回転球における遅い磁気流体波：レジスティブ不安定とアイデアル不安定

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Slow magnetohydrodynamic wave in a rotating sphere: Resistive and ideal instabilities

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The tendency that the geomagnetic field pattern observed at the surface slowly moves westward has been recognized as the geomagnetic westward drift. For example, relatively small-scale signals under Africa and the Indian Ocean are known to move westward at least for the last hundred years. The origin of the westward drift is not fully understood. It is possible to attribute it to advection because magnetic diffusion plays a secondary role, but it may be as a result of propagation of magnetohydrodynamic waves. Recent seismological studies suggest existence of a low-velocity layer at the top of the outer core. If this represents a stable stratification, it is unlikely that convection near the core surface creates the relatively small-scale drifting signal such as seen under the Indian Ocean. However, it may be more natural to consider that such field pattern and movement represents propagation of a wave confined in the stratified layer.

The magnetohydrodynamic wave in a rotating system, in particular a slow wave that is most relevant to the secular variation, is not fully understood. Previous studies mostly assume a cylindrical system in which a solution is periodic along the rotation axis. In this study, I perform a linear analysis on slow waves confined in a rotating sphere, assuming an axisymmetric toroidal field inside. In particular, I focus on magnetic instability and summarize the results obtained for various basic magnetic fields. When the magnetic field intensity is relatively weak, a resistive mode occurs with a slow eastward propagation. The critical wavenumber becomes higher with a more localized magnetic field near the equator. When the magnetic field is strong, at least greater than 10 mT, an ideal mode occurs with a rapid westward propagation. This mode is enough to explain the geomagnetic westward drift, but the critical intensity might be too high.

地表で観測される磁場のパターンがゆっくりと西方に移動するという現象は，地磁気西方移動として古くから認識されている。たとえばアフリカからインド洋にかけてみられる比較的短波長の地磁気パターンは，過去１００年程度にわたって，赤道に沿って西向きに移動していることが知られている。地磁気西方移動の原因は，きちんと理解されているわけではない。地磁気西方移動を含め，数十年から数百年程度の時間スケールをもつ地磁気永年変化は，磁気拡散の影響が小さいと見積もられることから，単純に移流の結果として解釈されることが多いが，一方で，磁気流体波動として解釈することも可能かもしれない。とくに，最近の稠密な地震観測網により，外核最上部に地震波の低速度領域が存在することの確実性が高まっている。もしこれが安定成層を示すものだとすると，そこでは磁場を増幅するような活発な対流運動が抑えられるため，たとえばインド洋近辺の短波長のシグナルを長期間維持するメカニズムはなかなか考え難い。しかし波動という観点でみれば，安定成層という空間スケールによって規定される固有のパターンが磁気流体力学的な復元力で伝搬している，というふうに自然に解釈できるかもしれない。

回転する系での磁気流体波動，とくに地磁気永年変化と関係するであろう「遅い波」については，すでに５０年以上の研究の歴史がある。しかし過去の研究では，主として円筒座標系をもちいていて，自転軸方向に周期性をもった解を仮定することが多い。地球のコアに直接適用可能な，回転球内の波動伝搬を扱った研究は少ない。そこで本研究では，回転球内に軸対称なトロイダル磁場を仮定し，その基本場に沿った無限小振幅の擾乱について固有モード解析をおこなった。とくに波の振幅が増幅する磁気不安定に着目し，臨界磁場強度と波の伝搬方向を，さまざまな基本磁場構造のもとでまとめた。まず比較的低い磁場強度で起こるレジスティブ不安定については，基本的には東向き伝搬で，伝搬速度は「遅い」時間スケールで規定される。基本磁場を赤道付近に局在させると，より高波数のモードが不安定になる。いっぽう比較的強い磁場強度で起こるアイデアル不安定も見出された。このモードは基本的に西向き伝搬で，伝搬速度は比較的速い。これは地球の磁気西方移動を説明するにじゅうぶんである。ただし必要な磁場強度は，コアの電気伝導度を考慮すると少なくとも 10 mT 以上であり，実際に存在するかは疑わしいかもしれない。

On a possibility to detect a stratified layer at the core surface from the geomagnetic field

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Recent seismic studies suggest that there may exist a stably stratified layer at the top of the Earth's outer core. This means that upwelling and downwelling flows should not exist just below the core-mantle boundary. Fluid motion at the core surface can be derived from the spatial distribution and secular variation of the geomagnetic field observed at the Earth's surface. Most of core flow models are estimated on the basis of the frozen-flux hypothesis, where the magnetic diffusion term is neglected in the induction equation.

We have developed a new method to estimate the core surface flow; that is, we take into account the magnetic diffusion inside the boundary layer at the core surface, while we neglect the magnetic diffusion below the boundary layer as in the frozen-flux approximation. In the method, the thickness of the boundary layer is one of parameters. This indicates that it might be possible to examine the existence of upwelling and downwelling just below the core-mantle boundary. Hence we attempt to detect a stratified layer at the top of the core using such parameterization.

コアーマントル結合熱史シミュレーションによって推定される磁場進化史

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On magnetic evolution inferred from a coupled core-mantle evolution

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We investigate the magnetic evolution over the geologic time-scale in a coupled core-mantle evolution model. The core evolution model is updated to include the pressure-dependent density profile fitted with PREM model and higher order effects. Evaluating the magnetic evolution, we use magnetic dissipation from core energetics and magnetic moment calculated from scaling law derived from geodynamo simulations. The heat flow across the core-mantle boundary (CMB) is substantially lower than the isentropic heat flow. This results that the thermal buoyancy flux caused by the core convection is likely to be the negative and completely cancels out the compositional buoyancy flux if the core thermal conductivity uses the recent range provided from high P-T physics. In this situation, the magnetic field generation is stopped. Thus, the continuous magnetic evolution over geologic time is difficult with high core thermal conductivity. Whereas, the continuous magnetic field generation would be expected when the core thermal conductivity is smaller than the lower-bound from recent high P-T physics. In addition, the sub-isentropic region below the CMB would be found with O(1000) km thickness. This means that the entropy production would not be uniform thus the assumption for computing magnetic dissipation and magnetic moment should be improved.

Testing a toroidal magnetic field imaging method using a numerical dynamo model

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The geomagnetic main field and its secular variations measured by orbiting satellites and at magnetic observatories correspond to those of the poloidal constituent, whereas the toroidal counterparts, which are bound to the core, are not observable above the core-mantle boundary (CMB). Constraining the strength and spatial distribution of the toroidal component of the geomagnetic field is essentially important to understand not only the dynamics of the geodynamo, but also the electromagnetic core-mantle coupling, one of a possible mechanisms of decadal variation in length of day.

A global distribution of the toroidal field at the CMB can be estimated by a method based on a core flow model inverted from the radial components of the geomagnetic field and its secular variation via frozen-flux approximation. However, there is no guarantee that the inverted core flows and the toroidal fields are unique, and no way to investigate how well the true distribution is retrieved from such a highly non-unique flow model. Here we quantitatively test a method of toroidal field imaging at the CMB using synthetic magnetic field and core surface flow data from a 3-D self-consistent numerical dynamo model with a thin electrically conducting layer above the CMB, like the D" layer. With complete knowledge of the core flow, the imaged toroidal field well reproduces magnitude and pattern of the dynamo model toroidal field. However, quality of the imaging depends strongly on latitude. In particular, amplitude and correlation between the dynamo model and the imaged toroidal field decline substantially at low-latitude. Such degradation in imaging quality is due to the fact that the low-latitude flux patches in the radial magnetic field are manifested as a result of flux expulsion, an effect of magnetic diffusion, which is not incorporated in the method.

Precession control on precipitation in the Western Pacific Warm Pool inferred from environmental magnetism

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The Western Pacific Warm Pool (WPWP) has highest water temperature in the global ocean, and its spatiotemporal variations have significant impacts on large-scale atmospheric circulation and global hydrology. An environmental magnetic study was conducted on ˜10 sediment cores taken from the West Caroline Basin offshore northern New Guinea in order to constrain hydrological variability over the WPWP on orbital timescales. The sediment cores cover the last several hundreds of thousand years. The age control of the cores is based on relative paleointensity, which is tied to the oxygen isotope stratigraphy in some cores.

