refining geomagnetic-field models because the number of available records in the Southern Ocean is still limited.

R004-10
D 会場 ： 11/26　AM1（9:15-10:45）
9:45〜10:00:00

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Evaluation of magnetostatic interactions for sediment samples using the oblique anhysteretic remanent magnetization

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Oceanic and lacustrine sediments can be used to reconstruct paleoclimatic, paleoenvironmental, and paleoceanographic changes. To accurately understand the causal relationships among these changes, it is essential to compare and evaluate multiple lines of environmental evidence derived from diverse physical, chemical, and biological proxies. This study focuses on oblique anhysteretic remanent magnetization (OARM) and aims to develop it as a new environmental proxy. OARM is acquired by applying an alternating field (AF) together with a direct current (DC) magnetic field oriented at an arbitrary angle to the AF direction. Sato et al. (2017) suggested that the angle between the OARM vector and the direction of the alternating field (the OARM angle) reflects the strength of magnetostatic interactions. The ratio of anhysteretic remanent magnetization (ARM) to saturation isothermal remanent magnetization (SIRM) varies depending on both magnetic interactions and grain-size variations. By combining OARM properties with the ARM/SIRM ratio, it may be possible to distinguish the respective contributions of magnetic interactions and grain-size variations. OARM measurements were conducted on marine sediments from the Okhotsk Sea (Yamazaki et al., 2013) and the Western Equatorial Pacific (Sakuramoto et al., 2017). These sediments exhibit significantly different ARM/SIRM ratios. Moreover, considering their depositional environments, the magnetic properties of these sediments are expected to reflect varying degrees of contributions from magnetic interactions and grain-size variations. During the OARM acquisition, a DC field is applied at a 45°　angle to the alternating field, and the DC and AF intensities are set at 71 μ T and 140 mT, respectively. The OARM vector is measuremed using a spinner magnetometer. The magnetization was also measured after AF demagnetization at 30 and 140 mT. In sediments from the Okhotsk Sea, OARM measurements were conducted on samples spanning the past 140,000 years. The OARM angle shows little variation throughout this period, except around 33 ka, where a deviation of approximately 8°　is observed. In contrast, the ARM/SIRM ratio exhibits large fluctuations. These results suggest that variations in grain size are the primary factor influencing changes in the ARM/SIRM ratio. This study proceeds to conduct OARM measurements on sediments from the Western Equatorial Pacific. By comparing the results from both regions, the study will evaluate the applicability of OARM properties as a proxy in paleoceanographic research.

R004-11
D 会場 ： 11/26　AM1（9:15-10:45）
10:00～10:15:00

ストロンボリ式噴火を伴う 2014-2015 阿蘇中岳噴火火山灰の岩石磁気学的特徴（予察）

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Preliminary results of rock-magnetic study on volcanic ash from the 2014-2015 eruption of Nakadake first crater, Aso Volcano

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In this study, we analyze the magnetic properties of volcanic ash collected immediately after a series of eruptions at active volcano to identify correlations between eruption processes and rock magnetic properties, as well as temporal changes, with the aim of establishing new observation methods and contributing to eruption prediction. The main magnetic mineral contained in volcanic ash is titanomagnetite ($Fe_{3-x}Ti_xO_4$). As the titanium content (x) of titanomagnetite varies, its Curie temperature and saturation magnetization intensity also vary. Therefore, it is possible to determine its detailed composition by obtaining several rock magnetic parameters.

It was observed that the rock-magnetic property of the ashes ejected during a series of volcanic eruptions is not constant but changes temporally (Anai et al., 2023). During the 2019-2020 eruption of Nakadake first crater, Aso Volcano, it became clear that there were periods when the ratio of saturation remanent magnetization (M_{rs}) to saturation magnetization (M_s) increased and magnetic particles with a non-interacting single domains which grain size of approximately 100 nm appeared. These periods coincide with the periods during which the volcanic glow has been observed.These magnetic particles are characterized by relatively high titanium content (x = 0.4-0.5) and single domain (SD) particles. These results suggest that, when volcanic activity increases, physical conditions in the volcanic conduit cause fine, titanium-rich titanomagnetite particles to crystallize.

In the present study, we conducted rock magnetic measurements on samples collected by Miyabuchi and Hara (2019) from the 2014-2015 Nakadake first crater eruption, which was a larger eruption accompanied by a Strombolian eruption. As a result, the period in which the non-interacting single domain particles are dominant was not observed, while the periods in which multi-vortex and/or single-vortex domain particles are dominant, indicating larger particle sizes, were recognized. The mixture of titanium-rich titanomagnetite (x = ˜0.5) and titanium-poor titanomagnetite (x = ˜0.2) was also observed for the ash samples ejected during the 2014-2015 eruption. The 2019-2020 ash samples showed that titanium-rich magnetite accounted for approximately 80% of saturation magnetization, a part of the 2014-2015 ash samples revealed this proportion decreased to around 20%. We plan to conduct low-temperature magnetic mapping and SEM observations to recognize more detailed rock-magnetic changes and their causes.

本研究では、活動的火山における一連の噴火直後に採取された火山灰の磁気的性質を解析することで、噴火プロセスと岩石磁気特性の関連性や時系列変化を見出し、新たな観測手法の確立を目的として、噴火予測への貢献を目指している。火山灰に含まれる主要な磁性鉱物はチタン磁鉄鉱（$Fe_{3-x}Ti_xO_4$）である。チタン磁鉄鉱は、チタン含有量 (x) の変化に伴い、チタン磁鉄鉱のキュリー温度や飽和磁化強度が変動するため、いくつかの岩石磁気パラメーターを得ることで詳細な組成を明らかにすることが可能である。

2019-2020 年の阿蘇中岳噴火では、一連の噴火活動中に噴出される火山灰の岩石磁気特性は一定ではなく、時系列で変化していることが確認された（Anai et al., 2023）。顕著な特徴として、飽和残留磁化（M_{rs}）の飽和磁化 (M_s) に対する比（M_{rs}/M_s）や保磁力が複数回上昇し、相互作用のない単磁区磁性粒子が出現することが明らかとなった。この単磁区磁性粒子の特徴は、チタン含有量 x=0.4-0.5 のチタン磁鉄鉱で、粒径は 100 nm 程度と推定される。また、この時期は、火映現象が観測される時期と同期していることが確認された。この結果から、火山噴火活動が活発になる時期には、火道内部では、チタン含有量に富みなおかつ細粒のチタン磁鉄鉱粒子が晶出するような物理条件となることが推察された。

本研究では、ストロンボリ式噴火を伴うより大規模な噴火であった 2014-2015 年噴火について、Miyabuchi and Hara (2019) で採取された火山灰試料の岩石磁気測定を行った。この結果、2014-2015 年火山灰では、単磁区粒子が明瞭に増加する時期は確認されなかったが、疑似単磁区粒子 (Multi-vortex または Single-vortex) が卓越する、すなわち、より大きな粒子サイズが卓越する時期が確認された。また、チタンに富むチタン磁鉄鉱（x ＝～0.5）と、チタンに乏しいチタン磁鉄鉱（x=～0.2）の両者を含むことは、2014-2025 年噴火と 2019-2020 年噴火の火山灰に共通した特徴である。2019-2020 年噴火ではチタンに富むチタン磁鉄鉱が一般的に卓越しており、常温での飽和磁化の 80 %を占めていたのに対し、2014-2015 年噴火では、常温での飽和磁化の 20 %程度まで減少する試料も見られた。今後はより詳細に岩石磁気特性の変動を捉えるために、低温磁気マッピングや SEM での観察などを行う予定である。

R004-12
D 会場 ： 11/26　AM1（9:15-10:45）
10:15〜10:30:00

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Investigation of thermoremanent and viscous remanent magnetization in the Zenkoji debris avalanche deposits

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Volcanic eruptions and associated massive debris avalanches triggered by unstable slope collapse are hazardous natural phenomena that cause severe damage to populations and infrastructure, including depositing debris over wide areas and long distances. Investigating the mechanisms of pyroclastic flow and debris avalanches deposition, as well as forecasting future events is critical for developing effective disaster prevention and mitigation strategies.

Mt. Usu (SW Hokkaido) is one of the most active volcanoes in Japan, erupted several times in historical times since its activization in 1663 AD. The Usu stratovolcano was formed around 30 ka, and subsequent sector collapse produced the large Zenkoji debris avalanche deposit (˜0.3 km3) on the southern slope. There is some debate over the timing of the collapse. Miyabuchi et al. (2014) suggests that the volcanic edifice collapsed around 30 ka based on sedimentary structures. Fujine et al. (2016) suggests that the volcanic edifice collapsed around 20 ka based on radiocarbon dating and analysis of volcanic ash, pollen, and diatoms. In this study, we performed comprehensive magnetic measurements of Zenkoji samples to reconstruct the transport processes of the debris avalanche and constrain its age.

We collected block samples from the boulders near Usu Bay. One-inch core samples were cut from the block samples and used for magnetic measurements. Stepwise thermal demagnetization (THD) of the samples was conducted to evaluate the temperatures during transportation. Then, viscous remanent magnetization (VRM) dating was also applied to constrain the age of the flow event. The age estimation was carried out by identifying the unblocking temperatures of the VRM components aligned with the geomagnetic field.

The THD results show no evidence of high unblocking temperature components aligned with the present geomagnetic field direction, suggesting that the deposits were transported as debris flows after cooling, rather than as hot pyroclastic flows. This result supports the interpretation that the mountain collapse was not synchronous with the eruption (Miyabuchi et al., 2014). The maximum unblocking temperatures of VRM components were identified in the range of 320 – 380 ℃, and the estimated ages were significantly older than 30 ka. Such high unblocking temperatures are likely affected by the remanence in the ferromagnetic minerals of the groundmass, including acquisition of thermochemical remanent magnetization during cooling or thermal alteration during laboratory heating.

