Japan Geoscience Union Meeting 2012
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堆積物から得られる相対古地磁気強度の長期的変動は、真の地磁気変動を反映しているか？
Long-term changes of relative paleointensity from sediments: geomagnetic field behavior or rock magnetic artifact?

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Since the 1960s, possible correlation between geomagnetic field strength and polarity length on 10ˆ6 years or longer time scale has been suggested, and its relation to geodynamo processes has been discussed (e.g., Cox, 1968). Paleointensity estimation using single crystal silicate indicated that the geomagnetic field was stronger during Cretaceous Superchron, when polarity reversal was inhibited in geodynamo (e.g., Tarduno et al., 2001). However, it has not yet been understood well whether such correlation exists when polarity reversals frequently occur. Tauxe and Hartl (1997) suggested a weak correlation using Oligocene sediments (ca 23-34 Ma) from DSDP Site 522. This is the only continuous paleointensity data of these ages published so far.

We have conducted a paleomagnetic study of sediment cores of Eocene and Oligocene ages taken at Sites U1331, U1332, and U1333 of IODP Exp. 320/321 ”Pacific Equatorial Age Transect (PEAT)”. The objective includes better understanding of long-term changes in relative paleointensity and revisiting the issue of intensity-polarity length correlation. Relative paleointensity records from individual sites showed good between-site consistency for variations of 10ˆ4 to 10ˆ5 year time scale, suggesting that geomagnetic field behavior was successfully recovered on these time scales. The results confirmed usefulness of relative paleointensity for high-resolution inter-core correlation, that is, paleointensity assisted chronostratigraphy. On the other hand, long-term changes (ca 10ˆ6 years or longer) in normalized intensity showed obvious anti-correlation with ARM/SIRM, a rock magnetic proxy of magnetic grain size and/or magnetostatic interactions among magnetic grains. Furthermore, the normalized intensity showed correlation with sedimentation rates. The emergence of significant correlation between normalized intensity and ARM/SIRM and sedimentation rates is not limited to PEAT cores, but occurs also in the Oligocene South Atlantic DSDP 522 cores of Tauxe and Hartl (1997). These results indicate lithological contamination to relative paleointensity records. For reliable estimation of long-term paleointensity changes from sediments, it is imperative to understand physical mechanism of such correlation and develop a method for correction.

キーワード: 古地磁気強度, 堆積物, 東太平洋, 統合国際深海掘削計画, 漸新世, 地磁気逆転
Keywords: paleointensity, sediment, east Pacific, IODP, Oligocene, polarity reversal

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火山岩データによる相対古地磁気強度変動曲線の絶対値較正
Calibration of relative paleointensity variation to absolute value using paleointensity data from volcanic rocks

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We made a direct comparison between absolute paleointensities obtained from welded tuffs of pyroclastic flows and relative paleointensities (RPIs) from sedimentary records. Widespread tephras extruding with the welded tuffs were indentified in sediments and dated in the oxygen isotope stratigraphy. Referring to the age estimates of the tephras in the oxygen isotope stratigraphy, the absolute paleointensities can be compared with RPIs of sedimentary records. For two RPI stack records reported from different oceans, we find that RPIs has a linear correlation to absolute paleointensities. On the basis of the correlations, the RPI variations were calibrated to geomagnetic field strengths (virtual axial dipole moments: VADMs). The two calibrated records show an almost consistent VADM variation. The consistency indicates that this new calibration procedure is successful and it can be applicable to RPI records on the Earth.

キーワード: 相対古地磁気強度, 絶対古地磁気強度, 溶結凝灰岩, テフラ, キャリブレーション, LTD-DHT ショー法
Keywords: relative paleointensity, absolute paleointensity, welded tuff, tephra, calibration, LTD-DHT Shaw method

SEM21-03 会場:301B 時間:5 月 25 日 09:30-09:45

ブルンー松山地球磁場逆転境界の磁場構造
Refinement on geometry of Matuyama-Brunhes polarity transition from paleomagnetic records

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The Bayesian model of the Matuyama/Brunhes (MB) geomagnetic polarity reversal was extended from the previous model IMMAB4 (Leonhardt and Fabian, 2007), which was based on one volcanic record and three sedimentary records from the Atlantic sector.The essential improvement on the model was achieved by incorporating a new volcanic record from Tahiti (Mochizuki et al., 2011). This record is unique in that it contains important absolute paleointensity data for the Pacific region, which provide new constraints for the global geomagnetic reversal scenario. The full vector development of transitional geomagnetic field in the central part of the Pacific significantly stabilized the solution in this important region, which was completely missing in the previous model IMMAB4. The sedimentary high-quality record of ODP Site 769 by Oda et al. (2000) previously was only used to check the reliability of the model IMMAB4 by comparing the VGP paths of the model and the data. An integrated sedimentary record of ODP Site 769 was developed from Oda et al. (2000) in combination with the relative paleointensity record provided by Schneider et al. (1992) and Kent&Schneider (1995). The record will also be included into the construction of the new model. Additionally, two records from the Antarctic region (Guyodo et al., 2001; Macri et al., 2010) were found, and might prove useful for further refining the model. To fulfill the aim, we have also revised the data structure, and developed a GUI based correlation software to simplify refinement of the model and further development of the scheme. In the presentation, we will show the revised morphological development of the Earth's magnetic field during the Matuyama-Brunhes polarity transition.
Keywords: geomagnetic reversal, Brunhes-Matuyama polarity transition, paleomagnetic records, Inversion, Tahiti, IMMAB4