Magnetite dominates magnetic mineral assemblages of the studied sediments. This is evidenced by that IRM acquisition curves are mostly explained by a low-coercivity component, and that the Verwey transition was obvious in low-temperature measurements. Existence of the sharp central ridges on FORC diagrams and TEM images indicate the occurrence of biogenic magnetite. Compared with pelagic sediments from other regions, however, FORC diagrams show a larger contribution of an interacting PSD and MD component, and the ratios of ARM susceptibility to SIRM (kARM/SIRM) are lower. These observations suggest a larger proportion of the terrigenous component in this region. This is probably due to a large terrigenous sediment input from nearby land, New Guinea, induced by high precipitation in the inter-tropical convergent zone (ITCZ).

Magnetic susceptibility and the kARM/SIRM ratio show strong correlation with northern-hemisphere summer insolation. Maxima in magnetic susceptibility and minima in kARM/SIRM correspond to insolation minima, which suggests a larger terrigenous input caused by higher precipitation at these times. Interestingly, in the western part of the West Caroline Basin magnetic susceptibility variations are dominated by the eccentricity periodicity (˜100 ky) and mimic the oxygen isotope curves, but the precession periodicity prevails in kARM/SIRM ratios. These cores were taken at depths close to the CCD, and thus the magnetic susceptibility variations cannot be explained by dilution caused by changes in carbonate production/preservation. Sedimentation influenced by global sea-level changes may control the magnetic susceptibility variations; this part of the basin is adjacent to a wider continental shelf compared with the eastern part of the basin.

北西大西洋ニューファンドランド沖のIODP Site U1403から採取された海洋コアの古地磁気層序と年代モデル

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Magnetostratigraphy of the marine sediment cores recovered from IODP Site U1403 in the Northwest Atlantic, off Newfoundland

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Marine sediment is an important recorder of the past environmental changes. It can provide important information to investigate the environmental change continuously back in time, once a high-resolution age model is constructed by multiple techniques. Integrated Ocean Drilling Program (IODP) Expedition 342 recovered marine sediment cores from the Northwest Atlantic, off Newfoundland, to investigate the environmental change from the Paleocene to the Eocene. For the investigation, construction of the high-resolution age model based on magnetostratigraphy is indispensable. We conduct paleomagnetic measurements on the 28-160 mcd (meter composite depth) interval of marine sediment cores drilled from Site U1403, and construct an age model based on the paleomagnetic measurement results.

In the measurements, we perform stepwise AF demagnetization (20-80 mT) on natural remanent magnetization of the sediments. The demagnetization results were analyzed by the principal component analysis (kirschvink, 1980) to determine characteristic (primary) components. The determined components mainly resulted in two groups: (1) inclination ranged between +15 and $+60^0$, and declination ranged between -30 and $+30^0$ (approximately north direction); (2) inclination ranged between -60 and -15^0, and declination ranged between +120 and $+210^0$ (approximately south direction). The group (1) could be regarded as normal polarity while the group (2) as reversed polarity. In total we recognized 22 polarity reversals within the studied interval (28-160 mcd).

We correlated the obtained reversal pattern with a standard geomagnetic polarity time scale (Geologic Time Scale 2012; Gradstein et al., 2012) to determine a magnetostratigraphy. The correlation was made to be consistent with the shipboard biostratigraphy (e.g. radiolarian and nannofossils; Norris et al., 2014). The resultant magnetostratigraphy indicates that the studied interval (28-160 mcd) corresponds to Chrons C16n.1n-C22n (35.706-49.344 Ma). There are 22 polarity reversals recognized in the interval, and thus we construct an age model based on the 22 control points. It reveals that sedimentation rate is about 0.3 cm/kyr for early Eocene, 0.5-1.5 cm/kyr for middle Eocene and 0.5 cm/kyr for late Eocene. The rate for middle Eocene is relatively large among marine sediments covering this time interval recovered so far. It is expected that past environmental and paleomagnetic changes can be investigated with high-resolution for this time period.

海底堆積物は過去の環境変動を時間的にほぼ連続して記録している試料であり、地質時代に遡る環境変動を解明する上で重要な情報源となる。統合国際深海掘削計画 (IODP) 第 342 次研究航海では、暁新世から始新世の気候変動解明を目的に、北西大西洋ニューファンドランド沖から海底堆積物が掘削された (Expedition 324 Scientisits, 2012)。目的の達成には掘削されたコアの高精度な年代モデルの構築が不可欠であり、古地磁気学的手法に基づいた年代モデルの構築は一つの重要な柱である。本研究では Site U1403 から掘削された海洋コア (28-160 mcd: meter composite depth) を対象に古地磁気測定を行い、年代モデルの構築を試みた。

主として自然残留磁化の段階交流消磁 (20-80 mT) および測定を行った。測定結果に対して主成分解析を適用して初生磁化方位を決定し、古地磁気極性を判定した。測定結果は、主に伏角が$+15^{\sim}+60^0$; および偏角が$-30^{\sim}+30^0$(北向き) を示す層準と、伏角が$-60^{\sim}-15^0$ および偏角が$+120^{\sim}+210^0$(南向き) を示す層準とに二分された。(偏角は未補正値を除く)。これらはそれぞれ、正帯磁、逆帯磁の層準と判断でき、深度 28-160 mcd の区間に計 22 回の極性反転が記録されていたことが明らかになった。

得られた極性の反転パターンを、船上初期分析により得られている放散虫およびナンノ化石生層序 (Norris et al., 2014) と最も整合的となるように地磁気極性年代表 (Geologic Time Scale 2012; Gradstein et al., 2012) と対比させ、古地磁気極性層序を決定した。その結果、28-160 mcd の区間はクロン C16n.1n-C22n (35.706-49.344 Ma) に相当すると推定された。この間に 22 回の極性反転が記録されており、22 点のコントロールポイントからなる年代モデルを構築することができた。堆積速度は始新世初期で約 0.3 cm/kyr、中期で約 0.5-1.5 cm/kyr、後期で約 0.5 cm/kyr となる。この時代をカバーする海洋堆積物としては、始新世中期における堆積速度が比較的速い。そのため、この期間における古環境変動および古地球磁場変動を高時間分解能で復元可能と期待される。

Resolving the components of the North Atlantic sediments by IRM acquisition experiments at room- and low-temperatures

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In general, a sediment sample is composed of various components. Resolving the components of the sediment sample is a fundamental issue in an oceanographic study. Since a coercivity of magnetic mineral varies sensitively with its state such as chemical composition, grain size, grain shape, stress, and so on (e.g., Dunlop and Ozdemir, 1997), sediments of different origin can be recognized by coercivity spectra. Therefore, coercivity spectra can be used as a proxy for the constituent spectra of the sediment sample. In this study we conducted rock-magnetic measurement of deep-sea sediments recovered from IODP Site U1314 on the Gardar Drift, to investigate the change in the sediment constituents.

The samples were collected at 16-50 cm resolution from 199.3 to 262.5 mcd of the core, which corresponds to the age between 2.22 and 2.75 Ma according to the age model by Hayashi et al. (2010). Rock-magnetic properties at room temperature were measured for these samples using a MicroMag 2900 Alternating Gradient Magnetometer at Kyushu University. The isothermal remanent magnetization (IRM) acquisition curve was obtained by the application of stepwise-increasing uniaxial fields to the sample at 30 steps from 1 mT to 1 T. The ratio of IRM acquired in a back-field of 0.1 T to that in a forward-field of 1 T (S-ratio) was measured for all samples. In addition, using an MPMS-XL5 Magnetic Property Measurement System at the Center for Advanced Marine Core Research, Kochi University, we carried out the IRM acquisition curve measurements at low-temperatures (50, 150, and 250 K) for selected samples.

In order to reveal constituents of the sediment, decomposition of coercivity spectra were conducted. The IRM acquisition curve was normalized by the IRM intensity at 1 T and then the first derivative of the curve was calculated with respect to log10 field (hereafter referred to as IRM gradient curve). A fitting calculation was performed so as to decompose the IRM gradient curve into linear combination of two end-members. The two end-member components were calculated by averaging the IRM gradient curves of selected samples. Samples with low S-ratio (less that 0.54) were chosen for component 1. Samples with high S-ratio (larger than 0.87), which were associated with the ice rafted debris, were chosen for component 2. These components were distinctly different from each other; coercivity distribution of component 1 was magnetically harder than that of component 2.