To address these issues, this study applies stepwise THD measurements to single plagioclase crystals. So far, a unblocking temperature has been successfully identified in one sample. The maximum unblocking temperature of VRM component of the plagioclase crystal is 180 ℃, significantly lower than those observed in the one-inch core samples. Although the estimated age still exceeds 30 ka, the single-crystal approach shows greater potential for accurate age determination. We will present the results of ongoing single-crystal experiments and discuss their implications for understanding the transport processes of the Zenkoji debris avalanche.

R004-13
D 会場 ： 11/26　AM1（9:15-10:45）
10:30〜10:45:00

アイスランド東部の連続溶岩層序群から解明する高逆転頻度期の古地球磁場変動－地球ダイナモの性質理解に向けて

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Variation in paleomagnetic field during a period of high reversal rate deduced from lava flows in eastern Iceland

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Recorded reversals date back to at least 160 million years ago (e.g., Ogg, 2020), and reversal frequency has changed with time. For example, on the geological timescale, the “recent” past 5 million years show a reversal frequency average about 3 per million years. During this interval, paleomagnetic records from volcanic rocks worldwide reveal a tendency for the virtual geomagnetic dipole moment (VDM) to exhibit larger fluctuations when the virtual geomagnetic pole (VGP) is located at higher latitudes, which may reflect a fundamental property of the geodynamo. However, paleomagnetic records capturing transitional polarities corresponding to low- to mid-latitude VGPs account for only ~3% of the dataset, and it remains uncertain whether this characteristic is universal or dependent on temporal changes in reversal frequency. In this study, we focus on a period of high reversal rate, during which a relatively large number of volcanic rocks are thought to have recorded intermediate paleomagnetic signals. By investigating variations in paleodirection and paleointensity preserved in these rocks, we aim to gain deeper insights into the relationship between VGP latitude and the amplitude of VDM fluctuations.

The highest reversal frequency since the Cretaceous is observed about 11 million years ago, with a reversal frequency of 4.7 per million years (a period of high reversal rate).Variations in paleomagnetic direction during this period have been reported from lava flows in eastern Iceland (Kristjansson et al., 1995), where lavas with intermediate polarity are relatively common in the Mjoifjordur region. We systematically sampled 138 lavas possessing clear relationships from two adjacent sections (EO,EP), and as well as two additional sections (ES, ET) stratigraphically higher in the Seydisfjordur region to the north, and conducting various paleomagnetic analysis on them.

According to the geological map published by the Icelandic Institute of Natural History, the paleomagnetic record from EO – ET spans approximately 0.8 Myr, between 12.2 to 13 Ma. In addition, about 30% of all lavas recorded intermediate VGPs, which is an order of magnitude higher than the proportion observed in volcanic records of the last 5 Myr.

Additionally, rock magnetic analysis confirmed that the paleomagnetic directions recorded in these samples are independent of changes in rock magnetic properties, indicating high reliability of the paleomagnetic record. Since absolute paleointensity measurements are ongoing, we calculated relative paleointensity (RPI) as a proxy, using the NRM/ARM ratio derived from stepwise demagnetization of natural remanent magnetization (NRM) and anhysteretic remanent magnetization (ARM). RPI tends to decrease around reversal boundaries, and its relationship with VGP latitude shows contrasting variability across ±45°, similar to trends observed over the past ~5 Myr. These findings suggest that the relationship between VGP latitude and VDM variability may represent an intrinsic property of the geodynamo, independent of reversal frequency.

地磁気の逆転史は約 1 億 6 千万年前までについて明らかになっており (e.g.Ogg, 2020)，逆転頻度は時間とともに変化してきたことが知られている．例えば，地球史スケールでは「最近」である過去約 500 万年間の逆転頻度は約 3 回/百万年である．この期間について，世界各地の火山岩の古地磁気記録からは，仮想地磁気極 (VGP) が高緯度に位置するほど仮想地磁気双極子モーメント (VDM) の変動幅が大きくなる傾向が確認でき，地球ダイナモを特徴づける重要な性質の可能性がある．しかし，低〜中緯度の VGP に対応する中間極性を捉えた古地磁気記録は全データ比で約 3 %と乏しく，また，この性質が逆転頻度の時間変遷に依存しない普遍的なものであるかは定かではない．本研究では，逆転頻度が高かった期間，すなわち，比較的多くの火山岩が中間極性の古地磁気記録を捉えたと考えられる期間に着目する．このような火山岩から古地磁気方位と強度の変動を解明することで，VGP 緯度と VDM の変動幅の関係についての洞察を深めることを目指している．

逆転頻度は，白亜紀以降では 11 Ma 頃が最も高く，4.7 回/百万年である (以下，高逆転頻度期)．この期間を含む古地磁気方位変動については，アイスランド島東部の連続溶岩層序群から比較的詳細に報告されており (Kristjansson et al., 1995)，Mjoifjordur 地域には中間極性を記録した溶岩が頻出するセクションが存在する．我々は，そのセクションに近接する 2 箇所のセクション EO, EP を選定するとともに，さらにこれらの上位にあたる 2 箇所のセクションを，Mjoifjordur 地域の北側の Seydisfjordur 地域から ES,ET として選定した．これら 4 箇所のセクション EO〜ET の計 138 枚の溶岩群から時間的前後関係が明確になる形で試料を系統的に定方位採取して，各種磁気分析を行っている．

アイスランド自然史博物館発行の地質図を参照すると，セクション EO〜ET の古地磁気記録は 12.2〜13 Ma の約 80 万年間に対応すると考えられた．さらに，全溶岩のうち約 30 %が中間極性に対応する VGP を示し，この割合は過去約 500

万年間の火山岩記録と比べて 10 倍にも上った．また，これらの結果は岩石磁気特性に依存せず，古地磁気記録としての信頼性が高いことを確認した．古地磁気強度については測定の継続中のため，代理指標として相対古地磁気強度 (RPI) を算出することとして，自然残留磁化 (NRM) と非履歴性残留磁化 (ARM) の消磁結果をもとに NRM/ARM 比を求めた．RPI は逆転前後で小さくなる傾向があり，また，VGP 緯度と RPI との関係からは，VGP 緯度± 45° を境にして RPI の変化幅に差があり，過去約 500 万年間に見られる傾向と類似していることが分かった．このような VGP 緯度と VDM の変動幅の傾向は，逆転頻度に依存しない地球ダイナモの本質的な性質を反映している可能性がある．

R004-14
D 会場 ： 11/26　PM2（14:50-16:20）
14:50〜15:05:00

エチオピア・アファール凹地の溶岩連続層による地磁気逆転期の地磁気ベクトル変動の研究

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Geomagnetic vector variation during the polarity reversal recorded in lava sequences in Afar, Ethiopia

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Geomagnetic reversals and excursions are characterized by a large decrease in the Earth's magnetic field strength. Therefore, to understand the characteristics of geomagnetic field vector behaviors during the reversals, it is important to reconstruct not only paleomagnetic direction but also absolute paleomagnetic intensity. In this study, lava sequences in the Tendaho Graben in Afar, Ethiopia, were collected to reconstruct the geomagnetic field variations at the geomagnetic reversal. The previous results of our research group have provided the distribution of paleomagnetic polarity of lavas of the past 1 Myr in the Tendaho Graben. In the 2022 survey, we collected rock samples at 2 sections of lava sequence that may record the Matuyama-Brunhes polarity reversal. We also sampled a section of lava sequence which contains an excursion record of 0.65 +/- 0.10 Ma. Section 1 (18 lavas) shows that the paleomagnetic polarity changes of reverse-normal-reverse. The obtained paleomagnetic intensities for the first reverse polarity period are slightly lower than the mean paleointensity for the past 1 Myr. Subsequently, paleointensity increased to 42 microT at the normal polarity period. It should be noted that paleointensity reduced to about 5 microT at the uppermost lava for the normal polarity period. Finally, paleointensities are 4 – 5 microT for the second reversed polarity period. These paleomagnetic behaviors with the paleointensity decrease suggest the 18 lavas in section 1 recorded the beginning of the Matuyama-Brunhes polarity reversal. For the lava sequence of section 2, all of the 10 lavas show reversed polarity, but gave very weak paleointensities of about 5 microT, which are comparable to the typical values during the reversals. Therefore, we consider the paleomagnetic behaviors of the section 2 is also related to the polarity reversal.