SEM21-04 会場:301B 時間:5月25日 09:45-10:00

Magnetostratigraphy and identification of the Reunion subchron from lava flows in the Dobi Cliff, Afar Depression

Magnetostratigraphy and identification of the Reunion subchron from lava flows in the Dobi Cliff, Afar Depression

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We sampled 28 continuous lava flows from the 340 meters long volcanic section of Dobi cliff for paleomagnetic investigations. Four oriented blocks from each lava flow were collected; block sampling technique was employed throughout. In the laboratory, 4 to 6 standard samples for each flow were prepared and then subjected to paleomagnetic routine procedures. The samples were treated by both thermal (Th) and alternating field (AF) techniques with 13 steps for the former and up to 15 steps for the latter techniques. The average natural remanent magnetization (NRM) for the entire lava flows is determined to be 4.0 A/m, strong to record and retain the remanence of the rocks. Generally, one to two components of NRM directions were identified. The first component, which in most cases is related to remagnetization is removed by heating to a temperature of 100^{o}C to 300^{o}C or by an AF of 20mT. The NRM direction after these steps for most of the samples defined straight-line segments that were directed towards the origin, which is interpreted as the characteristic remanent magnetization (ChRM) Direction. In a few cases, however, stable end points were not obtained due to strong overlap between the two components of NRM. Directions of magnetizations were determined by best fit lines using the least square technique of Kirschvink (1980) for samples that showed stable linear segments where as a remagnetization circles were used to determine the best fitting great circles according to Halls (1976, 1978). Site mean directions were then calculated by using Fischer (1953) statistics for stable linear segments while McFadden and McElhinny (1988) statistics was used for combined analyses of planes and lines. The overall mean direction calculated for the 28 lava flows is D = 6.0^o, I = 12.5^o, alpha95 = 5.9^o, N = 28, which when compared with the expected mean dipole field, obtained from the Apparent Polar Wonder Path (APWP) curve for Africa (Besse and Courtillot, 2003), D = 1.0^o, I = 20.9^o, alpha95 = 2.3^o, N = 26, a declination difference dD = 5.0^o +/- 5.2^o and inclination difference of dI=8.4^o +/- 5.1^o were obtained. These declination and inclination differences are interpreted respectively as vertical axis block rotation linked to rift propagation and overlap, and as the effect of long standing non-dipole field in Afar (e.g. Kidane et al., 2003). When the site mean directions are vertically plotted in accordance with the sequence of lava flow positions, magneto-zones of Reversed (R1) - Normal (N1) - Reversed (R2) - Normal (N2) polarities were identified from bottom to top with anomalous directions at the base of the section. K/Ar radioisotopic age determinations, made at the geochronology laboratory at the Research Institute of Natural Science, Okayama University of Science for three stratigraphic positions in the Dobi section, reveal ages of 2.12 +/- 0.09 Ma and 2.21 +/- 0.07 Ma at the N1, and 1.93 +/- 0.07 Ma at the N2 respectively. Using these ages and the geomagnetic polarity timescale (GPTS) of Cande and Kent (1995), we correlate the bottom anomalous inclinations and the N1 polarity interval with the Reunion subchron while the N2 polarity interval is correlated with the Olduvai subchron.
Keywords: Afar depression, magnetostratigraphy, Reunion subchron, Ethiopia

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インドシナ半島の Simao Arc の形成の様子を古地磁気学からさぐる
Oroclinal origin of the Simao Arc in the Shan-Thai Block inferred from the Cretaceous palaeomagnetic data

