帯磁率異方性による赤色泥中の生物源磁鉄鉱の定向配列推定

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Preferred orientation of biogenic magnetite in pelagic red clay from the anisotropy of magnetic susceptibility

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Biogenic magnetite is widespread in sediment. Being single-domain (SD), the preferred orientation of biogenic magnetite in undeformed sediment is closely related to the primary paleomagnetic remanence. On the other hand, a SD grain exhibits minimum susceptibility along the elongation, resulting in so-called inverse fabric of the anisotropy of magnetic susceptibility (AMS). Moreover, AMS of SD grains can be directly inverted to grain preferred orientation through grain anisotropy, which is well-controlled biologically for biogenic magnetite. Therefore, inverse AMS fabrics in sediment could inform paleomagnetism independent of remanence. Here we report the statistical separation of inverse AMS fabrics from pelagic clay. Overall, the AMS fabrics were controlled by compaction. Rock magnetic data indicated that biogenic magnetite accounts for more than 80 % of bulk susceptibility, but the bulk inverse fabrics were observed in limited number of specimens. This indicates that the biogenic magnetite has significantly weaker foliation compared to terrigenous minerals. This is confirmed by statistical separation of biogenic (inverse) and terrigenous (normal) sub-fabrics of AMS; the corrected anisotropy degree Pj is 1.01 for biogenic magnetite, while it is above 1.08 for terrigenous minerals. This suggests that biogenic magnetite is less affected by compaction than terrigenous minerals. This in turn implies that paleomagnetic inclination of sediment may vary along the proportion of biogenic magnetite such that less biogenic magnetite leads shallower inclination due to compaction. In addition, bulk inverse fabrics revealed subtle preferred declination, which may reflect the past geomagnetic North-South.

生物源磁鉄鉱が堆積物中に広く存在していることが近年改めて注目されている。生物源磁鉄鉱は単磁区粒子とみなせるため、堆積物が変形を被っていない場合、その粒子配列は初生的な古地磁気情報と密接に関係する。一方、単磁区粒子は帯磁率異方性において、長軸方向に最小帯磁率を持ついわゆる inverse fabric を示す。さらに、単磁区粒子の帯磁率異方性は、個々の粒子の異方性を通じ粒子配列と直接的に結びつけることができるが、生物源磁鉄鉱の形状は均質である。したがって、堆積物において inverse fabric を分離することができれば、生物源磁鉄鉱の古地磁気情報までを読み解ける可能性がある。本発表では、特異的に生物源磁鉄鉱が濃集している太平洋赤色泥を対象に、帯磁率異方性の統計的な成分分離から生物源磁鉄鉱の定向配列を推定した例を紹介する。バルクの帯磁率異方性は堆積面に平行な異方性が支配的であり、基本的に圧密による構造を見ている。岩石磁気測定から、帯磁率の 80 %以上を生物源磁鉄鉱が担っていると推定された。にもかかわらず、バルクの inverse fabric を示す試料はごく少数であった。これは生物源磁鉄鉱の帯磁率異方性が陸源粒子よりもかなり小さいことを意味する。実際に、成分分離により推定された異方性パラメータ Pj は、陸源粒子が 1.08 以上であるのに対し、生物源磁鉄鉱は 1.01 程度であった。この結果は、生物源磁鉄鉱が圧密による回転を比較的受けにくいことを示している。これから、堆積物の古地磁気伏角が生物源磁鉄鉱の含有量に影響され、生物源磁鉄鉱の比率が少ないほど圧密の効果で浅くなる可能性が示唆される。さらに、バルクの inverse fabric を示す試料からは、偏角の定向配列も観察された。これは古地磁気方位を示しているかもしれない。

樹木年輪中の微量磁性物質の SQUID 顕微鏡による高感度・高分解能検出

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High-sensitivity and high-resolution detection of magnetic material in tree rings with SQUID microscope

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We conducted continuous magnetic imaging of a thin section of a tree using scanning SQUID microscope. For the purpose of high sensitivity measurements, we improved signal-to-noise ratio and measurements were performed in a clean environments without dust particles. We prepared 1mm thickness sample of a tree trunk of a red pine of 4 cm length from the bark and polished on both sides. Surface magnetic fields were less than about 0.2 nT as natural state. After exposing to a vertical magnetic field of 2T, surface magnetic fields of a few nT were observed as stripes parallel to the annual growth rings. Strong magnetic field corresponds to spring layers with high growth composed of less dense material. Spring layer has reddish brown spots, which might be related to the strong magnetic signals observed.

本研究では、SQUID 磁気顕微鏡を用いて、樹木試料断面の磁気特性の連続測定を行った。高感度分析のために装置の信号対雑音比の向上と埃粒子を排除した清浄環境で測定を行った。分析試料には、伐採した直径 30cm 程度の赤松樹木の樹幹を用い、樹皮表層から約 4cm 厚さ 1mm を切り出して、両面を研磨した。自然状態の表面磁場は平均 0.2nT 程度以下であった。2T の強磁場で試料に鉛直上向きの人口磁場で着磁すると、年輪と平行な約数 nT の表面磁場が確認された。磁場が強い部分は春目部分（成長が速く、密度が低く色が薄い部分）であることがわかった。春目部分には赤茶色の斑点も散見され、磁気信号との関連性が示唆される。

陶邑窯跡群出土土器小片からの考古地磁気強度推定

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Archeointensity estimates from sue-ware ceramic fragments of the Suemura kiln group

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As pointed out in Yamamoto et al. (2015), there has been a long gap in time since the last internationally recognized archeointensity result was published from archeological artifacts in Japan (e.g., Sakai and Hirooka 1986). In contrast, new results with modern paleointensity techniques have been published from East Asia outside Japan: for example, Korea (Yu et al. 2010; Hong et al. 2013) and China (Cai et al. 2014)). A research group in Japan is now conducting a series of researches to obtain new archeointensity results from the artifacts in Japan. One of such researches is that by Kitahara et al. (2019JpGU): they reported new archeointensity results from baked-clay samples taken from a number of kiln floors in the Suemura kiln group, Sakai City, Osaka, Japan. They applied the Tsunakawa-Shaw method to the samples to obtain archeointensities, and showed that an archeointensity was relatively low (about 40 microT) at around the 6th century while that was almost equivalent to the present-day intensity (about 50 microT) at the 5th and the 8th centuries. This intensity trend is inconsistent with the published archeointensities in previous studies in Japan (Nagata et al., 1963; Sasajima and Maenaka, 1966; Sakai and Hirooka, 1986), but is not contradicted from the recently published archeointensities in Korea (Hong et al. 2013).

It is demonstrated that reliable archeointensities can be estimated from sue ware fired in simulated ancient climbing kilns by an application of the Tsunakawa-Shaw method (Yamamoto et al., 2017JpGU, 2017SGEPSS). By a courtesy of the Osaka Prefectural Board of Education, we have obtained sue-ware ceramic fragments of the 5-7th century kilns of the Suemura kiln group, which are counter-parts of the baked-clay samples used in the study of Kitahara et al. (2019JpGU). Each of 4-5 fragments were provided from the different eight kilns (TG22, MT84, TK317, TG51, TG35, TG41-III, MT206, and TG40-III in ascending chronological order). Mini-specimens were cut from the fragments and 65 specimens of them were subjected to archeointensity experiments by the Tsunakawa-Shaw method. In the experiments, the specimens were heated in either air or vacuum for acquisition of laboratory thermoremanent magnetizations. Fifty-two successful results were obtained by application of conventional selection criteria. Except the two kilns TG22 and MT206, an archeointensity could be determined for an each kiln with a relatively low dispersion after discarding a few outlier results: 55.2 +/- 4.9 microT (MT84); 51.2 +/- 6.0 microT (TK317); 43.7 +/- 3.3 microT (TG51); 43.4 +/- 3.7 microT (TG35); 51.5 +/- 3.6 microT(TG41-III); 47.6 +/- 2.1 microT (TG40-III). An intensity trend revealed from these archeointensities generally agrees well with the trend emerged from the results obtained from the baked-clay samples reported in Kitahara et al. (2019JpGU).

支笏カルデラ噴火堆積物の古地磁気学的測定：古地磁気永年変化にもとづく堆積物の時間スケールの推定

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Paleomagnetic study on the Shikotsu pyroclastic deposits: Implications for the timescale of the pyroclastic deposits

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We reported paleomagnetic results of the pyroclastic deposits of the ca. 46 ka Shikotsu caldera-forming eruption. Geological observation on the pyroclastic deposits indicated that these volcanic deposits were classified into several units in the previous study. In order to estimate possible temporal gaps between these units, we conducted paleomagnetic measurements of the pyroclastic flow deposits. Non-welded pyroclastic flow deposits were collected using an improved sampling procedure; a cube guide was firstly fixed to the outcrop, and subsequently a cube was put into the outcrop trough the cube guide, and then the orientation of the cube was precisely measured on the front plane of the cube guide. Paleodirections determined from six sites on five units show a continuous movement of more than 15 degree in the equal area projection, which is thought to be the paleomagnetic secular variation curve of the period of a few to several hundred years occurred at ca. 46 ka. The paleomagnetic secular variation curve determined in this study contributes to estimating the timescale of the process of the Shikotsu caldera-forming eruption.