地磁気逆転は地球磁場強度の大きな変動（減少）を伴う。このことから，地磁気逆転期の地磁気ベクトル変動を理解するには，古地磁気方位に加えて，絶対古地磁気強度の復元が必要である。本研究では，エチオピア・アファール凹地のTendaho Graben の溶岩連続層において試料採集を行い，逆転期の地磁気ベクトル変動の復元を試みた。これまでの我々のグループの研究により，Tendaho Graben 内部に露出する溶岩の古地磁気極性の分布が把握できていた。2022 年の調査において，松山-ブリュン逆転を記録している可能性がある溶岩連続層（2 セクション）および，エクスカーション（0.65 ± 0.10 Ma）が報告されている溶岩連続層（1 セクション）において試料採集を行った。3 セクション（計 33 溶岩）からは，1 溶岩あたり 5 つ程度の定方位試料を採集した。本発表では，地磁気逆転に関連する変動を記録していた Section 1 と Section 2 の古地磁気強度方位・古地磁気強度の測定結果を報告する。

古地磁気強度測定には，綱川ーショー法を適用した。Section 1（18 溶岩）は，下位から上位に向かって逆磁極－正磁極－逆磁極を示した。最初の逆磁極では過去 100 万年間平均値よりもいくらか弱い古地磁気強度を示した。正磁極では最大 42.1 μ T に増加し，正磁極の最上位の溶岩において古地磁気強度は 4 – 5 μ T に急減していた。2 回目の逆磁極においてはいずれも 4 – 5 μ T に弱い強度であった。この溶岩連続層が示した古地磁気強度の減少を伴う変動は，逆転の開始期に対応すると考えられる。Section 2（10 枚）は，すべての溶岩が逆磁極を示した。ただし，これまでに得られた古地磁気強度データは 5 μ T 程度を示すものが多く，逆転期にみられる典型的な値（弱い強度）であった。このような弱い古地磁気強度は，通常の逆磁極期に対応するとは考えにくく，Section 2 の古地磁気変動も逆転期に関連する変動と推察される。

R004-15
D 会場 ： 11/26 PM2（14:50-16:20）
15:05〜15:20:00

ε-Fe2O3 が記録する古地磁気強度のテスト測定

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Testing Thellier paleointensity determinations of ε-Fe2O3 bearing volcanic rocks

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ε-Fe_2O_3 (luogufengite) is a magnetic material characterized by a huge coercivity exceeding 1 T at room temperature and a low Curie point (~220 ℃). Single-domain ε-Fe_2O_3 are widely distributed in ceramics sintered at high temperatures (>1000 ℃) in an oxidizing atmosphere as well as red-brown obsidians. The remanent magnetization carried by ε-Fe_2O_3 exhibits a narrow unblocking temperature just below the Curie point. It has little to no viscous remanent magnetization, and remains stable over geological timescales as recording reversed magnetization. Compared to titanomagnetite or magnetite with pseudo-single- to multi-domains, which are typical carriers of remanent magnetization in volcanic rocks, ε-Fe_2O_3 is an ideal medium for recording geomagnetic field intensity.

Previously considered an extremely rare magnetic mineral found only in ceramics and red-brown obsidians, ε-Fe_2O_3 has recently been discovered in red to pink-colored andesites and dacites. In this study, we used dacite from the 1991-1995 eruption of Mount Unzen-Fugen-dake to verify whether it records the expected geomagnetic field intensity. ε-Fe_2O_3 had been identified in this location by Saito et al. (2007). We also performed paleointensity measurements using the Thellier method on andesite from Mount Yufu-dake, which erupted approximately 2,000 years ago.

Color measurements revealed that the a*(green to red) and b*(yellow to blue) values, which indicate color tone, were nearly zero for the gray blocks. In contrast, the red to pink samples exhibited high positive values for both a*and b*. The difference between the red and pink samples was evident in their difference in lightness (L*). The red-to-pink samples exhibited an unblocking temperature of ε-Fe_2O_3 of 150-220 ℃ during the thermal demagnetization of natural remanent magnetization. The proportion of ε-Fe_2O_3 remanent magnetization intensity is 5-20%, while titanomagnetite and magnetite contribute the rest. Hysteresis and isothermal remanent magnetization measurements up to 5 T confirmed the presence of both ε-Fe_2O_3 and titanomagnetite/magnetite.

The Thellier method was used to measure paleointensity in 21 red to pink-colored samples from three sites in Unzen-Fugen-dake. These measurements revealed that the magnetic components of ε-Fe_2O_3 in four samples yielded values within ± 5% of the geomagnetic field intensity at the time of eruption (47.1 μT). The magnetization components of titanomagnetite and magnetite in these samples also exhibit linear segments on Arai diagrams and equivalent paleointensities. Conversely, in many samples, the proportion of ε-Fe_2O_3 contributing to the natural remanent magnetization is small. This results in a low quality factor (q) and apparent paleointensities that are higher by several tens of percent. Titanomagnetite and magnetite in these samples exhibit sigmoid curves on Arai diagrams, and paleointensities cannot be determined. Note that gray samples could not yield paleointensity due to significant thermal alteration at temperatures above 350 ℃. The ε-Fe_2O_3 magnetic component in the red-to-pink samples from Yufu-dake has a larger proportion of natural remanent magnetic intensity than the samples from Unzen-Fugen-dake. The average value across the two sites is 51.2 μT, which agrees well with the standard curve value.

As predicted by its stable remanent magnetization and low demagnetization temperature, ε-Fe_2O_3 can reliably provide paleointensity through the Thellier method. However, coexisting titanomagnetite or magnetite act as contaminants in the Thellier method using ε-Fe_2O_3. However, to obtain paleointensity from ε-Fe_2O_3, the unblocking temperatures of titanomagnetite and magnetite must either not overlap or their remanence ratios must be low.

ε-Fe_2O_3 (luogufengite) は室温において 1 T をこえる巨大な保磁力と低いキュリー点 (~220 ℃) に特徴づけられる磁性体である．酸化的雰囲気中で高温 (>1000 ℃) で焼成された焼き物や赤褐色黒曜石には単磁区の ε-Fe_2O_3 があまねく含まれる．ε-Fe_2O_3 が担う残留磁化は，キュリー点直下にせまいアンブロッキング温度を示し，粘性残留磁化をほとんどもたず，逆帯磁を記録するように地質学的時間スケールで安定である．テリエ法においても，ε-Fe_2O_3 は単磁区であり低いアンブロッキング温度のため熱変質をこうむる可能性が低く，火山岩の残留磁化の通常の担い手である疑似単磁区〜多磁区のチタノマグネタイトやマグネタイトと比較して，理想的な地球磁場強度の記録媒体である．

ε-Fe_2O_3 は焼き物や赤褐色黒曜石以外には見られないきわめてまれな磁性鉱物であるとこれまで考えられてきた．しかし，赤〜ピンク色の安山岩やデイサイトが ε-Fe_2O_3 を含んでいる例を最近いくつかの地域で見いだした．今回は Saito et al. (2007) が ε-Fe_2O_3 を見いだした 1991〜1995 年に噴出した雲仙普賢岳のデイサイトを用いて， ε-Fe_2O_3 が期待される地球磁場強度を記録しているか確かめてみた．約 2000 年前に噴火した由布岳の安山岩についてもテリエ法による古地磁気強度測定を行った．

火砕流堆積物から赤〜ピンク色のブロックと比較のため灰色のブロックを採取した．色差計で測ったところ，色調をあらわす a*(緑〜赤) と b*(黄〜青) は灰色でほぼゼロであるのに対し，赤〜ピンク色の試料の a*と b*は高い正の値を示す．

赤色とピンク色の試料の違いは明度L*の差にあらわれた．赤〜ピンク色の試料は自然残留磁化の熱消磁において，例外なく150-220 ℃で ε-Fe_2O_3 のアンブロッキング温度をしめす． ε-Fe_2O_3 の残留磁化強度の割合は5〜20 %程度で，残りはチタノマグネタイトとマグネタイトが担う．最大5 Tでのヒステリシス測定と等温残留磁化付加において，高保磁力の ε-Fe_2O_3 と，低保磁力のチタノマグネタイト，マグネタイトの共存を確認した．

雲仙普賢岳の赤〜ピンク色の試料では3サイト21個についてのテリエ法による古地磁気強度測定の結果， ε-Fe_2O_3 の磁化成分から4個の試料において噴出時の地球磁場強度47.1 μT の ± 5% 以内の値をえた．これらの試料では，チタノマグネタイトやマグネタイトの磁化成分もアライ図上で直線的で同等の古地磁気強度をあたえる．一方，多くの試料においては ε-Fe_2O_3 が自然残留磁化強度においてしめる割合が小さいため quality factor q が小さく，数10 %高い見かけの古地磁気強度を与える．これらの試料ではチタノマグネタイトやマグネタイトはアライ図上でシグモイド曲線を描き，古地磁気強度が得られない．なお，灰色の試料は350 ℃以上で熱変質の影響が大きくなるため古地磁気強度が得られなかった．一方，由布岳の赤〜ピンク色の試料の ε-Fe_2O_3 の磁化成分は自然残留磁化強度においてしめる割合が雲仙普賢岳に比べて大きく，2サイトの平均は51.2 μT と標準曲線とよく一致する．

ε-Fe_2O_3 はその安定な残留磁化と低いアンブロッキング温度から予測されるように，テリエ法において期待される古地磁気強度を与えることができる．共存するチタノマグネタイトやマグネタイトは ε-Fe_2O_3 によるテリエ法では夾雑物である．ただし，チタノマグネタイトやマグネタイトのアンブロッキング温度が重ならないこと，もしくはその磁化成分の割合が低いことが， ε-Fe_2O_3 から古地磁気強度を得るための条件である．

R004-16
D 会場 ： 11/26 PM2（14:50-16:20）
15:20〜15:35:00

鉄マンガンクラストの極微細古地磁気層序における高精度年代推定手法

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High accuracy age estimate using ultrafine scale magnetostratigraphy on ferromanganese crusts

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Marine ferromanganese crusts are invaluable archive of past environments of the ocean recorded as internal microscopic structures and chemical compositions including isotopes. One of the key parameters is the dissolved oxygen concentrations in deep Ocean water, which is associated with the oxygen minimum zone developed in the intermediate water. For the reconstruction of the environments, it is quite important to develop a reliable age model for each ferromanganese crust. Utilizing one of the cosmogenic nuclides, 10Be, for dating is one of the reliable isotopic methods for the crust, which is effective back to ~15 Myr. Another independent method for age dating is ultrafine scale magnetostratigraphy (e.g. Oda et al., 2011; Noguchi et al. 2017). In order to further promote scientific outputs, a ferromanganese crust sample from Takuyo Daigo seamount in the North Pacific Ocean (NT09-02_Tak5_01_A; water depth 2987m) was measured with scanning SQUID microscope (SSM) at Geological Survey of Japan, AIST. 10Be dating on the sample suggest average growth rate of ~2.2mm/Myr for this samples (Usui et al., 2017). A thin section from the sample was measured with the SSM after AF demagnetizations at 0, 5, 10, 15, and 20 mT. All the results show magnetic stripes corresponding to geomagnetic reversal boundaries parallel to the growth layers. Preliminary interpretation of the magnetic stripes seems to be consistent with the age model suggested by 10Be dating. We also applied dipole subtraction and upward continuation on the magnetic image using software ProcSQMicro developed on Igor Pro (Oda et al., 2025). Especially, a new feature implemented to calculate X and Y from Z components of magnetic field based on an algorithm by Lima&Weiss (2009) exhibit enhanced magnetic stripes in X magnetic field image. From three components of magnetic field, we calculated the intensity of spatial differential vectors (ISDV; Seama et al., 1993) along a profile perpendicular to geologic layered structures. The identification of the boundary was partially successful, however, the results were not satisfactory. In the presentation, we further apply reduced-to-pole transformation, prior to the application of ISDV, and explore the optimum post processing treatments to further enhance geomagnetic reversal boundaries recorded in the ferromanganese crust sample for the development of reliable age model based on magnetostratigraphy.