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An active oroclinal bending is discovered in the Shan-Thai block to the south of the eastern Himalayan syntaxis. To investigate the evolution of the Simao Arc using paleomagnetic techniques, Middle Cretaceous red beds of the Nanxin Formation were sampled at the Zhengwan (22.8N, 100.9E) and Dadugang (22.4N, 101.0E) localities in the southern Simao Basin. Most of the studied samples revealed the presence of characteristic remanent magnetization with unblocking temperatures around 680C. A primary nature for this magnetization is interpreted based on a positive fold and reversal test. Tilt-corrected mean directions calculated for Zhengwan and Dadugang localities are characterized by large easterly deflected declination; Dec= 51.8, Inc = 47.9, ks= 45.0, ?95 = 6.9, N=11 and Dec= 64.1, Inc = 48.1, ks = 36.0, ?95 = 7.3, N=12, respectively. Steep inclination values at both these localities with respect to the expected one are in the range previously reported from the Shan-Thai Block, confirming their southward displacement as part of the Shan-Thai Block. Combination of the present data (2 localities) with those previously reported from Simao basin (7 localities) reveals a positive paleomagnetic oroclinal test, indicating that the arc-like present-day geometry of the Simao basin was formed by oroclinal bending. Comparison with recent GPS and structural data suggest that formation of the Simao curvature started after the early Pliocene (after 4 Ma) and continuing until the present. Origin of the Simao Arc is ascribed to southwestward movement of the crustal material across the Ailaoshan Red River Fault (around the eastern Himalaya syntaxis), which was accomplished by westward movement of the decollement with progressive eastward deepening of the Lanping-Simao basin. Decoupling between the upper and the middle-lower crusts associated with decollement formation is requisite condition for the arc formation on continents.

キーワード: テクトニクス, 古地磁気, 白亜紀, インドシナ半島, 東南アジア
Keywords: tectonics, paleomagnetism, oroclinal bending, Cretaceous, Indochina, SE Asia

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SEM21-06 会場:301B 時間:5 月 25 日 11:00-11:15

南太平洋低中緯度域における遠洋性粘土の環境磁気学的研究
Environmental rock-magnetism of pelagic clay from the South Pacific Ocean since the Pliocene

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We conducted a rock-magnetic study of pelagic clay in order to document variations of eolian dust input to the South Pacific Ocean since the Pliocene. The materials studied consist of four pelagic clay cores of about 10 meters long taken from the central to margin of the South Pacific Gyre. Three out of four cores were taken during IODP Expedition 329 at sites U1365, U1366 and U1367, and the other core was GH83-3 P398, within range from latitude 14-27^{o}S and longitude 138-165^{o}W.

We measured magnetic properties (magnetic susceptibility, NRM with stepwise alternating-field demagnetization, acquisition of ARM and IRM, low-temperature IRM) using discrete samples. In addition, magnetic hysteresis, IRM acquisition and first order reversal curve (FORC) measurements (Pike et al., 1999; Roberts et al. 2000) were conducted using an alternating gradient magnetometer (AGM) to characterize magnetic mineral assemblages in the samples. We estimated variations in the proportion of terrigenous to biogenic components.

The $X_{ARM/SIRM}$ ratio and $S_{-0.1T}$ (relative abundance of middle and high coercivity magnetic minerals) of the four pelagic clay cores decreased synchronously before Gauss-Matuyama boundary. The variation of $X_{ARM/SIRM}$ ratio and $S_{-0.1T}$ with time and region can be explained by that eolian dust has higher (lower) maghemaite (magnetite) concentration than other sources of magnetic minerals.

キーワード: 古地磁気学, 環境磁気学, 遠洋性粘土, IODP Exp.329, 南太平洋, GH83-3
Keywords: Paleomagnetism, Environmental rock-magnetism, Pelagic clay, IODP Exp.329, the South Pacific Ocean, GH83-3

SEM21-07 会場:301B 時間:5 月 25 日 11:15-11:30

キアマスーパークロン時の地球磁場：タリム盆地の玄武岩から
Paleomagnetism of Kiaman-aged basalts from the Tarim Basin

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多くのダイナモシミュレーションはスーパークロンの原因を核ーマントル間の熱フラックス低下としているが、この説明はマントルプリューム活動期に起こった白亜紀スーパークロンとは整合しにくい。一方キアマスーパークロン（約 3.1 - 2.6 億年前）は、プレート沈み込みが少ない超大陸期に起こっており、白亜紀スーパークロンと比べ、シミュレーションとより直接的に比較できる可能性がある。キアマスーパークロン時の地球磁場情報を得るため、中国・タリム盆地北部において 2.9 億年前の玄武岩を採取し、古地磁気測定を行った。まず、試料の磁化年代を推定した。段階消磁実験は明瞭な磁化成分を分離し、先行研究で近隣地域より報告されたペルム紀の古地磁気方位と調和的な方位を得た。ただし、タリム盆地においては石炭紀から現在までの古地磁気極が類似しているため、この結果から磁化年代を推定することは難しい。そこで、溶岩流に挟まれる粗粒砂岩を対象に、顕微鏡的礫岩テストを行った。玄武岩岩片を含む砂岩の薄片を作成し、走査型 MI 顕微鏡により表面磁場を観察した。表面磁場の外観は各岩片がランダムな磁化方位を持っていることを示唆し、玄武岩試料は初生磁化を保持していると考えられそうである。発表では古地磁気強度の推定も報告する予定である。これまでのところ、1 試料からテリエ法により 16.8 uT の強度を得た。この結果が本当なら、キアマスーパークロン時の古地磁気強度は現在の半分以下であり、白亜紀スーパークロンよりもかなり低い。しかし、顕微鏡観察から多磁区サイズの鉄酸化物の存在が明らかであるため、珪酸塩単結晶測定により細粒磁性鉱物を選択的に測定することを試みる。