In consequence of the decomposition, the fitting error was significantly small for all samples. Thus it is confirmed that North Atlantic sediments in the Garder Drift during late Pliocene and early Pleistocene are explained by mixing of two end-member components. Taking into account temperature variation of the IRM acquisition curves at low-temperature, we will discuss change in the sediment constituents.

北半球における大規模な大陸氷床発達前後の深層水循環の変遷

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Evolution of deep water circulation in the North Atlantic after intensification of Northern Hemisphere glaciation

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Ice sheets linked with ocean circulation play an important role in global climate change. Here we show millennial-scale rock magnetic records together with ice rafted debris (IRD) counts indicating links between ice sheet collapse and ocean circulation after the intensification of Northern Hemisphere glaciation (NHG). We report an abrupt change in the activity of water circulation associated with an IRD event in Marine Isotope Stage (MIS) 104 weakened to a similar degree to that occurred in MIS 100, the first pronounced glacial period in which widespread glaciation occurred in the northern hemisphere at the intensification of NHG.

We analyzed a sediment core IODP Site U1314 in the Gardar Drift in the North Atlantic. In this study, we analyzed sediments from 239.5 to 245.5 mcd (m composite depth) at 2 cm resolution, which corresponds to the age between 2.58 and 2.62 Ma according to the age model by Hayashi et al. (2010). This interval includes MIS 104, which is a prior glacial interval to MIS 100. We compare the result in MIS 104 to that in MIS 100 in the preceding study (Ohno et al., 2013, SGEPSS).

Magnetic hysteresis parameters, S-ratio (Mr_{-100mT}/Mr_{1T}) and IRM (isothermal remanent magnetization) acquisition experiments were done by using an Alternating Gradient Magnetometer (MicroMag 2900, Princeton Measurement Corporation). We sieved 0.5 g sediments and counted IRDs larger than 150 um. As a result, two IRD events were confirmed at about 2.602 Ma and 2.610 Ma.

Rock magnetic records showed 2 types of changes: a long-term change with glacial-interglacial cycle and a short-term change associated with an IRD event. Long-term change in magnetic coercivity (Hc) occurred at 2.58-2.61 Ma (for thirty thousand years) with an amplitude of 5 mT (from 20 to 15 mT). Short-term change associated with an IRD event occurred at 2.602 Ma and the value of Hc decreased by 7 mT (from 18 to 11 mT) for about thousand years. Then it increased to the value before the event after a time interval of 10 thousand years.

In our previous study in MIS 100, we reported repetition of sudden decrease and gradual increase of magnetic coercivity associated with IRD events. We interpreted these changes in magnetic coercivity with the change in the intensity of deep water circulation. It is well known that the continental ice sheets grew much larger in MIS 100 compared to in MIS 104. However, our study suggests the comparable level of decrease in deep water circulation occurred at not only in MIS 100 but also in MIS 104. It may be related with the difference in distribution of continental ice sheets between in MIS 100 and in MIS 104.

大陸氷床の発達・崩壊は気候変動に大きな影響を及ぼすと考えられているが、約 2.75 Ma に北半球に氷床が出現し、その後発達していった時期の詳細な気候変動については未解明な点が多い。本研究では、北大西洋で採掘された堆積物コア試料についてミレニアルスケールの岩石磁気測定を行い、その結果と氷山起源の漂流岩屑 (IRD) カウントの結果を比較することで、深層水循環と氷床量変動との関係について議論を行う。既に同堆積物コア試料について、大陸氷床が初めて大規模に発達したとされる海洋酸素同位体ステージ（MIS）100 付近 (2.50- 2.55 Ma) の分析結果が報告されている (大野ほか 2013, SGEPSS)。そのため、本研究ではその直前に当たる MIS104 付近 (2.58- 2.62 Ma) の試料について、測定・解析を行った。岩石磁気測定と IRD 数カウントの結果、MIS104 においても約 2.602 Ma に氷床の崩壊に伴う北大西洋深層流の変化が確認された。

測定に用いた試料は、IODP 第 306 航海においてアイスランド南方のガーダードリフトで採取されたコア試料（Site U1314： 北緯 56 度 22 分、西経 27 度 53 分、水深 2820 m）である。この海域周辺は、アイスランド北方で形成された北大西洋深層流の流路となっている。本研究では、239.5-245.5 mcd (m composite depth) の堆積層を 2 cm 間隔毎で分析した。Hayashi et al. (2010) の年代モデルを適用すると、約 2.58-2.62 Ma の間を約 100 年間隔で分析したことに相当し、堆積速度は約 10 cm /kyr となる。

岩石磁気測定は、凍結乾燥させた試料 (約 5- 10 mg) を 10 mm x 8 mm のアルミ箔に包み行った。交番磁場勾配磁力計 (MicroMag 2900, Princeton Measurement Corporation) を用いて、磁気ヒステリシス測定、S-ratio 測定 (Mr_{-100mT}/Mr_{1T})、等温残留磁化 (IRM) 獲得曲線測定を行った。IRM 獲得曲線測定では、交流消磁の後、1 mT- 1 T まで 30 段階で測定を行った。また、堆積物試料 0.5 g あたりの IRD(粒径 150 μ m 以上) 数をカウントした。

IRD 数カウントの結果、IRD の堆積するイベントが 2 回、約 2.602Ma と約 2.610Ma に確認された。これに対し、岩石磁気測定の結果、氷期・間氷期サイクルに対応する長周期の変化と、約 2.602Ma の IRD イベントに対応する急激な変化の 2 種類の変化が確認された。長周期の変化としては、2.58- 2.61Ma の約 3 万年間に振幅約 5 mT(20- 15 mT) の保磁力の変化が確認できた。また、約 2.602 Ma の IRD イベントに対応する変化として、約 1000 年間に振幅約 7 mT (18-11 mT) の急激な保磁力の低下が起こり、その後、約 1 万年間かけて緩やかに IRD イベント前の値に増加していくことが確認で

きた。一方で、約 2.610Ma の IRD イベントの前後では、大きな保磁力の変化は確認できなかった。また、ガウス・松山地磁気逆転境界において、約 5 千年間に振幅約 2.7 mT (19.5-16.8 mT) 程度の保磁力の低下が確認された。これまでの研究から、これらの保磁力の低下は、北大西洋深層水の流れが弱くなったことを表していると解釈される。

IRD イベントの際に確認された保磁力の変化は、MIS100 付近の堆積物試料でも確認されており、その保磁力変化は最大で約 5 mT(17-12 mT) である。MIS104 で確認された変化は MIS100 における変化と振幅・絶対値において同程度の値である。したがって、大陸氷床量が MIS100 よりも少なかったとされる MIS104 においても、MIS100 と同様な氷床の崩壊に伴う北大西洋深層流の変化が起こったと考えられる。これらの現象は MIS100 と MIS104 における大陸氷床の分布と密接に関係している可能性がある。

地震性タービダイトを含む東北沖深海堆積コアの古地磁気永年変化の記録

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Seismo-turbidite stratigraphy assisted by paleomagnetic secular variation of the North Japan.

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Turbidite sequence trapped in the lower slope terrace, Japan Trench were widely collected in order to reconstruct a earthquake occurrence of Tohoku region, North Japan. Major lithology of obtained cores is diatomaceous hemipelagic clay including several turbidite layers. Hr-FP tephra patches/layers derived from Honshu arc during 500-600 years A.D. (Usami et al., 2014) are widely recognized in the cores. We measured NRMs of 23 cores so far. Magnetizations are generally stable to A.F. demagnetizations. They are composed of a single component usually. In many cases, medium destructive field (MDF) ranges from 20 to 40mT. However, MDF is the lower as 5-10mT in case of turbidite layers. Variation of declination shows systematic shift within 60 degrees. Comparing references, which are archeomagnetic and sediment paleomagnetic data during the past 3000 years, the data show a good agreement to the references. The secular variations of cores hopefully contribute to date the seismo-turbidite stratigraphy.