別府湾のピストンコア試料に記録された完新世古地磁気永年変化

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Holocene paleomagnetic secular variation recorded in piston-core samples from Beppu Bay, Southwest Japan

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An increasing number of studies have been made on paleomagnetic secular variation (PSV) in recent years, utilizing archaeological materials, volcanic rocks, and marine or lacustrine sediments. The Holocene PSV data from Lake Biwa (Ali et al., 1999) is regarded as a representative record of Japan or East Asia. It is expected, however, to further improve the data distribution and quality in Japan, following recent advances in stratigraphy and geochronology of the Holocene sediments. We investigated sedimentary magnetism of core samples from Beppu Bay, a tectonic basin, where thick Quaternary deposits have been derived mainly from active volcanic fields on Kyushu Island. Previous studies utilizing multiple piston-core samples from northwestern part (Ohno et al., 1991) showed that the Beppu Bay sediments are characterized by stable remanent magnetizations suitable for reconstruction of the Holocene PSV. Then we made pass-through measurements of natural remanent magnetizations of u-channel samples from piston-cores recovered in 2009 and 2015 from the deeper southwestern part, where a new age-depth model was developed through detailed sedimentologial analysis and AMS radiocarbon dating (Kuwae et al., 2013; Yamada et al., 2016). These core sediments are composed of hemipelagic clay intercalating several event layers of turbidites and tephra deposits. Although our declination data was partly discontinued at section boundaries, variation of the relative declination is generally consistent with the data from the northern site (Ohno et al., 1991) and with the PSV records from Lake Biwa (Ali et al., 1999), particularly for the last 3,000 years. Long-term trends of the inclination variations are also consistent with the Lake Biwa record; however, anomalous inclination changes were observed at horizons of the event layers, even after deconvolution of the pass-through data by UDECON (Xuan and Oda, 2015). Except these intervals, the paleomagnetic data from Beppu Bay is expected to play a key role in synthesizing PSV records in Southwest Japan.

Forecasts of geomagnetic secular variation using core surface flow models

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The International Geomagnetic Reference Field (IGRF) is a standard mathematical description in terms of spherical harmonic coefficients, known as the Gauss coefficients, for the Earth's main magnetic field and its secular variation. We submit a candidate model to the next IGRF revision, the 13th generation of IGRF for Secular Variation from 2020 to 2025 (IGRF-13SV), relying on our strong points, such as geodynamo numerical simulation, data assimilation, and core surface flow modeling.

Fluid motion near the core surface can be estimated from distribution of geomagnetic field at the core-mantle boundary (CMB) and its temporal variation. Any constraint on the core flow, such as tangentially geostrophic flow or tangentially magnetostrophic flow, is often imposed on the core flow modeling. It should be noted, however, that core flow models used for data assimilation are to be obtained on a condition appropriate for numerical geodynamo simulations, in which the Ekman number, for example, would be much larger than that for the Earth. Therefore, we adjust typical time-scale of a geodynamo model (Takahashi 2012, 2014) to that of real geomagnetic secular variation as given by Christensen and Tilgner (2004).

In the present study, we investigate behaviors of secular variation of geomagnetic field for some core surface flow models. We use fluid velocity (and fluid acceleration) to forecast geomagnetic secular variations through numerical simulations based on a kinematic dynamo only near the CMB.

異なる内核半径における地球ダイナモに対する温度勾配に関する境界条件の効果について

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Effect of boundary condition of temperature gradient on geodynamo with various inner core size

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The Earth has sustained its intrinsic magnetic field for at least 3.5 billion years as revealed by paleomagnetic studies [e.g., Biggin et al., 2015]. The geomagnetic field has been sustained by dynamo action due to convection of liquid iron alloy in the outer core. Studies of the thermochemical evolution of the Earth's core suggest that the solid inner core has been growing up for approximately one billion years [e.g., O'Rourke and Stevenson, 2016]. Consequently, Heat flow in the core has also been changing for the Earth's history [e.g., Driscoll and Bercovici, 2014]. Driving force of dynamo is buoyancy force by temperature gradient larger than adiabatic reduction effect. Hence it is important to investigate dynamo condition on heat flux with various inner core size to understand environment of the past Earth. There are some numerical dynamo simulations focusing on the various inner core size. Heimpel et al. (2005) evaluated dynamo onset conditions with different inner core size for fixed temperature boundary. Hori et al. (2010) found that sustained magnetic field is likely to be more dipolar on the fixed heat flux condition than on the fixed temperature condition with two different inner core size cases. For considering a thermal evolution model, sustained magnetic field is dipolar for recent 0.6 billion years [Driscoll, 2016]. Lhuillier et al. (2019) points out that sustained magnetic field is less dipolar when the ratio of the inner to outer core radii r_i/r_o is 0.2 to 0.22. However, it is still unclear that the mechanisms of controlling factors of dipolar or non-dipolar regime are related with different inner core size.

In the present study, we investigate the effects of the thermal boundary conditions on numerical dynamos with various inner core size. First, we perform dynamo simulations with various inner core radii on temperature fixed at the inner core boundary (ICB) and at the core-mantle boundary (CMB) using a numerical dynamo code Calypso [Matsui et al., 2014]. We investigate the characteristics of the generated magnetic field following Heimpel et al. (2005) and survey the wide range of parameter. We fix the Ekman, Prandtl, and magnetic Prandtl numbers to be $E = 10^{-3}$, $Pr = 1$, and $Pm = 5$, respectively, and change the Rayleigh number (Ra) and the ratio of inner to outer core radii to be r_i/r_o = 0.15, 0.25, and 0.35. Examining the dominancy of the dipole component, we found non-dipolar components become larger for the smaller inner core. Second, we perform simulations with fixed heat flux boundary, incoming flux at the ICB and outgoing flux at the CMB. The Ekman, Prandtl, and magnetic Prandtl numbers are set the same as the fixed temperature boundary condition. In order to compare results between fixed temperature and fixed heat flux boundary conditions, we calculate the temperature gradient in fixed temperature cases and set the same gradient in fixed heat flux simulations. Here the Rayleigh number at the onset of thermal convection is called the critical Rayleigh number (Ra_{crit}). Especially in r_i/r_o = 0.25, the ratio of temperature gradient at ICB and CMB is 4.18/0.268 at Ra/Ra_{crit} = 1.11 and 4.06/0.255 at Ra/Ra_{crit} = 1.04. At closer Ra to Ra_{crit}, the ratio becomes 4/0.25. This is inverse of area ratio of ICB and CMB, so in this setting heat flow is balanced in the outer core. Ra_{fcrit} with heat flux is $1.1*10^4$. To investigate effects of the thermal boundary condition on numerical dynamos, we need to carry out further numerical simulations with balanced heat flow in the outer core so as to occur convection with the same temperature difference as the fixed temperature condition as possible. We will also discuss simulation results with in r_i/r_o = 0.15 and 0.35.

地球は少なくとも 35 億年間、固有磁場を維持してきたことが古地磁気研究から明らかとなっている [e.g., Biggin et al., 2015]。地球磁場は外核中の流体鉄の対流によるダイナモ作用によって維持されている。固体の内核は約 10 億年かけて成長してきたと熱化学進化研究から考えられている [e.g., O'Rourke and Stevenson, 2016]。同時にコアの熱流量についても地球の歴史から見ると変化してきた [e.g., Driscoll and Bercovici, 2014]。ダイナモの駆動力は断熱減率効果より大きな温度勾配から生じる浮力である。ゆえに過去の地球環境を理解するために異なる内核サイズにおける熱フラックスに対するダイナモ条件を調査することは重要である。内核サイズに着目した数値ダイナモ研究はこれまでにいくつか報告されている。Heimpel et al. (2005) は温度固定境界において複数の異なる内核サイズに対するダイナモ onset 条件を評価した。Hori et al. (2010) はふたつの異なる内核サイズについて、温度固定より熱フラックス固定を与えた場合の方が維持される磁場が dipole 卓越型になりやすいことを明らかにした。熱進化モデルを考慮すると最近 6 億年は維持される磁場が dipole 卓越型になるという研究がある [Driscoll, 2016]。Lhuillier et al. (2019) は外核内核半径比が r_i/r_o = 0.2 - 0.22 において維持される磁場は less dipole 型になると指摘している。しかしながら、維持される磁場が dipole 型になるか non-dipole 型になるかを決定するメカニズムが内核サイズとどう関係しているかはまだ十分理解されていない。

本研究では、異なる内核サイズにおいて数値ダイナモにおける熱的境界条件の効果について調査した。数値ダイナモコード Calypso[Matsui et al., 2014] を使用して、異なる内核半径の場合にまずは内核境界 (ICB) とコア-マントル境界 (CMB) で温度固定とする条件を与えてダイナモ計算を実施した。Heimpel et al. (2005) に従って、維持される磁場の構造を広い