キーワード: スーパークロン, ペルム紀, 超大陸, 磁気顕微鏡
Keywords: superchron, Permian, supercontinent, magnetic microscopy

SEM21-08 会場:301B 時間:5 月 25 日 11:30-11:45

広帯域磁化率スペクトルの応用 I: SP 粒子のサイズ分布
Application of broad-band frequency spectrum of AC magnetic susceptibility: Grain-size distribution of SP particles

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弱磁場中の交流磁化率（Low-field Alternating Current Magnetic Susceptibility, 以下 MS）は、Bartington 磁化率計や KappaBridge など市販測定器の普及によって、岩石鉱物磁気の基礎研究から環境磁気学などの応用研究まで広範な分野で活用されてきた．しかし、これら市販機器の測定方法や性能に由来する制約、特に設定可能な磁場周波数の制限により、MS という基礎的磁性が本来もたらす多くの情報を活用できていない．例えば Bartington 磁化率計では、470 Hz と 4.7 kHz の高低２周波数しか設定できないため、単純な仮定をもとにした半定量的な議論しかできなかった．その代表的な例が、SP 粒子のサイズと MS 周波数依存性の関係である．本報告では、これまでにない広い周波数帯域の MS 測定結果をもとに、磁気緩和理論および SP 粒子の岩石磁気理論にもとづく新たな SP 粒子サイズ分布推定法とその適用例を紹介する．

測定に用いた磁化率計は、ZH Instruments 製の SM-100 および-105 磁化率計である．前者は低周波数用（0.125, 0.25, 0.5, 1, 2, 4, 8, 16 kHz）、後者は高周波数用（16, 32, 64, 128, 256, 512 kHz）で、双方計 13 段階の可変周波数測定を行った．印加磁場強度は 80-320 A/m までの８段階可変、本研究では 80 A/m 固定とした．測定試料は、SP 粒子を主として含むとされる中国黄土高原（Luochuan section）の黄土（loess）・古土壌（paleosol），および Tiva Canyon tuff（TC04-11）を用いた．その他の岩石磁気パラメータ測定は、VSM（MircoMag 3900）および MPMS によった．粒子サイズ分布（Grain size distribution; GSD）を推定するためのモデルは、相互作用のない SD 粒子集団を前提とした Neel 超常磁性理論にもとづく．これに、磁化率と緩和時間・交流周波数の関係に対する適切な近似をおこない、測定された磁化率スペクトルの差分から GSD を求める方法を開発した．ただし、粒子の異方性エネルギーは形状異方性エネルギーのみとし、その分布は仮定していない．測定された磁化率スペクトルはすべて、周波数増加にともなって減少する共通パターンをもつ．これは SP 粒子の周波数依存性の一般的特徴であるが、詳しく見ると試料ごとに減少割合が異なる．この変化率をもとにモデル計算して得られた GSD の体積分布範囲は、0.5-3x10^{-24} m^3 と比較的狭いが、その分布形状は試料の種類ごとに特徴がある．Tiva Canyon tuff が最も分布が鋭く、2x10^{-24} m^3 あたりに中心値をもつ対数正規分布的形状を示す．中国古土壌の GSD 範囲も Tiva Canyon tuff とほとんど重なるが、明確なピークは見られない．このことから、古土壌の GSD はこれまでの推定（例えば，Liu et al., 2005）よりも SD 側に広い分布範囲をもつことがわかる．これに対し、黄土試料の GSD 範囲は 1x10^{-24} m^3 以下で最も細粒である．その磁化率強度自体が古土壌より一桁程度小さいことを反映して、分布強度はより小さく分布範囲も狭い．古土壌と比較して高い保持力をもつことから、maghemite あるいは hematite のナノサイズ粒子の存在を示唆する．

キーワード: 岩石磁気, 交流磁化率, 粒子サイズ分布, 超常磁性
Keywords: rock magnetism, AC susceptibility, grain size distribution, superparamagnetism

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Basic properties of transition remanent magnetizations due to the Verwey transition of magnetite

Basic properties of transition remanent magnetizations due to the Verwey transition of magnetite

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Nagata et al. (1963) found that synthetic stoichiometric magnetite (Fe3O4) acquired a fairly intense and stable remanent magnetization by warming in a magnetic field from -150 C to room temperature, called transition remanent magnetization. It is worth noting that while ordinary thermoremanent magnetization (TRM) is demagnetized by heating treatment, the magnetite acquired remanence during heating from low-temperature to room temperature. Ozima et al. (1963), Ozima and Ozima (1965), and Creer and Like (1967) further investigated the transition remanence.