2011年3月11日の地震津波により混濁流が発生し，斜面を流れ下ったと考えられている（e.g. Arai et al., 2013）．こういった混濁流は広く斜面の小海盆でトラップされ地震記録として保存されると考えられる．日本海溝の下部陸側斜面に発達する平坦面（4000-6000m）には沈み込む海洋プレートの複雑な構造に起因して形成された小海盆が発達している．こういった小海盆群で過去の東北地震発生の時間的空間的分布を求める事ができるか知るため南北300kmの範囲から採泥調査をおこなった．採取されたコアは珪藻質細粒堆積物からなり，ほとんどのコアにタービダイトの挟在が見られた．また歴史時代に噴出したテフラがパッチ状あるいは層状に挟在し，さらにいくつかのコアでは堆積速度が比較的一定である事が確認されている（宇佐見ほか2014）．コアの残留磁化の記録に永年変化が見られるか検討を行った．残留磁化は多くの場合一成分で，ほとんどのMDFは20mT-40mTである．一方タービダイト層では5-10mTになる．火山灰層準を基準にそれぞれのコアの深度方向の古地磁気偏角を検討したところ，多くのコアに変動幅60度程度で同期した変動が見られた．すなわちコアの表層から6世紀までに1回の東編と6世紀付近で西編，また6世紀以前に比較的鋭い東編を示す．こういったデータを既存の西南日本の考古地磁気データ，湖堆積物データ，グローバルモデル等と比較すると偏角の変動は1000年B.C.程度まで対比できる．一方，伏角のデータは永年変化を印画したコアも見られるが不明瞭な場合が多い．これは永年変化伏角の変動周期が，偏角のそれと比べると小さいため堆積物磁化獲得時のフィルタリング効果が働いていると推測される．すなわち偏角の周期の記録には十分であるが伏角の永年変動の振幅を記録するほど十分な堆積速度がないため多くのコアでは伏角対比が難しいと推定される．これまで東北地方の永年変化記録が確立されていないため重要な指標となることが期待できる．また大水深のため炭素14年代法が適応できない東北沖の深海地震性タービダイト層序の確立に大きく貢献できることが期待される．

中新世後期における野間エクスカーション期間中の古地磁気強度の推定

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Paleointensity study of the Noma excursion in late Miocene times

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A geomagnetic excursion is one of the largest geomagnetic variations, and detailed paleointensity data through a geomagnetic excursion have been expected to give important information of the dynamic processes of the geodynamo. We study about paleointensities of a geomagnetic excursion named Noma excursion in Miocene times (6.66+/-0.45Ma) (Otofuji et al., 2013) from andesitic lava sequence exposed in the Mt. Kamegaoka (31^{o}21'N, 130^{o}13' E), Noma Peninsula, Kyushu Island. For direction variations of the Noma excursion, reversed polarity directions are detected in the bottom and uppermost parts of the sequence, whereas anormalously positive inclinations have been observed in the middle parts of the sequence. About 170 oriented samples were collected from 13 consecutive lava flows, covering an area from mountain top to sea shore. In this presentation, we report paleointensities of the Noma excursion determined by the LTD-DHT Shaw method. We applied the LTD-DHT Shaw paleointensity metod to 40 samples from 11 consecutive lava flows which were selected with the reason of high blocking temperature and secondary component with low coercivity. Similar to previous studies (e.g. Yamamoto et al., 2003; Mochizuki et al., 2004; Oishi et al., 2005), we use following 3 criteria. (1) A primary component is recognized in the orthogonal plots obtained from AF demagnetization of the NRM. (2) A linear portion exsist in the NRM-TRM1$*$diagram, which is not less than 15% of the original NRM intensity and its correlation coefficient is not smaller than 0.995. (3) A linear portion also exisits in the TRM1-TRM2$*$diagram. The slope of the linear portion must fall within the range 1.00+/-0.05. These 3 criteria distinguished 20 successful results from 6 lava flow. These successful results include samples from the bottom, middle and uppermost parts of the lava sequence. Average paleointensities are calculated as 9.1+/-4.4 micro T for NM36 (the bottom part of the sequence), 2.0+/-0.4 micro T for NM32-3, 7.1+/-4.0 micro T for NM32-1, 7.8+/-4.1 micro T for NM32 (the middle parts of the sequence) and 7.1+/-3.5 micro T for NM13 (the uppermost part of the sequence). These results show the low intensity field is observed during the excursion in Miocene times and also the low intensity field is recognized before and after the large directional change of the excursion.

地磁気エクスカーションは地球磁場の大きな変動であり、地磁気エクスカーションの古地磁気強度の詳細なデータは地球ダイナモの重要な情報となる。我々は九州地方・野間半島の亀ヶ岡の溶岩連続層から既に報告されている中新世後期 (6.66+/-0.45Ma) のエクスカーション (野間エクスカーション : Otofuji et al., 2013) を対象として古地磁気強度測定を行った。野間エクスカーションの方位変化については溶岩連続層の最下層と最上部層では逆磁極を、中間層では伏角が正の異常な方向を示す。強度測定に使用するサンプルとして、約 170 個の方位付けされたサンプルを山頂から海岸にまでわたる 13 の安山岩質溶岩連続層から採取した。段階熱消磁において 550 ℃から 600 ℃にブロッキング温度を持ち、段階交流消磁において低保磁力で二次磁化が除去できているサンプル (11 溶岩層、40 サンプル) を選び、ショー法を用いて測定した。これまでの強度研究 (e.g. Yamamoto et al., 2003; Mochizuki et al., 2004; Oishi et al., 2005) に従って、信頼できる強度を得るために以下の 3 つの判定基準を用いている。(1)NRM の段階交流消磁結果を示す直交座標系において直線成分が初生磁化として存在すること。(2)NRM-TRM1$*$のグラフにおいて直線成分が存在し、その成分がもともとの NRM 強度の 15%以上 ($f_N \geqq 0.15$) であり、相関係数が 0.995 以上である ($r_N \geqq 0.995$) こと。(3)TRM1-TRM2$*$のグラフにおいて (2) と同様の条件 ($f_T \geqq 0.15$, $r_T \geqq 0.995$) の直線成分が存在し、その直線成分の傾きが 1.00+/-0.05($0.95 \leqq \mathrm{slope}_T \leqq 1.05$) であること。以上の 3 つの判定基準により 6 つの溶岩層から 20 サンプルの古地磁気強度を得た。これらの古地磁気強度は溶岩連続層の最下部、中間部そして最上部のサンプルに相当するものである。平均古地磁気強度は、最下部の NM36 については 9.1+/-4.4 micro T であり、中間部の NM32-3、NM32-1、NM32 についてはそれぞれ 2.0+/-0.4 micro T、7.1+/-4.0 micro T、7.8+/-4.1 micro T であり、最上部の NM13 については 7.1+/-3.5 micro T であった。以上の結果から中新世においてもエクスカーション期間中は地磁気強度が低く、エクスカーションにおける大きな方位変化の前後においても地磁気強度が低いと結論づけた。

陶邑試料より推定される5〜9世紀の西日本における考古地磁気強度

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Archeointensity results between 5th and 9th century in western Japan obtained from baked-earth samples of the Sue-Mura kilns

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There are 4 published studies which report archeointensity results for the past 2000 years in Japan (Nagata and Arai, 1963; Sasajima and Maenaka, 1966; Sakai and Hirooka, 1986; Yoshihara et al., 2003). These studies provide 76 independent site-mean archeointensity results. 43 site-mean results of them are considered to be reasonably reliable because they are screened ones by criteria that (1) results derived from archeological materials, (2) number of the successful samples for calculating site-mean is not less than two, (3) standard deviation of the site-mean is within its 20%. Some of the 43 site-mean results show inconsistency among ones which are reported to have the same ages, and the inconsistency sometimes beyond 20 microT.

In this study we present new archeointensity estimates from western Japan for a period of 5th to 9th century, which are obtained using a modern paleointensity experimental protocol. The experiments are conducted on baked-Earth samples which were collected from Sue-Mura kilns (14 sites) in the hill zone of Senboku, Osaka prefecture. The estimated ages based on pottery sequence range between 470 AD and 790 AD (e.g. Education board of Osaka prefecture, 1970; 1976; 1977). Archeointensity measurements are done by using IZZI-Thellier method (Tauxe and Staudigel, 2004), and the obtained results are judged by the following selection criteria: (1) Arai diagram showing neither curvature nor two segments; (2) linear segment showing correlation coefficient of |r|is 0.98 and more; (3) paleointensity parameter; f is 0.35 and more; (4) paleointensity parameter; drat is 0.07 and less.