パラメータ範囲で検討した。エクマン数E、プラントル数Pr、磁気プラントル数Pmをそれぞれ$E = 10^{-3}$, $Pr = 1$, $Pm = 5$と固定し、半径比を $r_i/r_o = 0.15, 0.25, 0.35$ と 3 通り変化させた場合にそれぞれレイリー数Raを変化させた。双極子成分の卓越性の解析から、内核が小さい場合には非双極子成分が大きくなることが明らかとなった。次に、ICB から熱が入ってきて CMB で熱が逃げていく向きに熱フラックスを固定したシミュレーションを行った。エクマン数、プラントル数、磁気プラントル数はそれぞれ温度固定境界での計算と同じ数値を設定した。温度固定と熱フラックス固定でのシミュレーション結果を比較するため、温度固定での計算で温度勾配を計算してその勾配を用いて熱フラックス計算を実施した。ここで熱対流の onset を表すレイリー数を臨界レイリー数 Ra_{crit} と言う。半径比 $r_i/r_o = 0.25$ の場合、$Ra/Ra_{crit} = 1.11$ の例では ICB と CMB での温度勾配の比は 4.18 : 0.268, $Ra/Ra_{crit} = 1.041$ の例では 4.06 : 0.255 であった。Raが Ra_{crit} に近づくに連れて勾配の比が 4:0.25 に近づくことが確認された。この比は ICB と CMB の面積比の逆比であるから、この設定では外核中の熱流量はバランスする。熱フラックスにおける臨界レイリー数を算出すると $Ra_{fcrit} = 1.1*10^4$ となった。数値ダイナモにおける熱的境界条件の効果を調査するため、外核中の熱流量がバランスするような数値シミュレーションをより多く行い、できる限り温度固定の計算と同じ温度差が実現される対流を起こすようにする。また半径比が $r_i/r_o = 0.15, 0.35$ の場合のシミュレーション結果も議論していく。

地磁気の逆転と気候変化、人類の進化・拡散に関する磁気・気候層序年代制約

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Geomagnetic reversal and climate change, and magneto-climatostratigraphy constraining the age of human evolution and dispersion

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http://www.planet.sci.kobe-u.ac.jp/geol/hyodo.html

Quaternary marine sediments have been influenced by orbital-scale paleoceanic environment variations. Marine oxygen isotope data from benthic foraminifera fossils reflect ice volume (sea level) changes, so that they enable to correlate marine sequences stratigraphically on a global scale. In addition, the synchronous global climate and paleoceanic changes extend application of the stratigraphic correlation tool to terrestrial deposits, such as lake sediments and loess sequences. These sediments sequences can have millennial-resolution chronology by orbital tuning based on the Milankovitch theory. Further, suborbital-scale climate variations yield higher-resolution climatostratigraphic correlation tools. Sediments containing ferrimagnets record geomagnetic field changes as depositional remanent magnetizations, and thus millennial-to-submillennial scale geomagnetic features can be examined. Recently reported high-resolution climatostratigraphy data enable to investigate even centennial scale geomagnetic changes. Furthermore, hybrid magnetic-polarity stratigraphy combined with climatostratigraphy increases the reliability of stratigraphic correlation. In this talk, we show 1) millennial-to-centennial scale features of geomagnetic reversal transition fields, 2) the influence of a geomagnetic reversal on the Earth's climate through galactic cosmic rays, and 3) magneto-climatostratigraphy constraining the early hominid evolution and dispersion.

第四紀の海成堆積物は軌道 (orbital) スケールの古海洋変動を記録している。海洋酸素同位体比の変動は主に氷体量（海水準）を反映しており、その特徴を使った層序対比は地球規模で行うことができる。古海洋変動は気候変動と同期しているため、同層序対比は湖沼堆積物やレス層など気候変化の影響を受けた陸成層にまで拡張できる。これらの堆積物シーケンスには、ミランコビッチ理論に基づく軌道調整により千年の解像度の年代軸が入れられる。また、軌道下 (suborbital) スケールの気候イベントはより高解像度の気候層序対比を可能にする。これらの堆積物のほとんどは強磁性粒子を含み、堆積残留磁化として地磁気変動も記録している。したがって、高解像度気候層序と組み合わせることで、100 年スケールの地磁気逆転磁場変動の解析や、地磁気と気候の関連性についての議論が可能となる。さらに、地磁気と気候の変動を組み合わせたハイブリッド型磁気・気候層序はより信頼度の高い年代法を提供する。ここでは本発表者が関わってきた、1) 百年－千年スケールの地磁気逆転磁場変動、2) 銀河宇宙線を介した地磁気逆転の気候への影響、3) 磁気・気候層序法を用いた初期人類の進化・拡散、の研究について紹介する。

西南日本，一志層群下部の古地磁気

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Paleomagnetism of the lower part of the Ichishi Group in Southwest Japan

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https://researchmap.jp/read0052454

The Ichishi Group is an early Miocene marine sedimentary succession in central Japan and will provide geological and paleomagnetic records of crustal movement during the formation of the Japan Sea (back arc basin)-Japan arc (island arc) system. We performed a paleomagnetic study of the Ichishi Group to determine the age of the sedimentary succession by means of magnetostratigraphy, and to quantify tectonic rotation during and/or after deposition. Because we have already reported data from the upper part of the group in a previous meeting, in this presentation we will present new data from the lower part (Haze and Oi formations). We concentrated our paleomagnetic sampling on fine grained sediments (Iu Member) of the Haze Formation and those (Isegi Member) of the Oi Formation. After detailed demagnetization experiments, paleomagnetic polarity was determined for 17 sites. The reverse to normal polarity sequence for the studied section can be correlated with Chron C5Er-C5En on the geomagnetic polarity time scale, with the help of age-diagnostic microfossils. This correlation indicates that the age of the marine transgression resulting in the deposition of the Iu Member is ca. 18.7 Ma. Site mean directions of characteristic remanent magnetizations obtained for 15 sites were used to show the paleodirectional change with time, which will be discussed in the presentation.

Magnetic anomaly caused by lightning stroke in the grounds of a shrine

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It was reported that intense electrical current on the surface of the ground generated by lightning stroke causes magnetic anomaly extended from the building hit by lightning. If the current intensity can be estimated based on the measurement of the residual field, it is useful to know the characteristics of the lightning that damaged the building or structures, and to calibrate the current intensity estimated by lightning detection network using radio waves. Moreover, some of the shrine has tradition of lightning hit. If we can detect the evidence of lightning hit, palaeomagnetics could contribute to archaeology.

We made a magnetic field survey in the grounds of Yamanomiya, Asama-jinja Shrine in Yamanashi prefecture, where we found a couple of tall Japanese cedars called Meoto-sugi behind the main building. We subtracted magnetic field at Kakioka from observed total intensity and made a magnetic anomaly map for the area of 28 m x 28 m at a resolution of 4 m. It is found that there was a gradient of the residual field intensity perpendicular to the radius vector from the cedars. This gradient is extended linearly for about 20 m. Though we need to investigate the broader area, this preliminary result implies the possibility of this methodology in order to examine the evidence of past lightning strokes recorded in shrines or forest area.

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赤褐色黒曜石中の巨大な保磁力をもつ luogufengite (ε -Fe2O3)

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Giant coercivity of luogufengite (epsilon-Fe2O3) found in reddish brown obsidians

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Luogufengite (epsilon-Fe_2O_3), a new mineral approved in 2016, is a polymorph of hematite (alpha-Fe_2O_3) and maghemite (gamma-Fe_2O_3). Synthetic epsilon-Fe_2O_3 has been sintered at intermediate temperature required for maghemite and hematite, and the magnetic property was marked by the unusually high coercivity around 2 T. Some pottery sherds contain epsilon-Fe_2O_3. This time we found and characterized luogufengite from reddish brown obsidians in Shirataki, Hokkaido and in Davis Creek, California.

A hallmark of luogufengite is the Curie temperature of 220 degC, which is undoubtedly distinguished from those of coexisting magnetite and hematite. Cycling of thermomagnetic measurements exhibited gradual increase of magnetization after cooling down to room temperature until the maximum temperature reached 230 degC. In some samples this magnetization enhancement induced by heating is exceptionally enormous by several orders of magnitude. Hysteresis measurement by using MPMS proved the extremely high coercivity nearly 1 T at room temperature. Cooling down to 10 K, coercivity showed a broad peak around 200 K and decreased rapidly below 50 K. Low temperature cycling, where 5 T IRM imparted at room temperature was cooled down to 5 K, exhibited a faint kink around 50 K, and little gain or loss of magnetization was observed after warming back to room temperature. This low temperature behavior may be another key for identifying luogufengite. When coexisting with magnetite, 100 K transition of maghemite was detected instead of the Verwey transition at 120 K.

Thermal demagnetization of natural remanent magnetization of the reddish brown obsidians showed two distinct spectrum of unblocking temperature carried by luogufengite and magnetite, but the magnetization directions were indistinguishable and no viscous magnetization was observed. This behavior indicates that luogufengite is capable of carrying a stable remanent magnetization. Although the unblocking temperature of luogufengite is mostly distributed below 200 degC due to the low Curie temperature, the giant coercivity ensures the stability of the remanence over a geological time scale without disturbed by viscous magnetization.