Dunlop (2006, 2007) studied a suite of experiments using crushed magnetite sample with various grain sizes and reported interesting features as follows: (1) A remanence was acquired not only during warming from 77 to 300 K (transition warming remanent magnetization, TrWRM) but also during cooling from 300 to 77 K in a magnetic field (transition cooling remanent magnetization, TrCRM). (2) Various sizes of magnetite ranging from 0.6 to 135 um (PSD-MD) acquired the remanences. (3) TrWRM has similar thermal demagnetization curve with 400C -T0 and 500C -T0 partial TRMs.

The acquisition processes of transition remanences are non-destructive and easily treat as bulk sample (e.g., one-inch core). Moreover, the remanences have the potential to reflect the information concerning low-temperature properties of magnetite. Therefore, we conducted systematic experiment using natural rock samples containing nearly stoichiometric magnetite, to understand the basic properties of the transition remanent magnetization. Depending on a magnetic field condition during cooling and warming cycle, we defined three transition remanences: (1) TrWRM, acquired during zero-field cooling (ZFC) and field warming (FW), (2) TrCRM, field cooling (FC) and zero-field warming (ZFW), and (3) transition cycle remanent magnetization (TrRM), FC and FW.

We prepared natural granite samples containing nearly stoichiometric magnetite. The samples were collected at five sites (SH03, SH09, SH29, SH49, and SH59) of the Scared Heart granite in Minnesota River Valley (Minnesota, USA). Two cylindrical core-samples of one-inch diameter (SH03-A and SH03-B) and small chip-sample of mineral assemblage were cut from the SH03 block, while fourteen core-samples were cut from SH09, SH29, SH49, and SH59 blocks.

The transition remanences were imparted to the SH03 core-samples by cooling to liquid N2 temperature (77 K) and warming back to room temperature in a DC (or zero-) field. We conducted stepwise alternating field (AF) demagnetization of the transition remanences, anhysteretic remanent magnetization (ARM), and low-temperature demagnetization (LTD) component of ARM. Magnetizations of SH03 chip-sample were continuously measured at 10-300 K with an MPMS. The TrWRM, TrCRM, and TrRM acquisition cycles were measured in the same procedures as those of the core-sample experiments.

TRMs were imparted for the fourteen core-samples of SH09, SH29, SH49, and SH59 by heating from room temperature to 610 C and cooling back to room temperature in a 50 uT field. After LTD treatment, TrRMs were given for each sample by cooling and warming in a 100 uT field. Then the ratio of LTD component of TRM and TrRM were estimated.

Based on the core-sample experiment, basic properties of the transition remanent magnetizations due to the Verwey transition are revealed as follows: (1) Directions of the remanences are parallel to directions of the ambient field (parallelism). (2) Intensities of the remanences are proportional to the weak magnetic field (proportion rule). (3) Median destruct fields (MDFs) are in the order corresponding to TrRM, TrWRM, and TrCRM. (4) Calculated values of TrWRM + TrCRM are well agree with TrRM in intensities and AF decay curves. Together with the results of chip-sample and TRM/TrRM acquisition experiments, we will discuss the detailed properties of the transition remanent magnetizations.

キーワード: transition remanent magnetization, magnetite, Verwey transition
Keywords: transition remanent magnetization, magnetite, Verwey transition

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SEM21-10 会場:301B 時間:5 月 25 日 13:45-14:00

地球ダイナモモデルにおける西方移動、ねじれ振動およびジャーク
Westward drift, torsional oscillations and jerks in a numerical geodynamo model