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R004-17
D 会場 ： 11/26　PM2（14:50-16:20）
15:35〜15:50:00

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Rock magnetic study of dredged rock samples from Marie Celeste Transform Fault, Central Indian Ridge

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The rock magnetic architecture of oceanic crust remains poorly constrained, and existing models of crustal magnetization are still incomplete. Beyond the influence of seafloor spreading rate, results from deep-sea drilling have revealed significant lithological variability, yet the heterogeneous structures produced by hydrothermal alteration are not well enough understood to be incorporated into magnetization models (e.g., Tivey and Dyment, 2010; Fujii et al., 2018). Moreover, the development of detachment faults has led to shallow exposure of serpentinites, a component often overlooked in crustal frameworks (e.g., Oufi et al., 2002; Fujii et al., 2016). In this study, we report on a rare case of dredged rock samples obtained from a transform fault setting, the Marie Celeste Transform Fault of the Central Indian Ridge, to highlight their magnetic and lithological characteristics.

During the KH-24-6 cruise (October 12 to November 8, 2024), twenty-seven dredge hauls were conducted along the Marie Celeste Transform Fault, yielding a diverse sample set of basalt, dolerite, gabbro, and their altered equivalents. To facilitate laboratory analyses, we employed a newly adapted onboard mini-core drilling system to prepare cylindrical subsamples of 18 mm and 25 mm diameter from the dredged rocks. This approach provided standardized specimens for rock magnetic measurements and petrological comparison.

Preliminary results reveal clear lithological contrasts in magnetic properties. Basalts show strong remanent magnetization (˜several to 20 A/m), whereas altered basalts generally exhibit weak remanence ($<$1 A/m) with variable intensity. Dolerites possess measurable magnetic susceptibility and titanomagnetite content but contribute little to remanence, with dolerites containing veins showing greater variability. Gabbros display a wide range of values, with a positive correlation between susceptibility and remanence, reflecting coarse titanomagnetite grains; serpentinization of olivine is limited. Olivine gabbros with leucocratic veins show heterogeneity in both susceptibility and remanence. Notably, although samples were collected widely from the ridge axis to the off-axis flanks, the Curie temperature of basalts showed little variation, consistently ranging between 500 and 550 °　C. This observation indicates that the Fe/Ti ratio remained stable over long timescales, suggesting little spatial variability in the magma source. These findings highlight the magnetic complexity of transform-fault lithologies and provide new constraints for models of oceanic crustal architecture.

R004-18
D 会場 ： 11/26 PM2（14:50-16:20）
15:50〜16:05:00

水熱加熱レス試料の岩石磁気－実験後乾燥保管試料の長期磁気変化

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Rockmagnetism of hydrothermally heated loess samples; long-term magnetic changes during storage of samples dried after experiment

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Hydrothermal (HT) experiments using loess samples from the Chinese Loess Plateau and Paks, Hungary were conducted to clarify the mechanism of formation of pedogenic magnetic minerals. We have already shown that post-experiment changes in remanent magnetizations were observed during storage of hydrothermally heated samples that were cooled and dried after HT experiments. Here, we report that magnetic susceptibility also changes during storage of the samples. The samples were heated at 200 degrees C for 1 to 17 hours, followed by cooling down to the room temperature. Samples subjected to HT experiments were dried until the original dryness (natural dry sample), some of which were dried heavily at two levels; super dry 1 (SD1), relatively high dryness, and SD2, very high dryness. Both natural and super dry samples have no pore water, but have inter layer water of phyllosilicates of clay minerals. Most of samples after HT experiments were stored at room temperature, ca. 20 degrees C. Some were stored at 4 degrees C.

Magnetic susceptibility of natural dry samples stored at room temperature increased monotonically for the first 1 month, followed by gradual decrease with small fluctuations. Magnetic susceptibility of natural dry samples stored at 4 degrees C represent similar patterns, but the peaks were delayed by a few months, having subsequent smooth cooling curves. Magnetic susceptibility of super dry samples, all stored at room temperature, first increased for a couple of months, followed by keeping almost constant values or a slight monotonic decrease curve. In consideration of the magnetic hysteresis and IRM acquisition experiment data, the results of magnetic susceptibility changes indicate that superparamagnetic magnetite and hematite particles have been formed even after the HT experiment under room temperature and dry conditions. The newly formed fine magnetic particles contribute to growing in size by condensation, causing decreases in the number of fine particles. Lower temperature storages suppress these processes. The post-experiment formation of fine magnetic particles and condensation of them would occur in interlayer water of phyllosilicates.

レスの土壌性磁性鉱物生成の解明をめざし、レス試料を用いた水熱加熱実験を行った。これまでに、加熱温度・時間に依存した実験直後の帯磁率増加と、その後乾燥試料で数 10〜100 日の時間スケールで起こる残留磁化の増減変動を確認している。本発表では、保管中に帯磁率も長期変化することを報告する。実験には中国黄土高原とハンガリーのパクシュで採取済の強く土壌化した温暖湿潤期のレス試料を用いた。温度 200 ℃、加熱時間 1〜17 時間の水熱加熱実験を行った。実験終了後、試料を 70 ℃の乾燥器に入れ実験前の質量に戻るまで乾燥させた（自然乾燥試料）。一部の試料は乾燥時間を大幅に延ばして、元の質量から 2〜4 %減の 2 種類の超乾燥試料を作成した（乾燥度がやや緩い Super dry 1（SD １）試料と非常に強い SD2 試料）。これら乾燥試料は砕屑粒子間の間隙水を全く含まず、層状珪酸塩鉱物の層間水は残している。磁気測定後、ほとんどの試料を室温（平均約 20 ℃）で、一部の試料は 4 ℃で保管した。

室温保管した自然乾燥試料の帯磁率は最初の約 1 か月間は単調に増加し、ピーク（実験直後の値＋ 1〜2 %）をとった後は緩やかに、小さく振動しながら減少する。4 ℃保管の自然乾燥試料も同様の帯磁率変化を示すが、約２〜３か月遅れてピークをとり、その後の減少はなめらかであった。室温保管した超乾燥試料の帯磁率は最初の 1 － 2 か月間は増加するが、その後はほぼ一定値をとるか（SD2 試料）、極めて緩やかな単調減少を示した（SD1 試料）。これらの帯磁率変化は、磁気ヒステリシス測定、IRM 獲得実験結果と合わせると、水熱加熱実験後も、磁鉄鉱と赤鉄鉱の超常磁性サイズ粒子の新規生成と、それらの凝結による粒径の成長がしばらく続くことを示唆する。低温保管はこれらの反応を減速させる。また、細粒磁性粒子の生成と成長は層状珪酸塩鉱物である粘土鉱物の層間水中で起こっていると思われる。

R004-19
D 会場 ： 11/26　PM2（14:50-16:20）
16:05～16:20:00

高分解能スピナー磁力計による残留磁化波形の FFT 解析

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FFT analysis of NRM waveforms using a high-resolution spinner magnetometer

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We investigated how magnetisations behave during stepwise AC demagnetisation in terms of the FFT spectra from the fundamental to the fifth-order harmonics using a high-resolution spinner magnetometer capable of real-time FFT analysis while spinning a sample. Results from artificial and natural samples (including volcanics and sedimentary rocks) demonstrated the following: 1) Stable NRM is predominantly composed of the fundamental harmonic component, 2) Secondary magnetisation superimposed on the stable component exhibits a greater harmonic component than the stable component, 3) The harmonic component's contribution gradually decreases as secondary magnetisation is demagnetised step by step, 4) The harmonic component's contribution in some volcanic rocks shows little variation with progressive AC demagnetisation. These results suggest that the harmonic component is present to a greater or lesser extent in natural samples. The fraction of the fundamental component in the total FFT is referred to as FDD in this study and is proposed as a new index for the quantitative evaluation of bulk magnetic properties. Preliminary measurements show that samples with stable initial remanent magnetisation have an FDD>80%, whereas an FDD<70% is observed for samples with a significant secondary component. The presence of harmonic components could reflect the various anisotropies and inhomogeneities of a sample, including the spatial distribution of magnetic particles, interparticle interactions, and the distribution of the internal magnetic field. Meanwhile, FDD is also related to the intensity of bulk magnetisation: strongly magnetised volcanic rocks exhibit dominance of the fundamental component, while weakly magnetised and/or low-coercivity volcanic and sedimentary rocks are characterised by lower FDDs. We will also discuss the other advantages of the high-resolution spinner magnetometer and its applications in rock magnetism.