Luogufengite is a new magnetic mineral capable of carrying paleomagnetic signals. Although luogufengite was previously identified after dissolving scoria by a NaOH solution and separating it by a hand magnet, the reddish brown obsidians can supply bulk samples containing luogufengite without any processing. Along with the unique magnetic properties of low Curie temperature and giant coercivity of luogufengite, the bulk samples provided opportunities to show stable remanent magnetization carried by luogufengite. Not restricted to reddish pottery sherds, luogufengite can be a stable remanence carrier in rocks formed in oxidized condition.

2016 年に承認された新鉱物である luogufengite (ε -Fe_2O_3) は，ヘマタイト (α -Fe_2O_3) とマグヘマイト (γ -Fe_2O_3) の多形です．合成された ε -Fe_2O_3 はマグヘマイトとヘマタイトの中間の温度で焼結されており，磁気特性は 2 T 付近の異常に高い保磁力を特徴としています．また，いくつかの陶器は ε -Fe_2O_3 を含んでいます．今回，北海道の白滝とカリフォルニアの Davis Creek で赤褐色の黒曜石から luogufengite を発見し，様々な磁気測定を行いました．

luogufengite の特徴は 220 ℃ のキュリー温度であり，それは共存するマグネタイトとヘマタイトと間違いなく区別されます．熱磁気測定のサイクルは，最高温度が 230 ℃ に達するまで室温まで冷却した後に磁化の増加を示しました．いくつかのサンプルでは，加熱によって引き起こされるこの磁化の増加は数桁に達するほど大きなものでした． MPMS を用いたヒステリシス測定により，室温で 1 T 近くの極めて高い保磁力が明らかになりました．10 K まで冷却すると，保磁力は 200 K 付近で緩やかなピークを示し，50 K 以下で急速に減少しました．室温での 5 T IRM の低温サイクルは，50 K 付近でかすかなキンクを示し，室温に戻した後に磁化はほとんど増加も減少も示しませんでした．この低温での挙動は，luogufengite を同定するための別の鍵となる可能性があります．マグネタイトと共存する場合には，120 K での Verwey 転移の代わりに 100 K 転移が検出されました．

赤褐色黒曜石の自然残留磁化の熱消磁は，luogufengite とマグネタイトによって担われた 2 つの明瞭に分かれたアンブロッキング温度スペクトルを示し，磁化方向は互いに識別不可能で粘性磁化は観察されませんでした．この挙動は，luogufengite が安定した残留磁化を担うことができることを示しています． luogufengite のアンブロッキング温度は低いキュリー温度のために大部分 200 ℃ 以下に分布していますが，巨大な保磁力は粘性磁化によって乱されることなく地質学的時間スケールにわたって残留磁化を安定に保持できることを可能にしています．

luogufengite は古地磁気の情報を担うことができる新しい磁性鉱物です．これまではスコリアを NaOH 溶液で溶解し磁気分離した後に同定されていましたが，赤褐色黒曜石は何の処理もせずに luogufengite を含有するバルク試料を供給できます．低いキュリー温度と巨大な保磁力という luogufengite のユニークな磁気特性により，バルク試料は luogufengite によって担われた安定な残留磁化を示す機会を提供しました．赤みを帯びた陶器の破片に限定されず，luogufengite は酸化状態で形成された岩石中の安定した残留磁化のキャリアである可能性をもっています．

丹沢複合深成岩体の道志ハンレイ岩中から分離した斜長石粒子の岩石磁気研究

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Rock-magnetic study on single plagioclase grains separated from the Doshi gabbro in the Tanzawa plutonic complex

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Data of the long-term variation of the geomagnetic field is essential for understanding the thermal evolution of the Earth. Plutonic rocks can be recording the time-averaged information of the geomagnetic field over their long cooling time, and therefore have potential for studying the long-term trend of the geomagnetic field evolution. So far, there have been a limited number of published paleointensity studies from plutonic rocks mainly because their main magnetic carriers are usually coarse-grained magnetic minerals. Such difficulty is considered to be avoided if silicate grains containing file-grained magnetic minerals are extracted from host plutonic rocks: recently, successful paleointensity data have been reported from silicate minerals such as feldspar, quartz, and zircon (e.g. Kato et al., 2018; Usui and Tian, 2017; Fu et al., 2017; Tarduno et al., 2007; 2010; 2014).

In this study, we performed a series of rock-magnetic measurements on single plagioclase grains separated from the Doshi gabbro, which has a potential to record the time-averaged paleointensity at about 5 million years ago. The Doshi gabbro unit is a part of the Tanzawa plutonic complex in the central Japan. Emplacement history and cooling history of the complex are well discussed in Tani et al. (2010) based on radiometric dating for an each plutonic body of the complex. The core and block samples were collected at central part of the Doshi gabbro unit.

We prepared 100 plagioclase grains of about 500 micrometer in diameter from a sample taken from the Doshi gabbro. We recognized tiny opaque minerals in the plagioclase grains by an optical microscope: the minerals are thought to be exsolved-magnetite phase. First, natural remanent magnetization (NRM) was measured on all the 100 grains, and NRM intensities except one grain was higher than $4*10^{-12}$ Am^2, and their average was $1.67*10^{-10}$ Am^2. We selected four grains and further conducted stepwise alternating field demagnetization experiments for NRM, anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM). We could isolate characteristic components from high-coercivity intervals of NRMs in all the grains. The median destructive fields resulted in 55-75 mT, 50-60 mT, and 30-40 mT for NRM, ARM, and IRM, respectively.

About 10 plagioclase grains were aggregated for a low-temperature magnetometry. Temperature-variations of the zero-field cooling (ZFC) and the field cooling (FC) remanences exhibit clear decreases at 120 K with minor changes at ˜100 K. This implies that the magnetic carriers of the plagioclase grains are mainly Ti-poor titanomagnetite though some minor amounts of Ti-rich titanomagnetite are also contained. The FC remanence always outweighed the ZFC remanence for all temperature range.

In addition, anisotropies of ARMs were measured on selected 11 plagioclase grains. The obtained anisotropy parameters imply that the effect of anisotropy on paleointensity estimate would be similar to, or slightly smaller than that of plagioclase grains in the Iritono granite reported by Kato et al. (2018). According to Kato et al. (2018), results of about ten grains should be averaged to cancel out the anisotropy bias on paleointensity estimate.

Overall results suggest that the magnetization of the plagioclase minerals in the Doshi gabbro are mainly carried by an amount of single domain Ti-poor titanomagnetite, and could be suitable for paleointensity experiments. In addition to the rock-magnetic measurement, we are planning to conduct paleomagnetic and paleointensity experiments on the gabbro samples and its plagioclase crystals.

Preliminary estimations of the exsolved magnetite content in crustal rock and its contribution to the crustal magnetization

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Natural plagioclase crystals sometimes contain fine-grained magnetite inclusions, which are considered to be originated from exsolution at subsolidus condition. The exsolution process can crystalize and hold nearly pure fine-grained magnetite in deep crustal rocks, and natural remanent magnetizations (NRM) carried by the magnetite bearing plagioclase should play an important role in the source of magnetic anomaly. Therefore, to elucidate crystallization mechanism of magnetite in plagioclase crystal and to understand origin of its NRM is of prime importance in paleomagnetism and rock-magnetism, while the mechanism has been poorly understood yet. In this study, to precisely determine the chemical species of Fe in the plagioclase crystals and to better understand the crystallization mechanism of magnetite, magnetic measurements combined with microscopic observation and synchrotron radiation study were conducted for single grain plagioclase crystals. The plagioclase crystals were prepared from natural mafic-plutonic rocks. The plagioclase crystals were collected under a stereoscopic microscope and used for the measurements after a hydrochloric acid leaching. The main series of measurements for the single grain plagioclase crystals were as follows: (1) To estimate a content of magnetic mineral in the plagioclase crystals, magnetic hysteresis loop was measured using an Alternating Gradient Magnetometer. (2) To investigate the average valence state of Fe, L_{III}-edge X-ray absorption near edge structure (XANES) measurement was performed at synchrotron radiation facilities. (3) To investigate chemical compositions of the plagioclase crystals, microscopic observation was conducted using electron microprobes. The plagioclase crystals used in this study showed the Fe valence state of 2.5–2.9, and it was confirmed that there was inverse relationship between the magnetite content and average valence states of Fe. Combining the empirically obtained relationship with calculations of the plagioclase crystallization from the melt and the Fe partitioning between plagioclase and melts, we will discuss the content of the exsolved magnetite in crustal rock and its contribution to the crustal magnetization.

磁性細菌 Magnetospirillum magnetotacticum MS-1 の磁気測定のための培養条件の検討

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Examination of culturing conditions of magnetotactic bacteria Magnetospirillum magnetotacticum MS-1 for magnetic measurements

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Variation of the past geomagnetic field is recorded in marine sediments as a fossil magnetization, called natural remanent magnetization (NRM). NRM is carried not only by detrital magnetic grains but also by biogenic magnetic grains originated from magnetotactic bacteria. To investigate characters of NRM carried by biogenic magnetic grains we have cultured the magnetotactic bacteria Magnetospirillum magnetotacticum MS-1 (here under, MS-1) in laboratory and made sample using them for remanent magnetization measurements by simulating a very early process of sediment formation.