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Recent high-resolution, low-viscosity geodynamo simulations have shed a new light on the origins of geomagnetic secular variations of time scales shorter than the convective turnover time (about 500 years in the Earth's liquid outer core). Here I report some results of my ongoing project to physically explain relatively short time-scale secular variations such as geomagnetic westward drift and jerks. I performed geodynamo simulations using the Ekman number of 5 x 10^{-7} and the magnetic Prandtl number of 0.2 (Sakuraba and Roberts, 2009). These parameters are far away from those of the Earth's core but are hopefully small enough to investigate some basic features of magnetohydrodynamic (MHD) flows of low-viscosity rotating fluids. In this model, there are several strong magnetic flux patches in the low-latitudes on the core-mantle boundary (CMB), moving westward with the angular velocity close to that of the thermal-wind-type westward flow beneath the CMB. The azimuthal wavenumber (m) of the low-latitude flux patches is 5 to 7, which roughly coincides with the recent core-surface field estimated by Finlay and Jackson (2003). However, if scaled by the magnetic diffusion time, the angular velocity is too slow because the magnetic Reynolds number is not so large (about 200). This suggests that it is better to scale the time by the convective turnover time. Fourier analysis indicates that the drift angular velocity depends on both m and the latitude. The higher-wavenumber components ($m>5$) coherently move with the westward flow in the low-latitudes and the amplitude becomes weak in the high-latitudes. The lower-wavenumber components of m=1 and 2 show an intermittent feature in the low-latitude and sometimes move eastward, indicating existence of MHD waves. In the high-latitudes, there is a tendency that the field pattern, dominated by low-wavenumber components, moves eastward because the tangent cylinder rotates eastward in my model. I suggest that the Fourier analysis (not the spherical harmonic analysis) of the geomagnetic secular variation gives insight into the origin of the westward drift and the dynamics of the core convection. The torsional oscillations signify oscillatory motions of axial cylinders inside the fluid core that are propagated along the cylindrically radial (the s-) direction with the Alfven speed, which is considered to be much greater than the flow speed. The numerical model clearly shows the torsional waves traveling both inward and outward. There is a slight asymmetry between the ingoing and outgoing waves, suggesting the locality of the excitation source. The power spectrum of the wave motion at a constant radius indicates a tendency that longer-period waves contain greater power, but the propagation speed of those significant components are slower than the theoretically expected Alfven speed. The Alfven-type torsional waves have periods close to or shorter than the convective turnover time. The model also shows clear jerk-like secular variations if observed at the planet's surface. Small-amplitude jerks occur frequently and large-amplitude ones scarcely. Jerks are largely explained by the changes of the core-surface magnetic field of $1 < m < 7$. Presently, I try to understand the mechanism that creates jerk-like zigzag pattern in secular variations. The small-amplitude frequent jerks seem to be explained by the field disturbance due to torsional waves, as has been indicated by Bloxham (2002).

キーワード: 地磁気, 永年変化, 磁気流体力学
Keywords: geomagnetic field, secular variation, magnetohydrodynamics

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二重拡散対流と安定成層を考慮した地球ダイナモモデル
A geodynamo model with double diffusive convection and stable stratification

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In the Earth's fluid outer core, thermal convection is driven by superadiabatic temperature gradient due to internal heating and latent heat release at the inner core boundary, while compositional convection is fed by chemical buoyancy arising from inner core crystallization. In order to examine effects of co-existence of different driving sources of convection on dynamo action, double diffusive convection should be adopted by solving heat and compositional transport equations separately. In such a case, different diffusivities of heat and composition should be taken into consideration.

A stably stratified layer at the top of the Earth's outer core is inferred from seismic wave observations. The stratified layer is likely to be a result from light element accumulation due to inner core growth. The thickness of the stratified layer is estimated to be roughly O(100) km, which may be thick enough to affect convection and also dynamo action in the core, because the Ekman and thermal boundary layers are much thinner. In numerical dynamo models, the effects of the stratified layer is examined mostly by adopting the codensity approach. Codensity is modeled based on an assumption that thermal and compositional diffusion coefficients are equal because of turbulent diffusion, which should not hold in a stratified region. Thus, an approach of double diffusive convection is more suitable to investigate effects of the stably stratified layer.

Here, we perform a numerical study on convection-driven dynamo in a rotating spherical shell to explore the effects of different thermal and compositional state of the Earth's core. We take two effects into account in our numerical dynamo modeling: co-existence of thermal and compositional sources of convection, and stably stratified layer at the top of the core. Effects of the layer on convection and dynamo action with double diffusive convection are examined and will be reported.

キーワード: ダイナモ, 二重拡散対流, 安定成層
Keywords: dynamo, double diffusive convection, stable stratification

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Effects of heterogeneous boundary from mantle convection modeling in dynamo simulations in a rotating spherical shell

Effects of heterogeneous boundary from mantle convection modeling in dynamo simulations in a rotating spherical shell