Preliminary application of the IZZI Thellier method has given each one successful result from 5 sites: Komyo-Ike-3 kiln (610+-10 AD) is 61.4 microT (n=1), Komyo-Ike-11 kiln (630+-10 AD) is 62.1 microT (n=1), Toga-40-III kiln (720+-10 AD) is 41.1 microT (n=1), Komyo-Ike-102 kiln (750+-10 AD) is 67.1 microT (n=1), and Komyo-Ike-38-II kiln (770+-10 AD) is 52.6 microT (n=1). They are generally consistent with the 43 reliable site-men screened from the published archeointensity results in Japan. We will continue the archeointensity measurements and report them.

過去2000年間の日本における考古地磁気強度に関しては、これまでに4編の論文報告 (Nagata and Arai, 1963; Sasajima and Maenaka, 1966; Sakai and Hirooka, 1986; Yoshihara et al., 2003)) が行われており、その永年変化の傾向について議論がなされてきた。これらの先行研究では年代的に独立した76サイトからの強度値が報告されているが、(1) 考古学的な遺物に由来するデータ、(2) 各サイトにおける合格試料数が3個以上、(3) サイト平均値に対する標準偏差が20%以内のものに限定すれば、信頼度が比較的高いデータは計43個と少なくなる。また、ほぼ同一年代とされる異なるサイトから報告されている強度の不一致も大きく、その差が20 microTを超える年代期間もある。

これらを踏まえ、本研究では最新の実験手法を用いて推定された5〜9世紀の西日本における新たな考古地磁気強度を報告する。用いた焼土試料は、大阪の泉北丘陵周辺に分布する陶邑窯跡群 (14サイト) より採取されたものである。土器編年に準拠する年代値は470+-10年 (陶器山-70窯跡)〜790+-10年 (光明池-38-I窯跡) である (e.g. 大阪府教育委員会, 1970; 1976; 1977)。考古地磁気強度測定はIZZI-テリエ法 (Tauxe and Staudigel, 2004) を用いて行った。なおデータの選別には (1) 広い温度区間に渡ってアライ・ダイアグラムが直線的であるもの、(2) 直線採用部分の相関係数 |r| が0.98以上、(3) 直線採用部分のテリエ法パラメータfが0.35以上、(4) 同パラメータ dratが0.07以下、の4つの基準を用いた。

予察実験の結果として、5サイトから各1個の合格結果が得られた。光明池-3窯跡 (610+-10年) が61.4 microT (n=1)、光明池-11窯跡 (630+-10年) が62.1 microT (n=1)、栂-40-III窯跡 (720+-10年) が41.1 microT (n=1)、光明池-102窯跡 (750+-10年) が67.1 microT (n=1)、光明池-38-II窯跡 (770+-10年) が52.6 microT (n=1) である。これらは先行研究において提示されている、日本の考古地磁気強度データ (信頼度が比較的高い43データ) とおおむね整合的である。今後も実験を進め、最新の結果について報告する予定である。

北西太平洋中生代磁気異常縞模様図の更新

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Improved Mesozoic magnetic anomaly lineation map in the northwestern Pacific Ocean

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We present the improved Mesozoic magnetic anomaly lineation map in the northwestern Pacific Ocean, which also includes the tectonic features such as fracture zones and abandoned spreading centers exposed by multibeam bathymetric data. Nakanishi et al. (1989; 1992) made the sophisticated map of the Mesozoic magnetic anomaly lineations in the northwestern Pacific Ocean. The map includes several blank areas where no magnetic anomaly lineations were identified because of lack of geomagnetic data.

Using geomagnetic and satellite-derived gravity data, Nakanishi and Winterer (1998) identified magnetic anomaly lineations between chrons M21 to M14 and discovered the abandoned spreading centers south of the Mid-Pacific Mountains. Nakanishi et al. (1999) revised magnetic anomaly lineations on and around the Shatsky Rise by geomagnetic data collected after Nakanishi et al. (1989). Comprehensive geomagnetic survey in the exclusive economic zone (EEZ) of Japan by Hydrographic and Oceanographic Department, Japan Coast Guard, revealed the magnetic anomaly lineations in the EEZ (e.g., Nakanishi 2011). The geomagnetic surveys by R/Vs Mirai, Hakuho-maru, and Yokosuka, adjacent to the SW flank of Shatsky Rise enabled us to identify the magnetic anomaly lineations and exposed the tectonic event just before the formation of the Shatsky Rise. (Nakanishi et al., accepted).

Measurements of the total force by towed magnetometers are not very often conducted in recent years. Thus, we are trying to identify magnetic anomaly lineations with geomagnetic data obtained by the shipboard three component magnetometer (STCM) mounted on deck of several research vessels of Japan Agency for Marine-Earth Science and Technology (JAMSTEC). The results of STCM will be shown in the poster presentation by Matsumoto and Nakanishi in this meeting.

The increase of multibeam bathymetric data make us possible precise identification of fracture zones and abandoned spreading centers so that we can exposed tectonic history in detail. Nakanishi (2011) and Nakanishi et al. (accepted) found the abandoned propagating rift near the Izu-Ogasawara Trench and adjacent to the SW flank of Shatsky Rise, respectively. Multibeam bathymetric data also reveal the topographic expression of Nosappu and Kashima fracture zones identified by Nakanishi et al., (1989) and Nakanishi (1993).

アデン湾の磁気異常縞模様

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Magnetic Anomaly Lineations in the Gulf of Aden

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We present the magnetic anomaly lineations in the Gulf of Aden. The Gulf of Aden has slow spreading ridges between the Arabia and Somalia plates. The Arabian plate moves away from Somalia Plate in an NE direction, at a rate of about 2 cm/yr. Previous works indicate that seafloor spreading started about 20 Ma in the eastern part of the Gulf of Aden (Fournier et al., 2010) and then propagated westward (Manighetti et al., 1997). It reached the Afar hotspot area about 10 Ma (Audin et al., 2001). The spreading system continues to interact with the hotspot up to the present. The spreading axis changes in strike from E-W to N60 W around 46 E.

We examined magnetic data acquired in the cruises by R/V L'Atalante in 1995, R/V Hakuho-maru from 2000 to 2001, R/V Maurice Ewing in 2001, and Shackleton in 1975 and 1979. We also used available data obtained from several databases. We calculated magnetic anomalies using the latest International Geomagnetic Reference Field (IGRF-11).

Elongated negative magnetic anomalies, which amplitudes are more than 500 nT, are dominant over the spreading centers. Most of the elongated anomalies over the spreading centers east of 46 30'E are parallel with the spreading centers. Those west of 46 30'E have E-W trend. Several discontinuities in the magnetic anomaly contour map illustrate the position of the fracture zones concealed by sediments.

We identified magnetic lineations from 43 E to 52 E. Magnetic lineations west and east of 46 30'E have N-E and N60-65 W strikes, respectively. The oldest lineations are C3r (5.48~5.74 Ma) between 43 10'E and 44 E and C5Ar (12.4~12.7 Ma) east of 44 E. Our identification of magnetic anomaly lineations indicates a symmetric seafloor spreading with a spreading rate of about 1.0 cm/yr, although Leroy et al. (2004) showed an asymmetric seafloor spreading of the Sheba Ridge, east of our study area. Several previous works proposed the change in motion of the Arabia plate changed about 5 Ma, but our results did not show any coeval change in spreading rates of the spreading system.