Preliminary reports on properties and characters of the remanent magnetization carried by the samples have been presented in Masaoka et al. (2018JpGU; 2018SGEPSS), but MS-1 cells used for the samples rarely contain magnetite grains: magnetite-containing rate was about 3 percent of the total cells. To try to increase the rate, Masaoka et al. (2019JpGU) have tested a density separation method using different density gradient centrifugation and have succeeded to increase the rate to be about 16 percent. It is preferable to further increase the rate, and thus we culture MS-1 under different conditions and make samples for magnetic measurements. We will report results of the magnetic measurements on these samples.

海底堆積物には自然残留磁化 (NRM) として，過去の地磁気変動がほぼ連続的に記録されている．この NRM を担う磁性鉱物は磁性細菌にも起源をもち，その量的な重要性が指摘されている (e.g. Yamazaki, 2012)．しかし，磁性細菌起源の磁性鉱物が堆積物形成時に当時の地球磁場を反映した残留磁化を獲得する過程，および，その残留磁化の性質については未解明の部分が多い．政岡ほか (2018JpGU; 2018SGEPSS) では磁性細菌 *Magnetospirillum magnetotacticum* MS-1(以下 MS-1) の分譲を受けて大量培養し，MS-1 の細胞群が堆積物形成のごく初期に当時の地球磁場を反映した残留磁化を獲得する過程の模擬実験を行って試料を作製し，その岩石磁気的性質を検討した．細胞数を一定（1 試料 $2.835*10^9$ cell/7 cc）とした一連の試料の NRM 方位は作製時の印加磁場の方向と一致（偏角 0 度・伏角 0 度および偏角 0 度・伏角 45 度）し，NRM 強度は伏角によらず外部磁場強度（0-100 μ T）の増加に伴ってランジュバン関数的に増加することを報告している．しかし，これらの実験に用いた MS-1 の細胞群は，細胞内にマグネタイトを形成している個体の割合が 3%程度と少なく，模擬実験に影響を与えている可能性がある．そのため，政岡ほか (2019JpGU) では密度分離によるマグネタイト形成個体の選択的分離を行い，その形成個体割合を 16%程度まで高めたが，さらに割合を高めることができるのが望ましい．

そこで，本研究では新たに MS-1 の培養方法について検討した．培養液の組成については分譲元の理化学研究所微生物材料開発室 (JCM) による標準 (JCM669) に従うが，(A) 培養液の酸化還元電位を低下させる還元剤を入れるタイミングを高圧蒸気滅菌 (121 度, 20 分) の前か後とし，(B) 培養容器内の気相の酸素濃度を 0.5, 1.0, 2.0 vol%と変化させ，(C) 培養液の量は 1000, 500, 200 ml のいずれかとした．培養容器を密閉する前に窒素ガスによる置換を行うため，気相の酸素濃度は置換後に空気を加えることで調整した．(A)〜(C) の条件の組み合わせで作製した 4 種類の培養液 [1] (A) 前, (B)0.5 vol%, (C)1000 ml； [2] (A) 後, (B)0.5 vol%, (C)1000 ml； [3] (A) 後, (B)2.0 vol%, (C)500 ml； [4] (A) 後, (B)1.0 vol%, (C)200 ml を用いて，MS-1 を 5 日間培養した．培養後の MS-1 の細胞群は遠心分離で回収し，蛍光顕微鏡で細胞数を計数した後，1 試料あたり MS-1 の細胞を $2.87\text{-}2.98*10^9$ cell 含む磁気測定用試料を作製した．試料作製の手順は政岡ほか (2018JpGU) と同様で，外部磁場の方向が偏角 0 度・伏角 0 度，強度が 50 μ T となるように作用させた．各試料が獲得した残留磁化の強度は [1] $0.994*10^{-9}$ Am^2，[2] $1.050*10^{-9}$ Am^2，[3] $0.741*10^{-9}$ Am^2，[4] $0.915*10^{-9}$ Am^2 であった．MS-1 の細胞群を含まないブランク試料も作製しており，その残留磁化の強度は $0.896\text{-}1.130*10^{-9}$ Am^2 であったため，[1]〜[4] の各試料の獲得残留磁化強度と有意な差は認められない．いずれの試料も，マグネタイト形成個体をほとんど含んでいないと思われる．今後，同条件で期間をさらに長くして培養を行うことや，新たな別の培養方法などの検討も行い，それぞれ細胞を回収して磁気測定用試料を作製し，これらの試料に対する磁気分析も行う予定である．

古第三系神戸層群の古地磁気方位：予察的検討

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Paleomagnetic direction of the Paleogene Kobe Group: preliminary results

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Paleomagnetic studies on tectonic rotation of Southwest Japan have been conducted using Miocene and Cretaceous rocks since 1980s. It is suggested that Southwest Japan was separated from Asian continent, experiencing clockwise rotation of about 40 ° in a short period in the Miocene (e.g., Hoshi et al., 2015) and that relative motion between Southwest Japan and Asian continent had not occurred in the Cretaceous (Uno et al., 2017). However, the apparent polar wander path, that is important to understand drift history of continents or crustal blocks, has not been established for Southwest Japan, partly due to lack of the Paleogene paleomagnetic data. The Kobe Group, distrubuted in the northern Awaji island, western Kobe city and Sanda areas in Hyogo prefecture, is dated at 30-37 Ma (Late Eocene to Early Oligocene) by K-Ar and fission-track dating, but its paleomagnetic directions have not been revealed yet. In attempt to obtain Paleogene poles representing Southwest Japan, we collected paleomagnetic samples from Sanda area, where the strata are relatively well exposed. After measuring magnetic susceptibility and its anisotropy with a Kappabridge, we made measurement of remanent magnetizations using a cryogenic magnetometer (2G SRM) and stepwise thermal or alternating field (AF) demagnetizations. At a site near Ansei-ike pond (upper part of the Ansei-ike tuff), a magnetic component showing eastward deflections of 10 to 60 ° was identified by thermal demagnetization from 250 to 500 ° C and by AF demagnetization from 20 to 40 mT. At another site on the stratigraphically equivalent horizon (Tojo-gawa River), however, the low-temperature component near the present geomagnetic field direction rapidly decreased toward the origin, not providing a high-temperature component. Remanence of these samples were mostly demagnetized by AF demagnetization below 20 mT, suggesting overprint of viscous remanent magnetization. It is necessary to investigate tuffaceous or mud samples with higher coercivity and high blocking temperature in order to obtain primary paleomagnetic directions from the Kobe Group.

西南日本の古位置に関して，1980 年代以降に中新世と白亜紀の岩石を対象に古地磁気の研究が行われてきた．これらの研究によって西南日本は中新世に短期間で約 40 ° の時計回りの回転を伴って大陸から分離したということが主張された（Hoshi et al., 2015）. また、白亜紀後期にはアジア大陸が一体となっていたということも明らかにされている（Uno et al., 2017）。しかしながら、大陸や地塊の移動過程を復元する上で重要な見かけの極移動曲線 (APWP) は確立されておらず、特に西南日本での古第三紀の古地磁気方位のデータが不足している。

神戸層群は兵庫県東南部の淡路島北部・神戸市西部・三田盆地に分布する古第三系の地層であり、砂岩と泥岩を主体とし複数の凝灰岩層を挟んでいる。その層厚は約 800 m と推定され、鍵層となる凝灰岩層を基準として 3 つの「累層」に分けられる（尾崎・松浦, 1988）。また、三田盆地と神戸市西部に分布する神戸層群からは、後期始新世～前期漸新世の年代を示す K-Ar 年代とフィッション・トラック年代 (約 30～37 Ma) が報告されているが（尾崎他, 1996）、これまでに古地磁気方位の検討は行われていない。そこで、西南日本を代表する古第三紀の古地磁気方位を得るため、比較的露頭条件の良好な三田盆地の神戸層群の地層を対象に残留磁化の測定を行った。

残留磁化測定用の試料の採取は、兵庫県加東市東部 (旧東条町) を中心に行った。本地域の神戸層群の岩相層序と地質構造は阪本他（1998）によって明らかにされており、4 枚の凝灰岩層が認定されている。本研究では、主として阪本他（1998）の記載したルートにおいて定方位ブロックを採取し、実験室に持ち帰って 1 インチのコア試料を作製した。これらについて、Kappabridge による初磁化率とその異方性 (AMS) を測定の後、超伝導磁力計を用いて残留磁化を測定した。また、段階熱消磁および段階交流消磁により、磁化成分の分離を試みた。

これまでに磁化測定を完了した地点のうち、安政池南西の凝灰岩試料 (安政池凝灰岩層上部) では、熱消磁によって 25～250 ℃の低温成分の他、250～500 ℃で原点に向かう磁化成分が認定でき、その方位は 10～60 ° の東偏する偏角を示した。同様の磁化方位は、20～40 mT の交流消磁でも確認できた。しかし、これとほぼ同層準にあたる東条川河床で採取した試料の熱消磁では、ほぼ真北を示す低温成分が原点に向かって減衰し、高温成分を見出すことができなかった。この地点の磁化は 20 mT までの消磁段階で消磁され、現在の地球磁場に近い方位の磁化が粘性残留磁化起源の二次磁化である可能性が示唆される。神戸層群から信頼性の高い初生磁化方位を得るためには、今後、より高い保磁力とブロッキング温度を示す凝灰岩あるいは泥岩を対象に残留磁化測定を行う必要がある。

エチオピア巨大火成岩岩石区から推定される約3000万年前の古地磁気強度変動

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The geomagnetic field variation around 30 Ma estimated from Ethiopian Large Igneous Province (LIP)

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The variation of geomagnetic field strength on the scale of tens of million years is important because it may reflect the history of the Eearth's outer core and mantle convection. However, estimations of paleointensity involve various difficulties, and it is still difficult to clarify the long-term changes of geomagnetic intensity from a database. Also, the reconstruction of continuous paleomagnetic intensity records during geomagnetic polarity reversals is fundamentally important for understanding the nature of the geomagnetic field during reversals.