残留磁化波形を基本波から第５高調波まで計測できる高分解能スピナー磁力計を開発し、種々の人工試料・自然試料の残留磁化波形の FFT 解析を行なった。さらに段階交流消磁における磁化の振舞いと FFT 結果の関連を調べた。その結果、１）単成分の安定残留磁化は中心双極子による基本波が卓越する場合が多い、２）粘性残留磁化のような二次磁化が重畳する場合には高調波成分の寄与が大きい、３）二次磁化が段階消磁されて安定な単成分磁化になるにつれて高調波成分は消失し双極子磁場的になる。４）安定残留磁化をもつ試料でも顕著な高調波成分を示すものがある。これらの結果は、これまで offset-dipole モデルによって説明された高調波が自然試料にも存在し、磁性粒子集団の特性やその段階消磁に対する反応と強い相関を持つことを示す。具体的には、試料内部の様々な異方性や不均一性（磁性粒子の空間分布、粒子間相互作用、内部磁場分布など）に起因すると考えられる。特に上記４）の特徴を持つ試料は、磁性粒子間の磁場相互作用による内部磁場分や微視的保持力の不均一性を示す可能性がある。一方、巨視的な磁化強度とも関連があり、強磁化火山岩では基本波が卓越するのに対し、弱磁化・低保持力の火山岩や堆積岩では高調波成分の存在割合が高い。そこで本研究では、FFT スペクトルにおける双極子起因基本波の存在割合を表す新指標（FDD, fft-derived dipole index）を用いて、段階消磁の有効性を定量評価する手法を提案する。予察的測定によると、主として初生安定残留磁化をもつ試料では FDD>80%、二次磁化が重畳すると FDD は減少し 70% 以下になる。これは段階消磁の初期段階から FDD>80% で安定する試料には、二次磁化がほとんど存在しないことを示す。また消磁初期は FDD<70% でも途中段階から FDD>80 % になれば、二次磁化が有効に消磁されたことを示す。これらは、FDD が初生安定磁化の判定ばかりでなく、段階消磁の有効性を定量評価する指標としても活用できることを示す。このほか、高分解能スピナー磁力計による測定のメリットや応用研究を SQUID 磁力計などとの比較を交えて議論する。

R004-P01
ポスター 1：11/25　AM1/AM2（9:15-12:35）

LP、かぐや、KPLO の高高度データを用いた月地殻磁気図の作成

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Lunar crustal magnetic anomalies mapping using LP, Kaguya, and KPLO high-altitude data

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A comprehensive magnetic map of the lunar crust is essential for understanding the Moon's surface environment and investigating its thermal evolution. The study of lunar magnetism dates back to the magnetic measurements of Apollo 11 samples (Doell and Gromme, 1970) and regional magnetic observations conducted by Apollo 15 and 16, as well as Explorer 35 (Coleman et al., 1972; Ness et al., 1967). Subsequent missions such as NASA's Lunar Prospector (LP, launched in 1998) and JAXA's SELENE (Kaguya, launched in 2007) provided global magnetic field measurements at low altitudes (~30 km). Various analytical techniques have since been applied to these datasets to produce global lunar magnetic maps (e.g., Purucker, 2008; Tsunakawa et al., 2015; Ravat et al., 2020). However, due to the weak magnetic field strength and the significant influence of external fields, data collected at higher altitudes (~100 km) were not previously utilized.

The Korea Pathfinder Lunar Orbiter (KPLO), launched in 2022, is currently conducting magnetic field observations at approximately 100 km altitude. These observations have revealed that spatial patterns of magnetic anomalies at this altitude are consistent with those obtained at lower altitudes, thereby demonstrating the viability of high-altitude data for magnetic mapping (Kim et al., 2025). Detailed analysis of the KPLO data also suggests directional differences in the magnetic field compared to existing spherical harmonic expansion models, indicating a need to re-evaluate the inclination, declination, and paleomagnetic pole positions of lunar magnetic anomalies.

To date, only Level-1 (partially processed) KPLO data from the first six months of the mission have been used in prior studies, limiting data quality. In this study, we utilize two years of Level-2 (calibrated) KPLO data, along with 100 km altitude magnetic data from LP and SELENE, to produce a new global lunar crustal magnetic field map. Our analysis employs correlation filtering (von Frese et al., 1997) and the forward and backward binning method. Compared with existing spherical harmonic models, our map demonstrates higher correlation with prior studies, although it reveals differing magnetic directions in specific regions. Notably, in the region between 0 – 40°　N latitude and 180 – 160°　W longitude, our results align with the RSH model (Ravat et al., 2020) rather than the TSH model (Tsunakawa et al., 2015).

This newly developed magnetic map is expected to support a wide range of future studies related to lunar magnetism, dynamo processes, and the Moon's thermal evolution.

月の地殻磁気地図は月面環境の理解および月の熱進化研究に重要である。月の磁場研究の歴史は古く、アポロ 11 号で回収されたサンプルの磁場測定 (Doell and Gromme,1970) やアポロ 15, 16 号と Explorer 35 号による軌道上からの月の地域的な磁場観測 (Coleman et al., 1972; Ness et al., 1967) に始まる。その後 1998 年に NASA が打ち上げた Lunar Prospector (LP) と 2007 年に JAXA が打ち上げた「かぐや (SELENE)」では月全球の磁場観測が行われた。この LP とかぐやの全球低高度（30 km）データに対して様々な解析手法を適用することで、これまでも月の磁気図作成が複数試みられてきた (e.g., Purucker 2008; Tsunakawa et al., 2015; Ravat et al., 2020)。その際、磁場強度が弱く外部磁場の影響が大きい 100 ㎞ 高度データは用いられてこなかった。2022 年に韓国が打ち上げた月極軌道探査機 KPLO は現在も高度 100 km 付近で磁場観測を継続しており、新たな全球月磁場データが蓄積されている。KPLO による磁場観測では、高度 100 km においても磁気異常の空間パターンは低高度データと同様に確認され、高高度データの利用可能性が示された (Kim et al., 2025)。また同データの詳細な解析は、従来の二つの球面調和展開モデルとは異なる磁場方向も確認されている。このことは磁気異常の伏角や偏角の値、さらには古地磁気極の位置についても再解析する必要性があることを暗示している。しかしながら、これまでの研究では KPLO 最初の 6 ヶ月間の Level-1 (Partially Processed) データのみ利用されたため、品質のよいデータは限られていた。そこで本研究では KPLO の 2 年間におよぶ Level-2 (Calibrated) データに加えて LP とかぐやの高度 100 ㎞ 磁場データを用いて新たな月地殻磁気図を作成する。データ解析に当たっては、相関関係フィルタリング (von Frese et al., 1997) と前後 Binning Method を利用する。既存の球面調和添加モデルと比較した結果、先行研究より高い相関関係を得られたが、一部地域では異なる磁気方向が得られた、特に緯度 0-40°　N、軽度 180-160°　W での地域では TSH モデル (Tsunakawa et al., 2015) と RSH モデル (Ravat et al., 2020) は異なる方向を見せるが、本研究で作成した地図は RSH モデルと同じパターンを持っていることを確認した。今後本研究で作成した地図で月磁場、ダイナモ、熱進化などの様々な研究で活用されることが期待される。

R004-P02
ポスター 1：11/25　AM1/AM2（9:15-12:35）

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Preliminary results of some budget analyses of a dynamo model in terms of equatorial symmetry

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The geomagnetic field shows some asymmetric features with respect to the equator, such as the South-Atlantic Anomaly. The asymmetric structure comes from the fact that the geomagnetic field consists of superposition of the equatorially anti-symmetric and symmetric components. The anti-symmetric component is referred to as the dipole family, while the other is to the quadrupole family. It is well known that the geomagnetic field is dominated by the dipole family components. Other than the Earth, the magnetic field of Mercury shows a notable deviation from that of the dipole family alone due to significant contribution from the quadrupole family component. Our previous study suggests that such a field morphology is maintained by the helical flows biased in one hemisphere. Moreover, such a biased flow is induced by the biased magnetic field via the self-regulation process (Takahashi et al. 2019). However, it is still not well understood that how the self-regulation process generates and maintains the biased flows and magnetic fields. Here, we examine the self-regulation process focusing on interaction between the equatorially symmetric and anti-symmetric components of the flow and magnetic field. For this purpose, budget analyses on energy, enstrophy, and helicity are considered to grasp their flows. In this presentation, our preliminary results for a purely dipole family dynamo, and the corresponding mixed-family dynamo at the same parameter values will be shown and discussed.

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R004-P03
ポスター 1：11/25　AM1/AM2（9:15-12:35）

数値ダイナモシミュレーションの制御パラメータの過去 40 億年間における変遷

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Time Evolution of Control Parameters in Numerical Dynamo Simulations Over the Past 4.0 Ga

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The geomagnetic field is essential for shielding the Earth from harmful cosmic radiation and maintaining the planet's habitability. To understand how the geomagnetic field has been sustained for over 3.5 billion years by dynamo action in the outer core and to investigate the causes of temporal changes in the frequency of geomagnetic reversals, it is important to elucidate the long-term dynamics of the outer core, considering the Earth's thermal history. However, since direct observation of the outer core is impossible and the fluid motions in the core are highly complex and nonlinear, numerical simulations have become an essential and effective tool for exploring the temporal variations of the geodynamo, state and evolution of the Earth's interior.