岩石磁気イメージングのためのSQUID顕微鏡の開発

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Development of a scanning SQUID microscope for magnetic imaging of rock samples

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Scanning superconducting quantum interference device (SQUID) microscope (SSM) is a useful tool to image very weak magnetic fields with high spatial resolution. The first practical SSM was developed by J. Kirtley and J. Wikswo in IBM (1999). Since then, some groups have developed and improved SSMs for various applications. L. Fong and F. Baudenbacher et al. (2005) developed an SSM with a monolithic SQUID, and applied to geological sample scanning. H. Oda et al. (2011) succeeded in imaging of the magnetic stripes of hydrogenetic ferromanganese crusts related to geomagnetic reversals using the SSM. In this project, we have developed an SSM to image vertical magnetic fields of the thin section of various rock samples such as sediments, volcanic rocks and meteorites for geological studies. We designed a hollow-structured cryostat to realize reliable SQUID assembly and repeatable adjustment of the vacuum separation from the sample. The SQUID based on niobium is a single-washer magnetometer with the pickup area of 200 x 200 square micrometers and the size of the chip is 1 mm x 1mm. The SQUID chip is mounted on a conical sapphire rod and electrically connected to the non-magnetic electrodes with silver paste. The electrodes are patterned on the surface of the sapphire rod using metalization technique. The sapphire rod is connected to a copper block, which is thermally anchored to the liquid helium reservoir with copper bundle wires. The copper block is connected to a rigid shaft through a flexure spring, and the shaft extends through the hollow of the cryostat to the spindle placed on the top flange at room temperature. Rotating the spindle, the SQUID chip can be simply moved up and down with an accuracy of ˜5 micrometers in the movable range of 1 mm. A 40-micrometer thick sapphire window separating the sample from the vacuum space can be adjusted toward the SQUID using a bellows structure. With this mechanism, we have achieved the separation of 800 micrometers between the SQUID and the sample, so far. Our goal of the separation is 200 micrometers or shorter with more careful assembly. The liquid helium capacity of the cryostat is about 10 litters and the SQUID can be maintained at operation temperature for 72 hours. The field resolution of the SQUID was 1.7 pT/rtHz at 100 Hz in a flux locked loop (FLL) operation. In this talk, we will introduce the progress of our SSM project, showing the performance and a scanning demonstration result of artificially magnetized natural zircons with magnetite inclusions.

広帯域磁化率の逆たたみ込みから得られる粒径分布

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Grain-size distributions from deconvolved broadband magnetic susceptibility

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A magnetic susceptibility meter with several-decade frequency band has recently made it possible to obtain superparamagnetic grain-size distributions only by room-temperature measurement. A rigorous deconvolution scheme of the broadband susceptibility data is already available. I have made some corrections on the deconvolution scheme and present its applications to broadband susceptibility data on loess and volcanic rocks.

Deconvolution of frequency dependence of susceptibility was originally developed by Shchervakov and Fabian [2005]. Suppose an ensemble of superparamagnetic grains distributed for two independent variables of volume (grain-size) and energy barrier against magnetization rotation. Applying alternating magnetic field with varying frequency results in differentiating grains by energy barrier - not directly by volume. Since the response function for frequency is known, deconvolution of frequency dependence of magnetic susceptibility provide a rigorous solution for the second moment of volume on the volume-energy barrier distribution. If accepting a common assumption of a linear relation between volume and energy barrier, we can obtain analytical volume or grain-size distributions of superparamagnetic grains without discretization or assuming any a priori parametric distribution function.

A ZH broadband susceptibility meter comprises of two separated devices for lower (SM-100, 65 - 16kHz) and higher (SM-105, 16k - 512kHz) frequency ranges. At every frequency susceptibility calibration was conducted using three kinds of paramagnetic rare earth oxides [Fukuma and Torii, 2011]. Measurements were carefully performed; Inch-core or cube specimens were placed exactly at a same position within an exciting coil, data with high noise indices were deleted and re-measured, and drift correction was made.

Almost all samples exhibited seemingly linear dependences of in-phase susceptibility on logarithmic frequency. This indicates that the measured data do not suffer serious noise, and that the second moment of volume is relatively constant against energy barrier. Nonetheless, third-order polynomial fittings revealed slight deflections from the quasi-linear susceptibility - logarithmic frequency relations. Deconvolving the polynomials showed that such slight defections come from peaks or troughs in varying second moment of volume against energy barrier. Assuming a linear relation between volume and energy barrier, peaks or troughs around 1 x 10^{-24} m^3 were found for the volume distributions derived from the deconvolution. Long-tailed volume distributions from Chinese loess samples would suggest the broad superparamagnetic grain-size distribution.

広い周波数帯域をもつ磁化率計を用いれば，室温での測定のみによって超常磁性粒子の粒径分布を得ることができる．磁化率の周波数依存性データの厳密な逆たたみ込みはすでに利用可能である．今回逆たたみ込みに関するいくつかの修正を行い，黄土や火山岩についての磁化率の周波数依存性データに適用した．

磁化率の周波数依存性データの逆たたみ込みは，もともと Shchervakov and Fabian (2005) によって開発された．体積 (粒径) および磁化の回転に対するエネルギー障壁の 2 つの独立変数にかかる分布関数をもつ超常磁性粒子の集合体を考える．交流磁場を周波数を変化させれば．体積ではなくエネルギー障壁によって磁性粒子を分別することになる．周波数に対する応答関数がわかっているので，磁化率の周波数依存性の逆たたみ込みは，体積-エネルギー障壁分布関数上の体積の二次モーメントの厳密解を与える．体積とエネルギー障壁との間に直線関係があるとする一般的な仮定を受け入れると，離散化，または任意の先験的なパラメトリック分布関数を仮定することなく，超常磁性粒子の解析的な体積または粒径分布を得ることができる．

ZH 広帯域磁化率計は，低い周波数（SM-100, 65-16k Hz）と高い周波数（SM-105, 16k- 512kHz）の 2 つの分離したデバイスで構成される．全ての周波数ステップで常磁性の希土類酸化物三種類を用いて磁化率の較正を行った．測定は慎重に行った．具体的には，インチコアまたはキューブを励磁コイル内の同じ位置に正確に置き，高い雑音指数を有するデータは削除して再測定し，ドリフト補正も行った．

ほとんどすべてのサンプルについて，in-phase 磁化率は周波数の対数に対してほぼ線形の依存性を示す．これは，測定データがノイズに重大な影響を受けていないこと，さらに，体積の二次モーメントはエネルギー障壁に対してほぼ一定であることを示している．それにもかかわらず，三次の多項式フィッティングは，ほぼ線形の対数周波数ー磁化率関係にわずかな屈曲があることを明らかにした．多項式を逆たたみ込みすると，このわずかな屈曲はエネルギー障壁に対する体積の二次モーメントにピークまたはトロフが存在することから来ていることがわかる．体積とエネルギー障壁の間の線形関係を仮定すると，1x10^{-24} m^3 (10 nm) 辺りにピークをもつ体積 (粒径) 分布が逆たたみ込みから得られた．また，中国の黄土サンプルからのロングテール型の分布は広い超常磁性粒径分布を示唆する．

Deconvolution of continuous paleomagnetic data from pass-through magnetometer: A new algorithm with ABIC minimization

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The development of pass-through superconducting rock magnetometers (SRM) has greatly improved our efficiency in collecting paleomagnetic data from continuous long-core samples. The output of pass-through measurement is the convolution of magnetization of a continuous sample with the magnetometer sensor response, which introduces smoothing and distortion to the paleomagnetic signal. Although previous studies have demonstrated that deconvolution can effectively restore high-resolution paleomagnetic signal from pass-through measurement, difficulties in accurately measuring the magnetometer sensor response have hindered the application of deconvolution. We acquired reliable sensor response of an SRM at the Oregon State University (OSU) based on repeated measurements of a precisely fabricated magnetic point source. In addition, previous deconvolution studies did not consider the effects of inaccuracy in sample length and measurement position. We present an improved algorithm of deconvolution incorporating new parameters 'position shift' and 'length correction' along with Akaike's Bayesian Information Criterion (ABIC) minimization of Oda and Shibuya [1996]. The new algorithm was tested using synthetic measurement data constructed by convolving 'true' paleomagnetic signal containing a geomagnetic excursion with the sensor response. Realistic noise was added to the synthetic measurement using Monte Carlo method based on measurement noise distribution in relation to gradient of magnetic moment, acquired from 200 repeated measurements of a u-channel sample. Deconvolution of 1000 synthetic measurements with realistic noise closely resembles the 'true' magnetization, and successfully restores fine-scale magnetization variations including excursion with errors and residuals mostly in the predicted range. Our analyses also show that inaccuracy in sample length and measurement position significantly affects deconvolution results, and can be accounted for using the new optimized deconvolution algorithm. Optimized deconvolution of 20 repeated measurements of a u-channel sample yielded highly consistent deconvolution results and estimates of optimized 'position shift' and 'length correction', demonstrating the reliability of the new deconvolution algorithm for real pass-through measurements.