We, therefore, conducted a paleointensity study on volcanic rocks in the Ethiopian Large Igneous Province (LIP), which is claimed to have erupted and formed at about 30+-0.4 Ma. We used four block samples collected from 93 lava flows. Thermomagnetic analyses were conducted on 125 samples from 93 layers. Among them, 33 samples of 30 flows showed signs of low-temperature oxidation. Furthermore, we excluded 23 samples of 21 flows that showed more than 30% differences between heating and cooling curves. The bulk domain stability (BDS) (Paterson et al., 2017) was calculated from the hysteresis data, and two samples of two flows below the threshold of 0.1 were excluded. Absolute paleointensity estimation experiments using the Tunskawa-Shaw method were performed on remaining 79 samples of 40 flows. Among them, 46 samples of 27 flows provided absolute paleointensities (API) ranging from 5.4 to 38.8 microT, which correspond to VDM of 1.4-10.0 ($10^{22}Am^2$). Among them, there are three lava layers that have three independent paleointensity values each, and the average of the means of the two flows that have a standard deviation of 15% or less is 4.8 ($10^{22}Am^2$) (N=2). This is about 60% of the present field, and close to the average of 3.6+-2.1 ($10^{22}Am^2$) for the last 5 Ma proposed by Yamamoto and Tsunakawa (2005) and the median value of 4.2 ($10^{22}Am^2$) for the last 200 Ma proposed by Tauxe et al., (2013).

Following the same procedure as absolute one, NRM/ARM slope, that is the natural remanent magnetization (NRM) intensity normalized with anhysteretic remanent magnetization (ARM) intensity, was calculated for 113 samples of 56 flows to recover relative paleointensity (RPI) variations. As a result, RPIs ranging from 0.037 to 4.9 were obtained from 106 samples of 52 flows. The average of the flows that have three independent RPI value each is 1.4+-1.0 (N=6). The correlation between the RPIs and APIs at the sample level was R=0.82. A bi-plot of the VGP latitudes and the RPIs shows a U-shaped distribution; RPIs are low when VGPs are in middle to low latitudes. This is similar to the relationship between Oligocene RPI and VGP latitude shown by Tauxe and Staudigel (2004).

数千万年スケールでの地球磁場強度の変遷は、過去の地球外核やマントル対流の歴史を反映している可能性があるため、重要である。しかし、古地磁気強度の推定には様々な困難が伴い、データベースを用いても地磁気強度の平均値を明らかにすることは難しい。また、地磁気逆転に伴う連続的な古地磁気強度の復元は、地磁気逆転時の性質を理解するために必要である。

そこで我々は、約3000万年前におよそ80万年という期間で噴出・形成したと言われているエチオピア巨大火成岩岩石区 (Large Igneous Province: LIP) の火山岩を対象に古地磁気強度研究を行った。熱磁気分析で低温酸化の兆候が見られる試料と、加熱曲線と冷却曲線の差が30%より大きい試料を除外した。そしてヒステリシスデータからバルク磁区安定性 (Bulk Domain Stability: BDS, Paterson et al., 2017) を計算し、閾値0.1を下回る試料を除外した。それ以外の40層中の79個の試料に対して、綱川ショー法による絶対古地磁気強度推定実験を行った。そのうち、27層中の46個の試料から、5.4-38.8 microTの絶対古地磁気強度が得られた。それらをVDMに換算した値は1.4-10.0($10^{22}Am^2$)であった。その中でも、３つの強度が１つの溶岩層から推定されている溶岩層は３層あり、標準偏差が15 %以下の２層の平均から計算した全平均値は4.8($10^{22}Am^2$) (N=2)であった。この平均値は現在の約60%であり、これまで提案されている過去500万年間の平均値3.6+-2.1 ($10^{22}Am^2$) (Yamamoto and Tsunakawa, 2005)、および過去２億年の中央値4.2($10^{22}Am^2$) (Tauxe et al., 2013)と近い値であった。

絶対古地磁気強度の際と同様に事前に試料を選別し、56層中の113個の試料について、非履歴残留磁化 (ARM) で自然残留磁化 (NRM) を規格化したNRM/ARM slopeから相対古地磁気強度変動の復元を試みた。その結果、52層106個の試料から0.037-4.9という変動幅の相対古地磁気強度が得られた。そのうち1層につき3個の強度が推定された層平均を全て平均した値は1.4+-1.0 (N=6)であった。試料レベルでの相対古地磁気強度と絶対古地磁気強度の相関はR=0.82であり、正の相関を持っていた。VGP緯度と相対古地磁気強度の比較を行ったところ、VGPが中-低緯度の場合相対古地磁気強度は比較的小さい特徴が分かった。これはTauxe and Staudigel (2004)によって示されたOligoceneの相対古地磁気強度とVGP緯度の関係に類似している。

伊能忠敬の山島方位記から十九世紀初頭の日本の地磁気偏角を解析する。

辻本 元博 [1]
[1] なし

Analyzing the geomagnetic declination in 19 century Japan from Santou Houi Ki recorded by Inoh. 8th report.

Motohiro Tsujimoto[1]
[1] none

The Santou-Houi-Kiis a national treasure of Japan,consist of 67 volumes ledger of approximately 200,000 magnetic compass survey azimuth data by 0 degree 05 minute unit in 1800 to 1816,cover from eastern Hokkaido to Yakushima island recorded by cartographic surveyer Tadataka Inoh. We executed the interdisciplinary and simultaneous analysis of real azimuth, magnetic declinaion,precise position of target points and the survey reference point where the value of magnetic declination to any target points are simlar or approximation. We analyzed the magnetic declination at 231points in Japan. In the world,there are lack of declination data in Japan from middle 17 century to middle 19 century equal to the term of national isolation of Japan. Itis naccessary to introduce the declinaton analyzed from Santou-Hou-Ki to Historical Declination Vierwer according to Gufm 1 by Andrew Jackson etal. Add the comparison table of both geomagnetic declination data in 1800 to 1816 in each region from Honshuu to Kyuushuu.

国宝山島方位記は地図測量家伊能忠敬により、1800年から1816年に記録された北海道から屋久島迄の67巻の磁針測量方位角帳で測量対象地点及び測量実施基点の地名と0度05分単位の推計約20万件の磁針測量方位角が記録されている。測量対象地点緯度経度、測量実施基点緯度経度、真方位、地磁気偏角を同時解析た。測量実施基点からいずれの測量対象地点への磁針測量方位角にも含まれる地磁気偏角が一定或いは近似になる精確な位置を逆算する。日本の231地点で地磁気偏角を解析した。欧米では日本が鎖国した１７世紀中期から１９世紀中期迄の日本の地磁気偏角のデータが不足している。

山島方位記からの解析値をアンドリユー・ジヤクソンらのGufm1に基づくNOAAアメリカ海洋大気庁のHistorical Declination Viewerに導入する必要がある。1800年から1816年迄の本州から九州の各地での両方の地磁気偏角データの比較表を付す。

考古岩石磁気学：鉄鉱物の磁性から考古学に必要な情報を取り出す試み

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Archeo-rock magnetism: an attempt to extract magnetic information from archeological relics

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Rock magnetism is often used to obtain the information of magnetic minerals carrying the paleomagnetic remanence. Archeological relic, site and remnant, is one of a target of paleomagnetism. Burned materials obtained from archeological sites have a good thermoremanent magnetization and those TRM are less likely to be a problem in primary magnetization. Moreover, many of archeological material have good age estimated. As a result, it is unusual to add the rock magnetic measurements in the archeomagnetic procedures.

On the other hand, rock magnetism is also a tool to estimate the paleoenvironments with measuring magnetic properties reflecting composition, state and concentration of the iron-bearing minerals. Iron can be a sensitive proxy, because the composition of which are due to the conditions of generation, accumulation and transformation of minerals. It is also possible to derive the information linking to the environments during the burning of the archeological materials from the magnetic properties. Here we introduce a test case of measurement and interpretation of the rock magnetic properties from the materials from the floors of old kilns.

