Japan Geoscience Union Meeting 2012
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SEM21-01 Room:301B Time:May 25 09:00-09:15

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.

Keywords: paleointensity, sediment, east Pacific, IODP, Oligocene, polarity reversal

SEM21-02 Room:301B Time:May 25 09:15-09:30

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.

Keywords: relative paleointensity, absolute paleointensity, welded tuff, tephra, calibration, LTD-DHT Shaw method

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SEM21-03 Room:301B Time:May 25 09:30-09:45

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 Room:301B Time:May 25 09:45-10:00

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

SEM21-05 Room:301B Time:May 25 10:00-10:15

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.

Keywords: tectonics, paleomagnetism, oroclinal bending, Cretaceous, Indochina, SE Asia

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SEM21-06 Room:301B Time:May 25 11:00-11:15

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.

Keywords: Paleomagnetism, Environmental rock-magnetism, Pelagic clay, IODP Exp.329, the South Pacific Ocean, GH83-3

SEM21-07 Room:301B Time:May 25 11:15-11:30

Paleomagnetism of Kiaman-aged basalts from the Tarim Basin

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Most of the numerical geodynamo simulations suggest that the superchron-like geomagnetic behavior results from reduced heat flux across the core-mantle boundary. This mechanism appears to be inconsistent with the Cretaceous Superchron, which was synchronous with vigorous mantle plume activity, implying the Cretaceous Superchron may not be a typical superchron. Kiaman superchron (ca. 310-260 Ma), on the other hand, was synchronous with a supercontinent, with which reduced plate subduction and reduced core-mantle heat flux are expected. A comparison between the Superchrons will clarify the relationship between the mantle activity and geomagnetic activity. However, compared to the Cretaceous Superchron, the geomagnetic behavior during the Kiaman Superchron is far less investigated. Here we report paleomagnetic results from ca. 290 Ma basaltic lavas from the Tarim Basin. Stepwise demagnetizations identify characteristic remanence directions that are consistent with previous researchs. Microscopic conglomerate test using a MI scanning magnetic microscope suggest randomly oriented remanence for basaltic clasts in coarse sandstone interbedded between the lavas. Thus, our basalt samples preserve the primary remanence. Preliminary paleointensity experiments using the Thellier-Coe method recovered intensity of 16.8 micro-T. This value is lower than the present-day field, and significantly lower than some estimates for the Cretaceous Superchron. However, microscopic observation identify multidomain-sized opaque minerals, and more sophisticated technique should be applied to obtain convincing paleointensity estimates.

Keywords: superchron, Permian, supercontinent, magnetic microscopy

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SEM21-08 Room:301B Time:May 25 11:30-11:45

Application of broad-band frequency spectrum of AC magnetic susceptibility: Grain-size distribution of SP particles

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Low-field alternating current magnetic susceptibility is among the most commonly used magnetic property, not only in rock and mineral magnetism but also in environmental magnetism studies. Particularly, frequency dependent susceptibility, defined as the change in susceptibility per decade frequency, has also been widely used for detecting the presence of fine-grained magnetic particles around SP to SD threshold. However, this conventional method is not sufficient to fully characterize SP-SD particles. This study proposes a new rock magnetic method for characterizing SP-size magnetic particles by measuring low-field alternating current magnetic susceptibility at a number of frequency steps spanning four orders of magnitude from 125 Hz to 512 kHz. Measurements were made for a set of natural samples, with various grain size distributions (GSDs), including loess and paleosol (Luochuan, Central Loess Plateau in China), and tuff (Yucca Mountain, Nevada). The resulting frequency spectrum of magnetic susceptibility (FSM) generally decrease with increasing frequency, but their rates of decrease were different. Quantitative estimates of GSD proposed in this study allowed reconstructing characteristic GSD patterns, demonstrating the difference in the GSD of SP particles in more contrasting and clearer fashion.

Keywords: rock magnetism, AC susceptibility, grain size distribution, superparamagnetism

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SEM21-09 Room:301B Time:May 25 11:45-12:00

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.

Keywords: transition remanent magnetization, magnetite, Verwey transition

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SEM21-10 Room:301B Time:May 25 13:45-14:00

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).

Keywords: geomagnetic field, secular variation, magnetohydrodynamics

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SEM21-11 Room:301B Time:May 25 14:00-14:15

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.

Keywords: dynamo, double diffusive convection, stable stratification

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SEM21-12 Room:301B Time:May 25 14:15-14:30

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.