磁気インピーダンスセンサーを用いた高感度岩石磁力計

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Ultra-sensitive rock magnetometer using pico-tesla magneto-impedance sensor

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Sensitive rock magnetometers have been developed, using pico-Tesla resolution Magneto-Impedance (pT-MI) sensor, a special kind of MI sensor with a resolution of 1 pT comparable with conventional SQUID sensors (e.g., Uchiyama et al., 2012). To detect weak magnetic signals from natural samples, we have employed in this study a MI gradiometer comprising of a pair of the pT-MI sensors to achieve high common-mode noise reduction. This MI gradiometer was tested first of all to a spinner magnetometer by replacing the flux-gate sensors. It was demonstrated that the new-type spinner made more sensitive and quicker measurements possible than the conventional ones, and that a suitable electric amplification combined with digital signal processing could enable ultra-sensitive measurements that only SQUID magnetometers have achieved so far. The MI gradiometer has also been tested to other different types of magnetometers, such as VSM, pendulum, and surface scanning magnetometers. These results suggest that the MI gradiometer would be useful as a new sensitive and convenient magnetic sensor with broad applicability to rock and mineral magnetic investigations.

磁気インピーダンス（magneto-impedance）センサーは、小型・高感度・低消費電力の特性を生かし、携帯電話などの電子コンパスとして広く実用化されている。用途に応じ種々の MI センサーが開発されているが、そのうち特に高感度のものは pT オーダーの感度をもつ。SQUID はさらに高感度であるが、極低温冷却や磁気シールドなど大掛かりな付帯設備が必要である。フラックスゲートセンサーを利用するスピナー磁力計はごく一般的だが、センサーの構造上、検出コイルと試料間の距離に制約がある。これに対し、上記の高感度 MI センサー（pT-MI センサー）は、検出回路系が小型基板化（10x30 mm）されているので、試料 - センサー間を 1mm 程度まで接近させることができる。本発表では、この pT-MI センサーを 2 個用いた差動センサー（gradiometer）とすることによって S/N 比の一層の向上を図り、種々のタイプの岩石磁力計としてテストした結果を報告する。テストした磁力計のタイプは、スピナー型、振動型、振子型、走査型などである。スピナー磁力計は、夏原技研製 SMD-88 のリングコアセンサーを pT-MI センサーで置き換えた。pT-MI センサーは、増幅回路なしの差動出力のみで、リングコアと同程度の感度を得ることができた。適切なフィルターと Gain 調整、ロックイン処理をすれば、さらに二桁程度の感度の向上を見込める。pT-MI gradiometer の利点は、その優れた同相ノイズ除去性能で、パーマロイシールドなしでも、従来型のスピナーと同程度の感度の測定ができる。試料 - センサー間距離の調整に余裕があるので、電気的な Gain 調整と組み合わせることによって、広いダイナミックレンジを確保できる。このような諸特性を生かすことによって、スピナー型以外の様々な測定用途に最適の高感度磁力計を開発・試作できる。

本州北部の笹岡層（鮮新-更新統）の古地磁気と岩石磁気：その地質学的意味

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Paleomagnetic and rock magnetic results from Plio-Pleistocene Sasaoka Formation in northern Honshu: geologic implications

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Felsic tuffs and fine clastic sediments of the Plio-Pleistocene Sasaoka Formation in northern Honshu were sampled for a paleomagnetic and rock magnetic study. Site-mean remanent magnetization directions were determined for 23 sites, which cover an interval from ca. 2.7 Ma to 1.7 Ma on the basis of correlation of the magnetostratigraphy with the standard geomagnetic chronostratigraphy. Recognizable tuffs mostly have stable remanent magnetization carried by magnetite. Despite the possible presence of magnetic iron-sulfides in fine sandstones, pre-folding remanent magnetization is confirmed by a bootstrap fold test and reversals test. The study area is located within a concentrated deformation zone that has developed along the eastern margin of the Japan Sea within a Quaternary compressional stress field, but a northerly overall mean direction is indistinguishable from the geocentric axial dipole field direction, suggesting no significant vertical-axis rotation. Comparison of the Sasaoka mean direction with Plio-Pleistocene ones reported from other areas indicates little or no rotation in and adjacent to the deformation zone, except for local rotations along strike-slip faults.

北中国クラトン北部で採取した1.35Ga貫入岩のテリエ法による古地磁気強度

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Paleointensities from 1.35 Ga diabase sills from Northern China Craton

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The long-term variation in the paleointensity during the Proterozoic-Archean offers the key to an understanding of the evolution of the geodynamo activity in the Earth's core. The aim of this study is to add new results and improve the paleointensity database during the Precambrian periods.

We have conducted paleomagnetic and rockmagnetic measurements on Mesoproterozoic diabase sills from Northern China Craton. An U-Pb age of 1.35 Ga have been reported from the diabase sills in the same area [Zhang et al., 2009]. We collected oriented block samples from 10 sills near Chendge, northeast of China. Host rock samples were also collected for the baked contact test.

The mean direction of characteristic high temperature components from 35 samples is D=-6.9^o, I=-5.3^o, and alpha95=34.6^o. This direction has passed the fold test [McElhnny, 1964] and the baked contact test, indicating the primary origin of the high temperature component.

IRM acquisition experiments, thermal demagnetization of 3-axis IRM and high-field thermomagnetic analyses (Js-T) reveal the main magnetic mineral of magnetite. The hysteresis parameters are consistent with PSD grain sizes.

Paleointensity experiments using IZZI method [Yu and Tauxe, 2005] have been conducted. Successful results were obtained from four samples. The mean paleointensity is 3.45+/-0.23 micro-T, which corresponds to a virtual dipole moment (VDM) of $0.89*10^{22}$Am^2. This is about one-tenth of the present VDM value, which suggests the low geomagnetic field during the Mesoproterozoic period.

太古代や原生代の地球磁場強度変化を知ることは、内核の形成や地磁気ダイナモの進化について知る重要な手がかりとなる。しかし、変成作用や風化の影響により、初生磁化を保持している火山岩試料は少ない。また、報告されている古地磁気強度データにおいてもばらつきがある。本研究では、原生代の信頼性の高いデータを得ることを目的として、北中国クラトン北部に貫入する diabase sill を研究対象とした。この貫入岩からは、1.35Ga の U-Pb 年代が報告されている（Zhang et al., 2009）。

本研究ではこの貫入岩を用いて、テリエ法 (IZZI 法; Yu and Tauxe, 2005) で古地磁気強度を求めた。また、準備実験として、古地磁気方向の測定と IRM 獲得実験、3 軸 IRM の段階熱消磁実験、熱磁気分析、磁気ヒステリシスの測定を行った。中国東北部 Chendge 付近において、sill 10 サイトから試料をブロックで採取した。また、コンタクトテスト用に母岩からも試料を採取した。

段階熱消磁実験により、35 の試料から高温磁化成分を 400^{o}C 以上で分離し、平均方向を求めた。この平均方向はコンタクトテストと、McElhnny(1964) の褶曲テストに合格し、初生磁化のものであると考えられる。傾動補正後の方向は、D=-6.9^o I=-5.3^o alpha95=34.6^o であった。

IRM 獲得実験と 3 軸 IRM の段階熱消磁実験、熱磁気分析により、磁性鉱物は主にマグネタイトであると考えられる。また、磁気ヒステリシスのパラメータを、Day et al.(1977) の図にプロットすると、17 個の試料中 14 個が擬似単磁区粒子 (PSD) であった。

IZZI 法では、判定基準を満たした試料は 4 個であった。その平均値は 3.45+/-0.23 micro-T であり、仮想地磁気双極子モーメント (VDM) は $0.89*10^{22}$Am^2 であった。この値は、1.35Ga 当時の古地磁気強度が現在に比べて弱かったことを示唆している。

カンボジアにおけるジュラ紀・白亜紀赤色砂岩の古地磁気学的研究

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Paleomagnetic study of Jurassic-Cretaceous redbeds in Cambodia