In geodynamo simulations, control parameters are supposed based on the spatial scale of the dynamo region (i.e., the thickness of the outer core), the physical properties of the outer core, the thermal and compositional buoyancy forces expected within it, and the angular velocity of Earth's rotation. In this study, as the first step toward constructing a geodynamo model to explain long-term evolution of the Earth's magnetic field, we estimate the time evolution of geodynamo control parameters over the past 4.0 billion years, reflecting the Earth's thermal history and long-term variation in Earth's rotation rate. We will employ a magnetohydrodynamic dynamo model using codensity characterized by four control parameters (Ekman number, Rayleigh number, Prandtl number, and magnetic Prandtl number). For thermal history calculations, the code by Landeau et al. (2022) that was based on the theory by Lister (2003) was utilized. The buoyancy forces considered in the calculations include thermal buoyancy from the cooling of the outer core, thermal buoyancy from latent heat and compositional buoyancy resulting from the release of light elements by crystallization of the inner core. These buoyancy sources are derived based on the temporal variations of heat flow and temperature at the core-mantle boundary (CMB), as well as the time evolution of the inner core radius. In this study, we assumed that the heat flow at the CMB has decreased linearly from 4.0 Ga to the present, and calculated the thermal history, including the growth of the inner core. Calculations were performed in reverse chronological order from the present to 4.0 Ga, and the results with different conditions were compared. The time evolution of Earth's angular velocity was assumed based on Touma & Wisdom (1994). These results were used to evaluate the time evolution of the four control parameters, and the parameters applicable to numerical simulations were also estimated using path theory by Aubert et al. (2017).

The results reported in this presentation are regarded as nominal variations of the control parameters under simple conditions, including spatially uniform CMB heat flow. The framework established here provides a basis for addressing more complex cases such that the heat flow of the CMB or physical quantities change in a complex manner over time. In the future, following the approach by Olson et al. (2013), we will conduct numerical dynamo simulations that incorporate factors such as spatially heterogeneous CMB heat flow in addition to the time variations in the underlying control parameters to elucidate the physical mechanisms governing the long-term evolution and reversal frequency of the Earth's magnetic field.

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地球磁場は、有害な宇宙放射線から地球を守り、惑星の居住可能性を維持するうえで重要な役割を果たしている。地球磁場が外核におけるダイナモ作用によって 35 億年以上にわたって維持されてきた要因や、地磁気逆転頻度の時間的変化

の原因を理解するためには、地球の冷却史を踏まえた長期的な外核のダイナミクスを明らかにする必要がある。しかし、外核を直接調査することは不可能であり、関与する流体運動は極めて複雑かつ非線形であるため、数値シミュレーションが地球ダイナモの時間変動と地球内部の状態や進化を探究するための不可欠かつ有効な手段となっている。

地球ダイナモシミュレーションでは、ダイナモ領域の空間スケール（外核の厚さ）に加え、外核の物性、外核内で期待される熱および組成浮力、地球自転の回転角速度に依存する制御パラメータが仮定される。本研究では、地球磁場の長期変化を説明する地球ダイナモ時間変化モデルの構築に向けた第一段階として、地球の熱史と自転速度変化を反映した、40 億年にわたる地球ダイナモ制御パラメータの時間変化を推定する。具体的には、codensity を用いた磁気流体力学ダイナモモデルを想定して、４つの制御パラメータ（エクマン数、レイリー数、プラントル数、磁気プラントル数）の時間変化を対象とした。熱史計算には、Lister (2003) に基づいた Landeau et al. (2022) のコードを改良して用いた。ここで、浮力は外核冷却に伴う熱浮力、内核成長に伴う潜熱による熱浮力と軽元素放出による組成浮力を考慮した。これらの浮力源は、仮定したコア-マントル境界（CMB）における熱流量や温度変化、さらにそれらから求められる内核半径の時間発展などに基づいて導出される。本研究では、CMB の熱流量が、40 億年前から現在の熱流量に至るまで線形に減少したと仮定し、内核成長を含む熱史計算を行った。計算は現在から 40 億年前まで逆年代順に実施し、複数のケースについて評価した。自転角速度の時間変化は、Touma and Wisdom(1994) のモデルを仮定した。これらの結果を用いて 4 つの制御パラメータの時間変化を評価し、さらに Aubert et al. (2017) による Path 理論を用いて数値シミュレーションで使用できるパラメータも推定した。

本発表で示す結果は、CMB の熱流量が空間的に一様かつ単純な条件下での制御パラメータの標準的な変遷を示すものである。ここで構築した枠組みにより、たとえば CMB の熱流量が複雑に時間変化する場合や、熱伝導率などの物理量を変化させる場合にも対応できる。Olson et al. (2013) でも試みられているように、将来的には基盤となる制御パラメータの時間変化に加え、空間的に不均質な CMB の熱流量等の要素を取り入れた数値ダイナモシミュレーションを実施し、地球磁場の長期的な進化や逆転頻度を支配する物理的要因の解明を目指す。

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R004-P04
ポスター 1：11/25　AM1/AM2（9:15-12:35）

CHAOS-8 地磁気モデルのスペクトル解析による赤道域外核上部成層構造の地域的特徴

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Regionality of the Stratified Layer at the Core Surface in the Equatorial Region Inferred from the CHAOS-8 Geomagnetic Model

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Geophysical observations suggest that the top of the Earth’s outer core is stably stratified. For example, Helffrich and Kaneshima (2010) inferred from seismic analyses that the ~300 km layer immediately beneath the core – mantle boundary (CMB) is stably stratified. However, some studies argue that a globally stable stratified layer may not exist, while others suggest that regional variations could arise from lateral heterogeneity in the lowermost mantle (e.g., Mound et al., 2019). In this study, we investigate the regional characteristics of stratification in the uppermost outer core by analyzing short-period secular variations of the geomagnetic field, using the CHAOS-8 geomagnetic field model (Kloss et al., 2024).

In the CHAOS-8 model, the magnetic potential due to internal sources is expanded in spherical harmonics up to degree 70. Temporal variations of the Gauss coefficients up to degree 20 are represented by sixth-order B-splines over the period 1997.1 – 2025.1 (Kloss et al., 2024). We analyzed the geomagnetic field in the period 2000.0 – 2025.0.

Following Chulliat et al. (2015), we calculated the second time derivatives of the Gauss coefficients from CHAOS-8 and applied a Hann window to the terms up to degree 10. Using these coefficients, we derived the second time derivative of the magnetic field at the CMB, d^2B/dt^2 (the secular acceleration, SA), at 0.1-year intervals. From these data, we constructed time – longitude plots of the radial component of SA along 5° N. We then decomposed the radial SA into equatorially symmetric and antisymmetric components and performed two-dimensional Fourier transforms in time and longitude. We added the results at 0°, 5°, 10°, and 15° N to obtain the frequency – wavenumber spectra. The spectra showed phenomena with periods shorter than 10 years. To investigate the SA and spectra further, we applied Butterworth filters to extract short-period components with periods <5 years and 5 – 10 years and repeated the analysis. This also served to examine the correspondence between the geomagnetic field variation and SA.

Chulliat et al. (2015), using CHAOS-5, reported a standing-wave – like phenomenon in the symmetric component over the Atlantic from 2005 to 2014. Our analysis confirms that this standing wave over the Atlantic persisted until 2020. In addition, we found a standing-wave – like feature over the Pacific from 2012 to the early 2020s. The characteristics of the standing waves differ between the Atlantic and Pacific. In the antisymmetric component, westward-propagating waves similar to those reported by Chulliat et al. (2015) were observed in the Pacific, although their characteristics differ from those in the Atlantic.

These wave-like features may be explained by magnetohydrodynamic waves propagating zonally within a stably stratified layer at the top of the outer core. Bergman (1993) analytically derived the dispersion relation of equatorial magnetic Rossby waves using a two-layer density model representing an equatorial stratified layer. We assumed that the differences in short-term geomagnetic variations between the Atlantic and Pacific are due to differences in stratification thickness and applied Bergman’s dispersion relation to estimate the stratified layer thickness in both regions. The results suggest that the stratified layer in the Atlantic is thinner than that in the Pacific. However, Bergman’s solution was derived for a simplified system and the waves are strongly damped. It remains uncertain whether his dispersion relation can be directly applied to our analysis.

To obtain more realistic estimates of the stratified layer thickness from the observed spatiotemporal spectra, it will be necessary to compute theoretical dispersion relations through numerical modeling of magnetohydrodynamic waves, assuming equatorial stratification.