Shino-Nishiyama kilns, #1-1 and #1-2, ware operated during the 10th to the 11th century in the west of Kyoto old capital. In these kilns, craftspeople produced a couple of types of potteries; Sue wares, green-grazed stonewares and roof tiles. The samples for paleomagnetism were obtained from floor of the entrance and upper-parts inside the kiln. Paleomagnetic direction and stability, and some kinds of rock magnetic property measurements were conducted. The results show the variations in species, sizes and oxidation states of the magnetic minerals, indicating different environments of the maximum temperature and the oxic-anoxic conditions.

岩石磁気学は古地磁気学において残留磁化の保持鉱物に関する情報を得るために用いられる。古地磁気学の対象のひとつとして考古学の遺跡・遺物が挙げられるが（考古地磁気学）、考古学資料のうち熱を受けているものは、自然の岩石試料と比べても良質な熱残留磁化を保持していて年代値も確実であるため、良質な古地磁気試料として扱われる。そのため初生性にほとんど疑いの余地がなく、考古地磁気学においては付随して岩石磁気学的測定が行われることはあまり無い。

一方で岩石磁気学は、磁性鉱物の生成・集積・変質環境を反映した鉄鉱物の組成・状態・量等を測定することで古環境推定等に用いられることも多い。このような使い方を考古遺物にも施すことで、考古学的な情報が何か引き出せるかも知れない。本研究ではそのような目的で岩石磁気測定を行い、解釈を試みた。

今回は事例として京都府亀岡市にある篠西山1号窯跡（10〜11世紀）2基の窯床面から採取した。この窯では須恵器、緑釉陶器、瓦といった複数種の土器を生産していたことがわかっている。我々は同試料について、段階交流消磁を施した古地磁気方位測定のほか、各種岩石磁気測定を行った。その結果、磁性鉱物の種類、サイズ等に部位ごとの変化が見られ、焼成環境の不均質性を反映していると考えられる。そこから、被熱の分布や酸化還元状態などの考察を行った。

鉱物分析結果に基づく考古地磁気強度データの精査

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Valuation of archaeointensity data based on the results of a mineralogical analysis

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Archaeomagnetism is an academic branch that reconstructs aspect of ancient field from baked archaeological materials, and is expected to apply for age estimation of archaeological remains or artifacts and reconstruction of deep-Earth dynamics. In the research field of archaeomagnetism, a study for reconstruction of archaeointensity uses to be one of the most important research subjects recently. The development of studies of archaeointensity in the last several years is remarkable, and we also have been trying the construction of a secular variation curve in East Asia including Japan now. However, the studies of archaeointensity also have a variety of problems which should be resolved. One of them is the magnitude of dispersion of the archaeointensity values obtained by archaeointensity experiments. Therefore, finding the cause of the dispersion and minimizing them are needed to construct the field model with a higher accuracy.

In order to solve these problems, we carried out the valuation of archaeointensity data based on the results of a mineralogical analysis in this study. First, we carried out a XRD analysis of baked earth specimens (a total of 98 specimens collected from 39 kilns belonging to Suemura old kiln complex in Osaka prefecture) which already carried out the archaeointensity experiment (by Tsunakawa-Shaw method; e.g. Yamamoto et al., 2003). Then, we distinguished these specimens like which peaks of Mullite and Cristobalite were detected and not detected. Finally, we considered characteristics of those results by comparing results of archaeointensity experiment. Previous studies have reported that Mullite and Cristobalite are minerals produced at high temperatures more than 1000 ^{o}C (e.g. Schomburg, 1991), those can use as the criteria of validity of the archaeointensity experiment (e.g. Kitahara et al., 2018).

As a result of comparing the correspondence between the presence of Mullite and Cristobalite and the archaeointensity values, it was confirmed that the archaeointensity values which both minerals were not detected tended to deviate from the center of a group of intensity data of every kiln (or every pottery sequence). The fact is expected to be useful in minimizing the dispersion that caused by archaeointensity experiments. We intend to continue with this study in the future, and want to consider the next ideas such as combining data of rock magnetism.

考古地磁気学は、被熱遺物から過去の地球磁場の様相を復元することを目的とした研究分野であり、考古遺跡・遺物の年代推定や地球深部のダイナミクスの復元などへの応用が期待されている。同分野における主要な研究課題のひとつに、考古地磁気強度の復元に関する研究が挙げられる。ここ十数年間における考古地磁気強度研究の発展は目覚ましく、筆者らも現在、日本を含めた東アジアにおける強度永年変化曲線の構築に取り組んでいる。しかしながら考古地磁気強度研究をより深化させていくためには、いくつかの課題を克服しなければならない。それらの課題のひとつとして、考古地磁気強度実験によって復元された強度値のばらつきの大きさが挙げられる。より高精度な考古地磁気モデルを構築するためにも、これらのばらつきの原因を突き止め、最小化する工夫が必要となる。

本研究では、上記の課題解決のための方法の検討を目的として、鉱物分析結果に基づく考古地磁気強度データの精査を行った。具体的には、考古地磁気強度実験（綱川－ショー法; e.g. Yamamoto et al., 2003）による強度復元を実施した焼土試片（大阪府陶邑遺跡の 39 基の窯跡から採取された 98 個の試片）に対して XRD 分析を行い、ムライトとクリストバライトのピークが検出されたものと検出されなかったものに分類し、強度実験の結果と対比することによって、その傾向を考察した。ムライトとクリストバライトは、1000^{o}C 以上の高温下で生成される鉱物であることが先行研究によって報告されており（e.g. Schomburg, 1991）、考古地磁気強度実験の妥当性（およそ 600^{o}C 以上の温度で試料が焼成されていること）をチェックするための基準として用いることができる（e.g. Kitahara et al., 2018）。

上記の方法でムライトとクリストバライトの有無と考古地磁気強度値の分布の対応を比較した結果、両鉱物が検出されなかった試片の強度値は、窯（あるいは土器編年の型式）ごとの強度データ集団の中心から外れて位置する傾向が確認された。これらの結果は、不適格な強度データを選択的に除外し、ばらつきを最小化する際に役立てられると考えられる。今後も引き続き研究を継続するとともに、岩石磁気データと組み合わせるなど、今後の展開についても適宜検討していきたい。

阿蘇火山・富士火山の火山岩による古地磁気強度変動の研究

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Research of paleointensity variation with volcanic rocks in Aso and Fuji volcanoes

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In the SGEPSS fall meeting in 2018, we reported that paleointensity variation determined from volcanic rocks in Aso volcano showed a monotonic increase from 50 microT to 70 microT for the period between 4.5 and 3.3 ka. For this paleointensity variation, the date is based on the paleomagnetic secular variation curve combined with the two 14C ages. The results from Aso volcano indicate the sites of similar paleomagnetic directions give consistent paleointensities, which infers a high reliability.

In this study, we apply the Tsunakawa-Shaw method to volcanic rocks in Fuji volcano to obtain paleointensity data for the period of 4-3 ka, where we have determined the paleointensity variation from volcanic rocks in Aso volcano, and also to obtain paleointensities for the younger and older periods. The studied lavas in Fuji volcano were dated with 14C ages or historical documents. We think that comparing paleointensity estimates from volcanic rocks in Aso and Fuji volcanoes, which are dated with different methods, is important to restore a more reliable paleointensity variation curve.

Seventy-two samples of 16 sites were subjected to the Tsunakawa- Shaw paleointensity experiment and 64 samples passed the selection criteria. For some sites, consistency of paleointensity estimates within site appears to be not enough: these results are now under consideration based on rockmagnetic properties. For five sites, the paleointensity estimates are consistent within site, that passed the selection criteria on site-level consistency (n is 3 or more, s.d./Mean is lower than 0.15). Two sites of 4-3 ka gave 53.2 microT and 61.3 microT. These values are consistent with the paleointensity variation determined from volcanic rocks in Aso volcano. The other 3 sites of ca. 2000-1000 year BP yield paleointensity estimates which are smaller than the reported data.

2018年のSGEPSS秋季講演会では，阿蘇火山の火山岩から得られた4~3千年前の古地磁気強度変動について報告した。阿蘇火山の火山岩からTsunakawa-Shaw法を用いて得られた古地磁気強度は、4.5kaから3.3kaの間に、約50 μ Tから70 μ Tまでの単調な増加を示した。この阿蘇の火山岩での研究では、古地磁気永年変化曲線（2溶岩の炭素14年代を含む）を利用して年代を推定している。阿蘇火山で得られた強度値は、近い年代に噴出したと推測できる溶岩同士でもまとまった値を示しており、信頼度の高い結果となっている。本研究では、阿蘇火山の火山岩から得られた強度と同じ年代と、その前後の期間の古地磁気強度を復元するために、富士火山の火山岩を用いて古地磁気強度の測定を行っている。これらのサンプルは炭素14年代・古文書によって噴出年代が報告されている。阿蘇と富士火山、異なる手法で年代決定がされた二つの地点から得られた古地磁気強度を比較することは、信頼性が高い古地磁気強度変動を推定する上で重要である。富士火山溶岩流の16サイト72個のサンプルについてTsunakawa-Shaw法による古地磁気強度の測定を行ったところ、64個のサンプルが合格基準を満たした。これらの測定値をサイトごとに見てみると、測定値のばらつきが小さいものと大きいものがある。測定値のばらつきが大きいサイトについては、岩石磁気による検討を進めている。今回は、得られた各サイトの古地磁気強度の結果のうち、測定値の数が3個以上あり標準偏差が平均の15%以下となった5サイトの結果を中心に紹介する。このうちの2つのサイトから得られた古地磁気強度は、53.2 +/- 4.2 μ Tと61.3 +/- 7.5 μ Tであり，阿蘇火山岩から得られたデータと調和的である。また、それよりも若い年代（2000-1000年前）の溶岩からも3つの強度値を得た。これらの値は、既存のデータと比較すると低い。

富士火山の火山噴出物から推定する過去2300年間の地磁気永年変化

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Paleomagnetic secular variation of last 2300 years inferred from volcanic products of Fuji volcano, Japan.