Keywords: dynamo simulation, core-mantle boundary, inner core boundary, mantle convection, heat flux heterogeneity

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SEM21-13 Room:301B Time:May 25 14:30-14:45

Ancient dynamos more sensitive to core-mantle boundary heat flows

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The early dynamos of Earth and Mars probably operated without an inner core being present. They were thus exclusively driven by secular cooling and radiogenic heating, whereas the present geodynamo is thought to be predominantly driven by buoyancy fluxes which arise from the release of latent heat and the compositional enrichment associated with inner core solidification.

The impact of the inner core growth on the ancient geodynamo has been discussed extensively but is still controversial. While earlier paleomagnetic and thermal evolution models proposed a large impact, recent numerical dynamo simulations suggest that the effect on field would be rather minor.

As for Mars, the Mars Global Surveyor detected a strong northern-southern dichotomy in the crustal magnetization. A scenario proposed so far is due to such an ancient dynamo, where thermal heterogeneities at the core-mantle boundary (CMB) were imposed by the lower mantle structure. A key question for this scenario is how easily influence of the boundary anomalies emerges.

Here we show that the dynamos without inner core solidification are much more sensitive to the CMB heat flows imposed by the lower mantle structure. We compare three-dimensional convection-driven MHD dynamos either driven by homogeneously distributed internal heat sources or by buoyancy sources at the inner core boundary (ICB). Several different CMB heat-flux patterns are used. In the dynamos driven by internal heating a rather small CMB heat-flux heterogeneity suffices to break symmetries and leads to boundary-induced structures and different field strength. The effect is much smaller for dynamos driven by ICB associated buoyancy sources. The result indicates that the field intensity and morphology of the ancient dynamos of Earth or Mars were more variable and more sensitive to the thermal CMB structure than the geodynamo after onset of inner core growth.

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Effects of latitudinally heterogeneous buoyancy flux conditions at the inner boundary on MHD dynamo

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Outer core flows, contributing to generation and maintenance of the intrinsic magnetic field of the earth, is considered to be driven by buoyancy caused by the light elements released at the inner core boundary (ICB) through selective condensation of iron and nickel along with the inner core growth. On the other hand, existence of inner core flows has come to be studied as a candidate of the origin of the anisotropy of seismic velocity in the inner core (Karato, 1999; Yoshida et al., 1996; Takehiro, 2010). The typical flow pattern expected in the inner core is axisymmetric and flows are directed from the equatorial region to the polar regions or vice versa. Since such a flow accompanies mass flux through the ICB, it affects the condensation process of iron and nickel, and as a result, latitudinal heterogeneity of the buoyancy (light elements) flux is expected to occur at the ICB.

In the present study, we investigate effects of latitudinally heterogeneous buoyancy flux at the ICB on dynamo process in the outer core through numerical experiments of a 3-dimensional rotating spherical MHD Boussinesq dynamo model. The buoyancy flux vanishes at the core-mantle boundary (CMB), while the distribution of buoyancy flux at the ICB consists of a homogeneous component and a spherical harmonic function with degree 2 and order 0. Three types of the buoyancy flux at the ICB is considered; 1) homogeneous distribution, 2) strong flux around the equatorial region and weak flux around the polar regions, 3) strong flux around the polar regions and weak flux around the equatorial region. The ratio of the inner and outer radii, the Prandtl number and the Ekman number are fixed to 0.35, 1, 10^{-3}, respectively. The magnetic Prandtl number is varied from 1 to 10, and the modified Rayleigh number is from 100 to 500.

Firstly, numerical time integrations of purely compositional convection are performed starting with a point wise disturbance of light element concentration. After statistical equilibrium states are established, MHD dynamo calculations are performed by adding dipole magnetic field. Flow fields of fully developed non-magnetic compositional convection with different ICB buoyancy flux patterns are similar except for the distributions of mean zonal flow. However, a prominent difference in development and maintenance of magnetic field becomes apparent in the MHD dynamo calculations. Solutions with simultaneously developed and sustained magnetic field (dynamo solutions) are obtained in the cases of homogeneous buoyancy flux and strong equatorial flux. On the contrary, in the case of strong polar buoyancy flux, all solutions are failed to sustain the magnetic fields in the surveyed ranges of the parameters. This difference in development of magnetic fields is considered to be affected by the different pattern of mean zonal flow. In particular, in the case of strong polar buoyancy flux, direction of mean zonal flow around the inner core is reverse through the thermal wind balance and strong shear layer is produced there. This shear may stretch the convection columns and prevent localization of the vortex columns and magnetic field.

The consequence that dynamo solution cannot be established when strong flux is given around the polar region might suggest the flow direction of the earth's inner core, because such a buoyancy flux pattern may be unfavorable for development and maintenance of the strong geomagnetic field. It may not be expected that the inner core flows is directed from the polar regions to the equatorial region. However, since the values of the parameters dealt with the present study are quite different from those of the real central core of the earth, further investigation in more broad ranges of the parameter space is needed.

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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