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019-0381-z

地球物理観測により, 外核最上部が安定成層している可能性が示唆されている。例えば, Helffrich and Kaneshima (2010) は地震学的な解析により, コア-マントル境界（CMB）直下 300 km が安定成層していると推定した。一方で、外核上部の安定成層は全球的には存在しないとする説や, マントル最下部不均質の影響により地域差が存在する可能性についての指摘がある（例えば，Mound et al, 2019)。本研究では, CHAOS-8 地磁気モデル（Kloss et al., 2024）を用いた地磁気の短周期永年変動の解析から, 地球外核上部における成層構造の地域的特徴を明らかにする。

CHAOS-8 モデルでは, 内部起源磁場ポテンシャルが最大次数 70 まで球面調和展開されており，時間変化については, 1997.1 – 2025.1 年の期間において次数 20 以下のガウス係数が 6 次 B スプライン関数を用いて表現されている（Kloss et al., 2024)。本研究では 2000.0 – 2025.0 年を対象として磁場解析を行った。

解析手法は主に Chulliat et al. (2015) に従った。まず, CHAOS-8 からガウス係数の時間二階微分を求め, 最大次数 10 までを対象として Hann window を適用した。次に, この係数を用いて, CMB における磁場の時間二階微分 d^2B/dt^2 (Secular Acceleration : SA) を算出した。計算は対象期間に対し 0.1 年ごとに行った。このデータを用いて, 北緯 5° における SA の動径成分の時間–経度図を作成した。また , SA の動径成分を赤道に対して対称成分と反対称成分に分解し, それぞれに時間と経度に対する二次元フーリエ変換を実施した。さらに北緯 0° , 5° , 10° , 15° における結果を加算し, 周波数–波数スペクトルを求めた。その結果 10 年以下の周期を持つ現象が確認された。これをより詳細に調べるため, Butterworth フィルターを用いて 5 年以下および 5 – 10 年の短周期成分を抽出し, 同様の解析を行った。これは磁場と SA の対応を確認する意味もある。

Chulliat et al. (2015) の CHAOS-5 を用いた解析では, 大西洋域の対称成分に定在波的な現象が 2005 年から 2014 年にかけて見られたことが報告されている。本研究の解析では、前述の大西洋域の定在波が 2020 年まで続いていることに加えて、2012 年から 2020 年代前半まで太平洋域でも定在波的な現象が存在することを確認した。一方で，大西洋と太平洋では，定在波の特徴は異なる。また反対称成分では Chulliat et al. (2015) と同様の西向きに伝播する波が太平洋域でも確認できたが, こちらも対称成分と同様に太平洋域に大西洋域とは異なる挙動が見られた。

これらの波動的な特徴は外核表層に存在する，東西方向に伝搬する磁気流体波で説明できる可能性がある。Bergman (1993) は, 赤道域に存在する安定成層を表現した密度二層モデルを用いて, 赤道磁気ロスビー波の分散関係を解析的に求めた。本研究では, 大西洋域と太平洋域における短期地磁気変化の差が安定成層の厚さの違いによると仮定し, Bergman の分散関係を用いて両領域での安定成層の厚さを推定したところ, 大西洋の方が太平洋に比べて成層が薄い可能性が示唆された。しかし, Bergman の解析解は単純化された系に対して求められたものであり, また波動としては damping が強いため, この分散関係を本解析に直接適用できるかについては議論の余地がある。

本研究で得られた時空間スペクトルを用いて，よりもっともらしい安定成層の厚さを推定するためには，赤道域に安定成層を仮定した磁気流体波の数値モデリングにより，理論的な分散関係を求める必要がある。

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R004-P05
ポスター 1：11/25 AM1/AM2（9:15-12:35）

太宰府市小正府遺跡から出土した瓦を用いた考古地磁気強度研究

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Archeointensity study of roof tiles excavated at the Koshobu Site, Dazaifu City

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Reconstructing the variation of the strength of the geomagnetic field is important both to develop our understanding of the geodynamo and to improve the precision of archeomagnetic dating. To construct a high-resolution variation curve of archeointensity, reliable archeointensity data with accurate age are required. In this study, we conducted archeointensity experiments on roof tile fragments excavated from the remains of old kilns in the Koshobu Site, Dazaifu City, Fukuoka. A roof tile with transcription of kanji characters meaning "7th July 975 CE" was discovered from the kilns, indicating the year of kiln operation, namely, the age of the archeointensity recorded. Five samples were preselected based on surface magnetic susceptibility measurements on the excavated roof tiles without archeologically meaningful transcriptions or surface patterns. The samples were further screened by rock-magnetic analyses and stepwise demagnetization of the natural remanent magnetization (NRM). Two samples with blackish color showed little thermal alternation during thermomagnetic analysis and moderate coercivity distribution upon isothermal remanent magnetization (IRM) acquisition experiments. Curie temperature estimated from the thermomagnetic curve and the results of Three-axis IRM experiments indicate that the magnetic carrier of these samples is dominated by single-domain magnetite with low Ti or Al content. On the other hand, three samples with reddish brown to white color showed less magnetic and thermal stability. Archeointensity experiments by the Tsunakawa-Shaw method was conducted on ten specimens taken from the former two roof tiles. The results from seven specimens passed the standard selection criteria for reliable archeointensity, and the mean value was 63.0 ± 5.0 μT. In addition, IZZI-Thellier archeointensity experiments were carried out on two specimens and gave preliminary values of 60.1 and 60.8 μT. The obtained archeointensity is relatively high compared to the variation of archeointensity of Japan and South Korea reported by recent studies, but generally consistent with the trends in preceding and following periods. Together with the accurate age of the samples, the present study will provide an anchor point of the archeointensity reference curve for East Asia.

R004-P06
ポスター1：11/25　AM1/AM2（9:15-12:35）

ケルゲレン海台玄武岩から推定された白亜紀スーパークロンにおける弱い絶対古地磁気強度：速報

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A preliminary report of weak paleointensity during the Cretaceous Normal Superchron estimated from the Kerguelen plateau basalts

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The absolute paleomagnetic field intensity (paleointensity) during the Cretaceous Normal Superchron (CNS) is a key constraint on the heat flow heterogeneity at the core － mantle boundary at that time. However, no consensus has been reached so far. Studies using plagioclase single crystals extracted from lava have reported strong paleointensity mean and small variations ($12.5 \pm 1.4 \times 10^{22}$ Am^2 ; Tarduno et al., 2001, Science), whereas studies on submarine basaltic glass ($8.1 \pm 4.3 \times 10^{22}$ Am^2 ; Tauxe & Staudigel, 2004, G-Cubed) have reported large paleointensity variations. Furthermore, based on the absolute paleointensity of gabbros and temporal variations in oceanic crustal magnetization, Granot et al. (2007, EPSL) and Granot et al. (2012, Nature Geoscience) have pointed out that the range of paleointensity variation has temporal variation during the CNS. To clarify the variation in absolute paleointensity during the CNS, it is necessary to address issues such as determining absolute paleointensity from numerous lava flows, alteration during paleointensity experiments, and constraining the eruption duration of the lava flows. In this study, we used basalt core samples from the Kerguelen Plateau at Site 1137, located in the southern Indian Ocean to the Southern Ocean, drilled through the Ocean Drilling Program (ODP). We used a lava flow from the shallowest section of Site 1137 (Basement Unit 1). Initial thermomagnetic analyses showed that about half of the samples had Curie temperatures around 500 to 550 ° C and reversible thermomagnetic curves. This result suggests that roughly half of the Basement Unit 1 samples mainly contain Ti-poor titanomagnetite, which is less affected by low-temperature oxidation. Next, we applied the Tsunakawa － Shaw method to two specimens that showed reversible thermomagnetic curves and estimated two paleointensities of 24.0 μ T and 28.7 μ T. The former result showed an ideal behavior with almost no alteration of magnetic minerals before and after the first heating, as indicated by changes in ARM, and is therefore considered a more reliable paleointensity value. The latter result showed slight differences in ARM before and after the first heating. Converting the obtained absolute paleointensity values into virtual axial dipole moments (VADM) based on the reported paleolatitude (43.6 ° S; Antretter et al., 2000, EPSL), we obtained values of 4.0×10^{22} Am^2 and 4.8×10^{22} Am^2 . These correspond to 32 － 38% of the VADM mean values estimated from plagioclase single crystals (Tarduno et al., 2001). Furthermore, because the Kerguelen Plateau and the Rajmahal Traps (Tarduno et al., 2001) are volcanoes that erupted close to each other, the difference is unlikely to be due to local field intensity variations. Therefore, the temporal variations of paleointensity during the CNS were likely large. Such large paleointensity fluctuations suggest that the thermal heterogeneity generating the CNS may have been similar to an increase in heat flux at both poles of the core － mantle boundary (Glatzmaier et al., 1999, Nature) rather than a minimum in heat flux at the core － mantle boundary (Driscoll & Olson, 2011, GRL).

白亜紀スーパークロン中の絶対古地磁気強度は当時の核マントル境界の熱的な条件を制約する鍵であるが、いまだに統一見解が得られていない。溶岩中に含まれる斜長石単結晶を用いた研究では強い平均古地磁気強度と小さい変動（$12.5 \pm 1.4 \times 10^{22}$ Am^2、Tarduno et al., 2001, Science）、海底玄武岩ガラスを用いた研究では大きい変動（$8.1 \pm 4.3 \times 10^{22}$ Am^2、Tauxe & Staudigel, 2004, G-cubed）が報告されている。さらには、斑れい岩の絶対古地磁気強度や海洋地殻磁化の時間変化から、強度の変動幅そのものが白亜紀スーパークロンにおいて時間変化しているという指摘もなされている（Granot et al., 2007, EPSL; Granot et al., 2012, Nature Geoscience）。白亜紀スーパークロン中の絶対古地磁気強度変動を明らかにするためには、多数の溶岩流からの絶対古地磁気強度復元、絶対古地磁気強度実験における変質、溶岩流の噴出期間の制約、などに対処する必要がある。そこで本研究では、国際深海掘削計画（ODP）Leg 183 で掘削されたケルゲレン海台の Site 1137 掘削コア試料を対象とした。本研究では、Site1137 の最も浅い位置の溶岩流（Basement Unit 1）を用いている。最初に熱磁気分析を行ったところ、キュリー温度は 500～550 度かつ可逆的な熱磁気曲線を示すものが半分程度含まれていた。この結果から、Basement Unit 1 サンプルの半数程度に、低温酸化の影響が少ない Ti に乏しいチタノマグネタイトが主に含まれていることが推定された。次に可逆的な熱磁気曲線を示した２つのスペシメンに対し、綱川-ショー法を適用して絶対古地磁気強度推定を行った結果、それぞれ 24.0 microT、28.7 microT という古地磁気強度を復元することができた。前者は、１回目の加熱前後の ARM の対応関係が１：１の直線とほぼ一致している。これは、加熱