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Paleomagnetic secular variation (PSV) records in Japan has been presented by archaeomagnetic studies of old kilns and hearths (e.g. Hirooka,1977) and paleomagnetic studies of sediment cores (e.g. Ali et al.,1999). The paleomagnetic directions and intensities have changed incessantly, therefore utilized for dating tool of volcanic products (e.g. Miki,1999). However, the archaeomagnetic results are restricted to the last 1600 years, and PSV records from sediment cores are inconsistent. Here, we present paleomagnetic directions from volcanic products of last 2,300 years at Fuji volcano.

Fuji volcano is one of the largest, basaltic and active volcanos in Japan. Recent volcanologic studies have revealed the eruption ages in detail from historical records, tephrochronology by trench excavations, and ^{14}C datings. Takada et al., (2016) has been revised the geological map of Fuji volcano, the rock-stratigraphic units has been categorized 185 units during 17,000 B.C.E to C.E.1,707. Especially of last 2,300 years (Subashiri-d stage), the volcanic activity were newly determined using ^{14}C datings and stratigraphic relation with Iz-Kt (C.E.838) tephra (Yamamoto et al., 2005 ; Kobayashi et al., 2007). Those developments enable us collecting paleomagnetic direction data using those volcanic products, sufficiently. Paleomagnetic samples were collected from 35 units of lava flows, pyroclastic flows and pyroclastic cones of mostly known eruption ages. We selected carefully several sites from each volcanic product and collected 6 to 20 samples using an engine powered core picker. Samples were oriented by a sun compass to eliminate the influence of local magnetic anomalies. Magnetization of the samples are measured using a spinner magnetometer with alternating field demagnetization (AFD) and thermal demagnetization (ThD). Our criteria of paleomagnetic direction is a95 less than 5.0 degree and the total average is 2.0 degree.

As a result of our study, the paleomagnetic directions agree with archaeomagnetic secular variation during the last 1,600 years. The PSV curve can be extended further beyond C.E.400. A few lava flows show directions disagree with other flows. In the case of Norikawa lava flow (C.E.600), the paleomagnetic directions totally different from the PSV. We believe that it is due to wrong age assignments by stratigraphy in the geological map of Fuji volcano. One of the historical eruptions, Aokigaharamarubi lava flow (C.E.864-866) shows paleomagnetic directions shallower than archeomagnetic secular variation curve. It is, however, fit with the recent archaeomagnetic results of old kilns in mid 9th century, within a95 range (Hatakeyama and Kitahara, 2019). These results indicate that it is necessary to reconfigure the stratigraphy of Fuji volcano and also redraw the PSV curve. Our findings suggest that paleomagnetic method can improve eruption history of Fuji volcano, and the volcanic products can contribute to extend the Holocene PSV in Japan.

Data assimilation for prediction of geomagnetic secular variation

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The terrestrial magnetic field is generated by a dynamo in the outer core of the Earth. Since the physical processes of the geodynamo is nonlinear, it is difficult to predict the geomagnetic secular variation in the future. It is therefore desired to make use of a physical geodynamo model for the prediction of the secular variation. Data assimilation of geomagnetic data on the Earth's surface is essential for the prediction based on the physical model.

In this study, the geomagnetic field given by the MCM-0020 model (Ropp and Lesur, 2019) is assimilated into a geodynamo model (Takahashi, 2012; 2014) by using the 4-dimensional ensemble variational (4DEnVar) method (Liu et al., 2008), which is easy to implement if the results of a large number of simulation runs are prepared in advance. By iteratively applying the 4DEnVar method, the estimate converges to at least a local maximum of the log-likelihood function. It will be demonstrated that this method provides a plausible estimate of the current state of the geodynamo.

Analysis of magnetic secular acceleration in a numerical dynamo model

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Geomagnetic jerk is known as a sudden change in the trend of geomagnetic secular variation, which typically occurs in annual timescale. Wavelet analysis is a useful tool to detect singular variation in time-series data. Alexandrescu et al. (1995) applied wavelet analysis to geomagnetic field data obtained at ground observatories in Europe. They detected geomagnetic jerks in 1901, 1913, 1925, 1969 and 1978, and showed that regularity of the magnetic field variation is about 1.5 rather than 2.

We have studied magnetic field variation in numerical dynamo models using wavelet analysis to see if any jerk-like event occurs. In spite of the fact that magnetic field variation in dynamo models occurs more slowly compared with the geomagnetic secular variation due to assumed values of the fluid viscosity very far from that in the Earth's core, we have found jerk-like magnetic field variation with respect to all of the three components in a numerical dynamo model. Regularity of such variations is typically larger than 2, suggesting a less singular variation than the geomagnetic jerk. It is also noted that jerk-like variation occurs both globally and locally. We then examine the magnetic field variation in a numerical dynamo model in terms of secular acceleration, that is, second time derivative of the magnetic field. In this study, correspondence of the results from two different analyses is to be compared. We will discuss similarity and dissimilarity in characteristics of magnetic field variation obtained from wavelet analysis and secular acceleration.

東西磁場が印加された回転球面上の磁気流体浅水波の極トラップモード

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Shallow water MHD waves trapped in the polar regions on a rotating sphere with an imposed azimuthal magnetic field

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Magnetohydrodynamic (MHD) shallow water waves on a rotating sphere with a background toroidal magnetic field are investigated to provide the physical interpretations of the geomagnetic variations which originate from Earth's core. We focus on the MHD waves within a stratified outermost Earth's outer core (e.g. Helffrich and Kaneshima, 2010; Kaneshima, 2018) in common with some previous studies, which including Braginsky(1993) and Buffett(2014), Chulliat et al.(2015). Not only the explanation of the geomagnetic fluctuations but also constraints on the obscure properties of the stratification can be provided by comparing with wavy variations in the geomagnetic field.

An azimuthal equatorially antisymmetric field ($B_p(t)=B_0\sin(t)\cos(t)$, where t (theta) is colatitude, p (phi) is azimuth) is adopted as an imposed magnetic field in this research. Previously, an equatorially symmetric one ($B_p(t)=B_0\sin(t)$) was examined in Marquez-Artavia et al.(2017), whose results we replicated and reported in JpGU 2018. We was also found that eigenvalue problems with the background field varying in the theta direction, except for $B_p(t)=B_0\sin(t)$, possess a continuous spectrum, which is sometimes called the Alfven continuum (Goedbloed et al., 2004), in the range where an azimuthal phase velocity is coincident with a local Alfven velocity divided by sin(t) (Nakashima and Yoshida, JpGU2019). Since the Alfven continuum results from the singularity of the governing equations with ideal MHD approximation, introducing the horizontal magnetic diffusion can exclude the continuous modes by transforming them into discreate eigenvalues, whose eigenfunctions exhibit an internal resistive boundary layer around a critical latitude which a local Alfven wave resonates. By the numerical calculation with small magnetic diffusivity, the polar trapped westward modes are found for the Earth-like parameters. As a several azimuthal wavenumber, for instance m=6, these polar trapped mode propagates with a few years period. On the other hand, the eastward modes and the equatorial trapped modes are not likely to observe according to our results.

Buffett and Matsui(2019) recently obtained the equatorial trapped waves propagating to the east with a background radial magnetic field varying in the north-south direction without horizontal magnetic diffusion. Although their system also can have the Alfven continuum, since the assumed main field do not vanish in the equator, the eigenvalues of the found slow equatorial mode are outside of the continuum.

惑星ダイナモにおける時間スケール

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Timescales in planetary dynamo process

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In the previous 2019 Jpgu Meeting we presented recent results of kinematic dynamo calculations and pointed out importance of linear magnetic field growth rates of kinematic dynamo and magnetic instability in the process of nonlinear planetary dynamos. Considering a simple two-scale model consisting of an axisymmetric (A) field and a non-axisymmetric (N) field of azimuthal wavenumber m, we gave an idea that the energy transfer rates between these two scales might determine the magnetic field saturation. The A- and N-fields are both created by a (kinematic) dynamo process, while a part of the A-field energy is transferred to the N-field energy due to magnetic instability in which an axisymmetric toroidal field is destabilized when the intensity exceeds a certain critical value. Two timescales, kinematic dynamo and magnetic instability, can be roughly obtained by linear models, so there is a possibility to estimate a relation between the A-field intensity, flow speed that creates magnetic field, and length scale (m). In this presentation, we show results of further investigation and discuss the availability.