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Numerical dynamo simulations in a rotating spherical shell with boundary heterogeneity at the top are used to investigate the possibility of dynamo solutions with the heat flux heterogeneity inferred from numerical thermo-chemical mantle convection simulations. Here we focus on the possibility to find the dynamo solutions with huge value of amplitude of heat flux heterogeneity and correlation between CMB and ICB heat flux. In order to evaluate boundary heterogeneity from mantle convection models, five scenarios are prepared: 1. Thermally uniform CMB, 2. CMB heat flux converted from seismic tomography based on Amit and Choblet [2009] ($q* = 0.5$), 3. CMB heat flux calculated from numerical mantle convection with recycled basalt, 4. CMB heat flux including the effect of continental lithosphere and 5. CMB heat flux including both effects of continental lithosphere and compositionally-distinct material in the CMB region. With thermally uniform and heat flux heterogeneity inferred from seismic tomography cases, the dipolar magnetic field is found at the top boundary and correlation between CMB and ICB heat flux seems to be good, which has been inferred from other study [Gubbins et al., 2011], because, for the tomographic case, the amplitude of heterogeneity is small so that the dipolar solution can be found. For cases of CMB heat flux calculated from numerical mantle convection simulations, the dynamo action is found with large amplitude of heat flux heterogeneity but not dipolar solution. Strong patches of magnetic field corresponding to large amplitude of CMB heat flux are found. The correlation between CMB and ICB heat fluxes is lower than for uniform and tomographic models. This means that the ICB heat flux does not tend to be the transparency of CMB heat flux. Since the heat flux heterogeneity inferred from numerical mantle convection is likely to be larger than the expected value from numerical dynamo simulations [Nakagawa and Tackley, 2008], the possible magnetic field features at the CMB seem to be more complicated than the expected.

キーワード: ダイナモシミュレーション, コアーマントル境界, 内核ー外核境界, マントル対流, 熱不均質
Keywords: dynamo simulation, core-mantle boundary, inner core boundary, mantle convection, heat flux heterogeneity

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CMB における熱的水平不均質構造に敏感な古代ダイナモ
Ancient dynamos more sensitive to core-mantle boundary heat flows

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地球および火星の初期ダイナモは、内核が存在しないコア内で駆動されていたと考えられている。したがって、そこでの対流の駆動源は主に、永年冷却および放射性元素による加熱だったと考えられる。一方、現在の地球ダイナモでは、内核の固化に伴う潜熱や軽元素の放出が、主な浮力源であると考えられている。

地球ダイナモにおける内核の成長の影響はながく議論されてきているが、未だ明らかではない。古地磁気や熱史計算に基づく先行研究でその影響が提唱されたが、近年の数値ダイナモ計算では、その影響は弱いだろうことが示されてきている。

火星に関していうと、マーズグローバルサーベイヤーによる観測により、火星地殻の残留磁化に強い南北二分性があることが明らかになった。この成因の一つとして、古代ダイナモによる説があげられている。下部マントルの影響により CMB に熱的水平不均質構造が形成され、それによって強制された古代ダイナモが、南北二分性をもつような磁場を生成した、という説である。しかし、ここでの一つの問題は、このようなダイナモがどの程度簡単に起こりうるか、という点である。

本研究では、内核が存在しないときのダイナモが、内核が存在するときと比べて、CMB における熱的水平不均質構造に対し敏感である、ということを示す。水平不均質な熱的境界条件を与えられた対流駆動型 MHD ダイナモにおいて、対流の浮力源が永年冷却および放射性元素による加熱の場合（内部発熱型）と内核に伴う潜熱の放出の場合（下部加熱型）とで比較を行った。その結果、内部発熱型のダイナモでは、より小さい CMB 熱的水平不均質によって、流れ構造および磁場強度が変化することがわかった。この結果は、古代地球または火星における磁場の強度や構造が、内核の成長が始まった後のものと比べて、CMB における熱的境界条件により敏感であり、より変化しやすかっただろうことを示唆する。

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回転球殻ダイナモに対する緯度方向不均一な内側浮力フラックス境界条件の影響
Effects of latitudinally heterogeneous buoyancy flux conditions at the inner boundary on MHD dynamo

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地球固有磁場の生成維持に寄与しているであろう外核中の流れは, 地球全体の冷却に伴い内核が固化成長する際の主成分の鉄およびニッケルの選択的な凝結により内核-外核境界 (ICB) へ放出される軽成分の浮力により生じると考えられている. 一方で, 近年の地震波観測から内核の結晶構造の異方性が明らかとなっており, その有力な成因として内核内部の流体運動が考えられるようになってきている (Karato, 1999; Yoshida et al., 1996; Takehiro, 2010). 考えられている内核中の流れ場の典型的なパターンは, 極から赤道あるいは赤道から極へ向かう軸対称なものである. このような流れ場が存在すると, 内核ー外核境界を通しての質量フラックスを伴うため, 境界表面における液体鉄の凝結過程に影響し, 結果として境界面で生じる浮力に緯度方向の不均一が生じることが予想される.