で磁性鉱物に変質がほとんど発生しない理想的な挙動を示すため、信頼性の高い強度値だと言える。後者にはある程度の ARM 変化が見られたが、ARM 補正によって前者に近い強度値が得られたことになる。得られた絶対古地磁気強度を、既報の古緯度（43.6° S、Antretter et al., 2000, EPSL）を元に地心双極子モーメント（VADM）に変換すると、4.0×10^{22} Am^2 と 4.8×10^{22} Am^2 となった。これは、斜長石単結晶から推定された VADM 平均値（Tarduno et al., 2001）の 32〜38% である。さらに、本研究のケルゲレン海台と Tarduno et al. (2001) のラジマハールトラップは地理的に近距離で噴出した火山体であるので、ローカルな地磁気強度の差ではないと思われる。そのため、白亜紀スーパークロン中の古地磁気強度の時間変化量は大きいと結論づけられそうである。大きく変動する古地磁気強度は、核マントル境界の熱フラックスの極小 (Driscoll & Olson,2011, GRL) よりも、核マントル境界の両極における熱フラックスの増加 (Glatzmaier et al., 1999, Nature) が白亜紀スーパークロンを発生させる熱的条件に近いことを示唆している。

R004-P07
ポスター1：11/25　AM1/AM2（9:15-12:35）

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Analysis of the location and geomagnetic declination in early 19th century's survey by Tadataka Inoh

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(1Japan cartographer Association

I will be conducting a simultaneous, interdisciplinary analysis of the humanities and sciences to determine the detailed location of each survey point (latitude and longitude 0.1 inches) and the geomagnetic declination of each point on the day of the survey, using the magnetic azimuth and place names recorded in the 67-volume National Treasure "Santou Houiki" (1800-1816), which records magnetic azimuth angles in 0 degree 05 minute increments from the southern coast of Hokkaido to Yakushima, as recorded by the Ino Tadataka surveying team. I will explain Shirasuka in Kosai city, Shizuoka prefecture; Eigashima in Okubo town, Akashi city, Hyogo prefecture; Kochi city; Suetsugu in Matsue city; and the Asamayama magnetic anomaly site in Ise, Mie prefecture, among others. Furthermore, this will bring about a revolution in humanities-based cultural heritage research in Japan, which has avoided analyzing numerical data for the past century.

R004-P08
ポスター 1：11/25　AM1/AM2（9:15-12:35）

日本考古地磁気データベースの更新

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Update of Japan Archaeomagnetic Database

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In this study, we collected newly organized data and archaeomagnetic orientations that have been published since the last update and updated the Japan Archaeomagnetic Database. In Japan, most of the paleomagnetic data from the past 2,000 years has been obtained from archaeological sites (i.e., baked earth). By the 1970s, numerous researchers had contributed to creating a "standard secular variation curve" spanning the past 2,000 years (Hirooka, 1971, 1977). Subsequent archaeomagnetic measurements were conducted to provide chronological dating based on comparisons with the standard curve. In the 2010s, our group compiled and published a Japan Archaeomagnetic Database (Hatakeyama et al., 2013) by cross-referencing data accumulated since the 1980s with chronologies that were not dependent on paleomagnetism. Now we update the database with numerous data from followings. The GEOMAGIA50 database (Brown et al., 2015) is a global paleomagnetic database that contains paleodirection data from 250 Japanese archaeological sites. About 20 of these sites were not included in the Japanese Archaeomagnetic Database, but we added them after confirming their locations, names, and sample numbers. Additionally, we verified the paleomagnetic data from published excavation reports and significantly expanded the data for Tokyo, Shimane, and Okayama Prefecture, among other regions. Furthermore, we added approximately ten sets of data measured and reported since 2015, all of which underwent stepwise alternating demagnetization. As a result, the database now includes approximately 900 sites.

本研究では、新たに整理したデータと前回公開以降に公表された考古地磁気方位を集め、データベースを更新する。日本において、2000 年前から現在までの年代の古地磁気データの多くは考古遺跡（焼土）から得られたものである。1970 年代までに多くの研究者が寄与してその成果として過去 2000 年分の「標準曲線」が作成された（Hirooka, 1971, 1977)。その後も多くの考古地磁気方位測定がされ、上記の標準曲線との対比による年代測定データを提供した。2010 年代に入り、我々のグループが 1980 年代依頼蓄積したデータと古地磁気とは独立な年代を突き合せた日本考古地磁気データベースを作成し、公開した（畠山ほか 2013)。本研究ではこのデータベースに以下のように大幅なアップデートを加えた。1) 現在、全世界の古地磁気データベースである GEOMAGIA50（Brown et al., 2015）には約 250 サイトの日本の遺跡からの古地磁気方位データが記載されている。このうち 20 サイトほどは日本考古地磁気データベースには記載されていなかった。今回、この未記載データについてサイト位置と遺跡名、試料数などを確認して追加した。2) また、発刊済みの発掘調査報告書などから古地磁気データを確認し、東京都、島根県、岡山県などのデータを大幅に追加した。さらに、3) 2015 年以降に測定・報告されているデータを約 10 基（いずれも段階交流消磁を施してある）分追加した。今回の作業の結果、掲載データ数は約 900 サイトになった。

R004-P09
ポスター 1：11/25　AM1/AM2（9:15-12:35）

磁気測定を用いた街路樹の環境汚染の評価手法開発

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Development of an evaluation method for environmental pollution in street trees using magnetic measurements

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As one of the major environmental issues, air pollution caused by automobile traffic poses a serious concern. Particulate matter (PM) generated from vehicle exhaust gases, wear of brake linings and tires, and resuspension of road dust can adversely affect both the natural environment and human health. Therefore, evaluating these pollutants is an important research objective. While environmental pollution is commonly evaluated through chemical analyses, such methods often face limitations—such as the inability to perform chemical measurements on certain samples, or insufficient data acquisition due to the financial and time costs associated with these analyses. In this study, we aimed to develop a simple, low-cost, and rapid method for evaluating environmental pollution by collecting bark from street trees and analyzing their magnetic properties.

Most magnetic minerals in the atmosphere are anthropogenic origin and contained in PM2.5, PM10, and suspended particulate matter[1]. Measuring the magnetic parameters of plants and soils that have accumulated such particles enables pollution assessment. However, most previous studies[2]−[5] have used magnetic susceptibility (χ) and intensity of saturation isothermal remanent magnetization (SIRM) as magnetic parameters, and very few have employed anhysteretic remanent magnetization (ARM), oblique ARM[6] (OARM), and the results of stepwise alternating field demagnetization (AFD) for these remanences. This is mainly because magnetic signals from environmental samples are often weak, making ARM, OARM, and post-demagnetization measurements of these remanences difficult.

In this study, we collected tree bark samples of Acer buergerianum from street trees along roads with different traffic volumes in an urban area of Tokyo, Japan. After grinding and compressing the bark, the samples were packed into 7 cm^3 plastic cases, and the magnetic parameters such as χ, SIRM, ARM, OARM, and AFD of these remanences were measured. Our results demonstrated that bark from street trees can be used to efficiently assess areas where pollutants accumulate, and that various magnetic parameters can be reliably measured. Based on these results, we will compare the magnetic parameters among sampling sites and will discuss the potential of magnetic measurements as a practical tool for environmental pollution assessment.

References

[1] Chaparro et al. 2010, [2] Marié et al. 2020, [3] Préndez et al. 2023, [4] Mejía-Echeverry et al. 2018, [5] Chaparro et al. 2020, [6] Sato et al. 2017

環境問題の一つとして，自動車の交通による環境汚染がある．自動車の排気ガスやブレーキライニングとタイヤの摩耗，道路粉塵の浮遊などによる粒子状物質 (PM) は自然環境や人間の健康に影響を及ぼすため，これらを評価すること は重要な研究課題である．環境汚染の評価は，主として化学分析を用いて行われているが，試料によっては，化学測定が不可能な場合，化学分析に必要な予算的・時間的コストのため十分なデータ量を確保できない場合，などの問題にしばしば直面する．本研究では，街路樹の樹皮を採取し，磁気測定を行うことで，簡易かつ低コスト・迅速な環境汚染評価手法の開発に取り組んだ．

大気中の磁性鉱物の多くは人為起源であり，PM2.5，PM10，浮遊粒子状物質などに含まれている [1]。これらの物質が付着・蓄積した植物や土壌の磁気パラメータを測定することで，環境汚染を評価することができる．また，先行研究の多く [2]−[5] は磁気パラメータとして帯磁率や飽和等温残留磁化の強度を用いており，非履歴性残留磁化や斜交非履歴性残留磁化 [6]，および，それらの段階交流消磁結果を用いた研究例はほとんどない．これは，サンプルの磁気的なシグナルが弱いため非履歴性残留磁化や斜交非履歴性残留磁化，および，それらの段階交流消後の磁化測定が難しいことが主たる理由として挙げられる．

そこで本研究では，新たな環境汚染評価手法の開発を目指して，東京都の都市部において，自動車交通量の異なる道路沿いの街路樹（トウカエデ）の樹皮を採取し，それらの磁気測定を行った．採取した樹皮を粉砕・圧縮後に 7cm^3 のプラスチックケースに詰め，帯磁率，飽和等温残留磁化，非履歴性残留磁化，斜交非履歴性残留磁化，および，それらの段階交流消磁測定を実施した．測定の結果，街路樹の樹皮を用いることで，汚染物質が濃集している部分を効率的に評価することが可能となり，各種磁気パラメータが測定可能であることが確認された．本発表では，これらの結果を元に各地点の磁気パラメータの比較を行い，磁気測定による環境汚染評価の有用性について議論する．