そこで本研究では, 緯度方向に不均一な浮力 (軽成分) フラックスを ICB にて与えた場合に外核中のダイナモ過程がどのような影響を受けるかを, 3 次元回転球殻ブシネスク磁気流体モデルを用いた数値実験を通して調べてみた. 内核は外核の流体と同じ密度と磁気拡散率を持つ電気伝導性の剛体であるとし, マントルの回転軸と同じ軸で異なる回転角速度で剛体的に回転することを許容した. 外核の流れ場に対しては境界で滑べり無し条件を課した. 浮力境界条件は, 外側境界において浮力フラックスが 0 である条件を与えた. 一方で, 内側境界で与える浮力フラックス分布は, 一様浮力フラックスに加えて球面調和函数 Y_2^0 の分布を与えた. 無次元パラメータは, 内径外径比を 0.35, プランドル数 を 1, エクマン数を 10^{-3} に固定し, 磁気プランドル数 Pm を 1 から 10, 修正レイリー数 Ra を 100 から 500 まで変化させた. 内側球面での浮力フラックスは, 1) 緯度方向に一様な分布, 2) 赤道で強く極域で弱い浮力フラックス分布, 3) 極域で強く赤道域で弱い浮力フラックス分布, の 3 通りをあつかった.

最初に磁場の存在しない静止場に対して 1 点軽成分濃度擾乱を与えて対流計算を実行し, 対流構造が統計的平衡状態に達した後に双極子磁場を球殻中に付与して MHD ダイナモ計算を行った. 磁場の影響のない発達した対流の流れ場には平均帯状流の分布を除いて大きな違いは見られなかった. しかしながら, MHD ダイナモ計算では磁場の発達維持の状態に大きな差があらわれた. 一様内側浮力フラックスの場合, および赤道域で強い内側浮力フラックスの場合には自励的に磁場が発達維持される解 (ダイナモ解) が得られた. Ra=300 の場合にもっともダイナモ解が発達維持しやすく, Pm が 3 以上の場合にダイナモ解が得られた. これよりもレイリー数を大きくしても小さくしてもダイナモ解が成立しづらくなり, Ra=100, 500 の場合には Pm = 10 でないとダイナモ解が得られなかった. これに対して, 極域で強い内側浮力フラックスを与えた場合には計算したパラメター範囲ではダイナモ解が得られなかった. このような磁場の発達維持の違いには, 浮力フラックス緯度分布の違いに伴う平均帯状流の差異が影響していると考えられる. 特に, 極域で強いフラックスを与えた場合には温度風バランスを通じて赤道内球付近での平均帯状流の向きが逆になり, 強いシアー層が形成されている. このシアー層が対流カラムを引き伸ばし, 局在化を妨げているのかも知れない.

極域で強いフラックスを与えた場合にダイナモ解が成立しなかったことは, 地球内核内部での流れの向きを示唆しているかも知れない. 強い地球磁場が生成維持されるためには極域に集中した浮力フラックス分布は適当でないかもしれないからである. このことは, 内核内部での軸対称的な流れが, すくなくとも極域から赤道への向きにはなっていないことが推測される. しかしながら, 調べたパラメターは現実の地球中心核のものとはかなり差があるので, より広いパラメターでの調査が必要である.

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キーワード: 内核異方性, 内核流れ, 浮力フラックス不均一, 組成対流, MHD ダイナモ
Keywords: Inner core anisotropy, Inner core flows, Heterogeneous bouyancy flux, Compositional convection, MHD dynamo

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地球コア内における非等方熱拡散率と熱的境界条件の影響
Effects of thermal boundary condition and anisotropic thermal diffusivity in the Earth's core

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Very small molecular viscosity of the Earth's core fluid gives rise to small-scale fluid motions, which are highly anisotropic because of the Earth's rapid rotation and a strong magnetic field. As a result, a large-scale diffusive process is to be enhanced by such flows in the core. This suggests that a thermal eddy diffusivity should not be a scalar but a tensor. We have been carrying out numerical simulations of magnetohydrodynamic (MHD) turbulence in a rapidly rotating system to investigate the effect of anisotropy on dynamics in the core, by prescribing elements of anisotropic thermal diffusion tensor.

It has been found that a certain degree of anisotropy has an insignificant effect on the character, like kinetic and magnetic energy, of magnetoconvection in a small region with periodic boundaries in the three-directions. However, in a region with top and bottom rigid boundary surfaces, the same degree of anisotropy can enhance kinetic and magnetic energy in magnetoconvection depending not only on prescribed anisotropic tensor diffusivity but also on location of the computational region expressed in terms of direction of gravity, or latitude. That is, anisotropic tensor diffusivity, consequent on the anisotropy of turbulent flows, affects dynamics in the core near the boundary surfaces depending on the latitude. We have so far imposed a fixed temperature boundary condition, but the argument above suggests that different thermal boundary condition may influence the dynamics in the core. We examine kinetic and magnetic energy in magnetoconvection for a fixed heat-flux boundary condition.
Keywords: anisotropic diffusivity, magnetoconvection, Earth's core