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The Indochina Peninsula, which consists of several blocks, was subjected to complicated tectonic deformations. We carried out the paleomegnetic study of Jurassic-Cretaceous redbeds from the southwestern Cambodia to constrain deformation mode of the Indochina Peninsula. We collected rock samples at the Sihanoukville area (10.5^{o}N, 103.6^{o}E, 15 sites) and the Koh Kong area (11.6^{o}N, 103.1^{o}E, 14 sites) around the boundary between the Indochina and Sukhothai Blocks. Stepwise thermal demagnetization experiments revealed high temperature magnetic component with a unblocking temperature of 620-690^{o}C in most samples, and it was recognized as characteristic remanent magnetizations (ChRMs). The ChRMs indentified were grouped into two directions : the northerly and easterly directions. The in-situ mean of the northerly direction is D=5.4^o, I=18.5^o, alpha95=3.1^o, N=19 , and the mean after tilt-corrected is D=4.4^o, I=14.7^o, alpha95=5.1^o. We judged that the northerly direction is acquired secondarily because of negative fold test. The in-situ mean of the easterly direction is D=41.6^o, I=30.9^o, alpha95=5.1^o, N=11, and the mean after tilt-corrected is D=42.0^o, I=32.1^o, alpha95=5.0^o. Although fold test is inconclusive, the easterly direction is apart from the northerly one and is recognized as primary magnetization. The easterly direction is concordant with Jurassic-Cretaceous directions reported previously in the Indochina Block. We conclude that the southwestern Cambodia belongs to the Indochina Block and have experienced clockwise rotation as its part.

いくつかのブロックから構成されるインドシナ半島は、テクトニックな変形を経験してきた。インドシナ半島の変形様式を調べるために、我々はカンボジア南西部に分布するジュラ紀・白亜紀赤色砂岩の古地磁気学的研究を行った。シアヌークビル地域（10.5^{o}N, 103.6^{o}E, 15 サイト）とコッコン地域（11.6^{o}N, 103.1^{o}E, 14 サイト）において試料を採取した。これらの地域は、Indochina Block と Sukhothai Block の境界付近に位置している。すべての試料に熱段階消磁を施し、残留磁化をそれぞれ測定した。239 試料のうち 221 試料において、620〜690^{o}C のアンブロッキング温度を持つ高温磁化成分を分離し、北向きと東振りの 2 つの平均方向を求めた。北向きの方向は、傾動補正前 D=5.4^o, I=18.5^o, alpha95=3.1^o, N=19、傾動補正後 D=4.4^o, I=14.7^o, alpha95=5.1^o であった。褶曲テストに合格しないことから、この方向は二次的に獲得された磁化であると判断した。東振りの方向は、傾動補正前 D=41.6^o, I=30.9^o, alpha95=5.1^o, N=11、傾動補正後 D=42.0^o, I=32.1^o, alpha95=5.0^o であった。褶曲テストは Inconclusive であったが、褶曲テストに合格しない北向きの方向と大きく異なることから、我々はこの東振りの方向を初生磁化であると判断した。Indochina Block から報告されている古地磁気結果と比較すると、従来の方向は、20〜40^o 程度北から東に振り、20〜40^o 程度の比較的深い伏角を持つことから、本研究で求まった方向は従来の方向と調和的であった。このことから、本研究対象地域である、シアヌークビル地域とコッコン地域は Indochina Block の一部として時計回り回転を経験したと結論付けた。

Deformation due to the Collision between South China Block and North China Block

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Middle Triassic red sandstones and Early Triassic limestone were sampled at 37 sites at two locations in the north margin (108.18E, 31.82N) of South China Block (SCB) to detect regional deformational features due to the collision between SCB and NCB. Most of the samples indicate characteristic remanent magnetization with unblocking temperature up to 590 centigrade or 690 centigrade. Thermal demagnetization isolated low temperature component (LTC) of 25 centigradeto 450 centigrade and high temperature component of 530 centigrade to 590 centigrade, or 560 centigrade to 690 centigrade. LTC shows a direction towards present earth field, while the HTC shows a NE-down-towards direction or SE-up-towards direction. Based on the direction of HTC, it is expected that a clear clock-wise rotation around study area, which indicates a significant constructural deformation due to the collision between NCB and SCB. It is also possible that the study area was subjected to the same mechanical motion of Yangtze belt, which is located to the south of the NCB-SCB boundary, and received the same regional deformation within the area of Yangtze fold belt.

The details of the deformation will be presented in the presentation.

漸新世のエチオピア洪水玄武岩から得られた古地磁気方向および岩石磁気特性

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Paleomagnetic directions and rock-magnetic properties from Oligocene Ethiopian flood basalts

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Paleomagnetic observations of continental flood basalts can provide much more complete and complex high-fidelity records for understanding features of the ancient Earth's magnetic field varying rapidly with time (e.g., Jarboe et al., 2011) as well as magnetostratigraphic contributions such as a stratigraphic correlation and dating.

We focus on the Oligocene Ethiopian flood basalts, in which there is a 2000 m-thick exposures of the flood basalts at Lima-Limo (LL) region (13.25 ^{o}N, 37.93 ^{o}E). In this studied region, only previous paleomagnetic investigation from a sparse sampling of Rochette et al. (1998) was carried out, and thus it has been required to resample the whole section to obtain a better detailed and precise paleomagnetic recording.

We sampled a successive of 93 lava flows and 5 acidic inter-layers for paleomgnetic measures with 11 flows for geochronology. And stratigraphic relationship between flows was well controlled by their altitudes.

The goal of this work is to restore time-variation of paleo-geomagnetic field in its direction and strength for the Oligocene. Here we report rock magnetic results with thermomagnetic (TM) analysis, magnetic hysteresis parameter measurements and isothermal remanent magnetization (IRM) acquisitions, and paleodirectional results, which newly revised from the report of SGEPSS 2013, for the LL lavas.

Results of TM analysis and IRM acquisition experiments as well as behavior of thermal demagnetizations of NRM shows that all the samples have magnetite as a dominant carrier of remanence. A majority of ferromagnetic phases has either single phase with a Curie temperature of magnetite or multiple phases with Curie temperatures of 200 - 400 ^{o}C and magnetite, while for a few cases, a higher Curie temperature phase of ˜620 ^{o}C besides magnetite is also observed. Resultant Day plot (Day et al., 1977) of the hysteresis parameters measured shows a magnetic grain size distribution with a diagonal elongated band within the pseudo single domain region bounded by Dunlop (2002).

In most of the paleomagnetic measurements, paleomagnetic directions of characteristic remanent magnetization (ChRM) are well isolated by an alternating field (AF) of ˜40 mT at least or by a temperature of 200 - 400 ^{o}C using both AF and TH demagnetization techniques, while rather AF demagnetization is more straightforward to separate ChRMs for several cases.

Our current magnetostratigraphic result appears to contain a succession of 3 magnetic chrons roughly as previous study (Rochette et al., 1998), but clearly reveals that there are further 4 reversals in the lower part of central normal chron at 1800 - 1950 m in altitude and also recognize possible 3 geomagnetic excursions in two reversed chrons.

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Post-Jurassic Tectonics of the Southeast Asia inferred from Paleomagnetism

乙藤 洋一郎 [1]
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Post-Jurassic Tectonics of Southeast Asia inferred from Paleomagnetism

Yo-ichiro Otofuji[1]
[1] Earth and Planetary Sciences, Kobe Univ.

Post-Jurassic tectonics of differential rotation between the Indochina and South Sundaland blocks in Southeast Asia remained an issue to be properly investigated. Because the Sibumasu Terrane is located between the clockwise rotated Indochina Block and counter-clockwise rotated South Sundaland Block, its tectonics is a clue to understanding deformation feature of the Southeast Asia. For this purpose, we focus our paleo magnetic study on the lower to middle Jurassic red sandstones in the Sibumasu Terrane. The Umphang Group is collected at 33 sites from the North Trang Syncline (7.6N, 99.6E) in the Peninsular Thailand and at 21 sites around Ratchaburi area (13.6E, 99.6E) in its root. After a stepwise thermal demagnetization a pre-folding characteristic remanent magnetization is identified. Easterly deflection in declination (D = 31.1, I = 12.2, a95 = 13.9) appears at the Trang area in a mean direction of this component at 100% unfolding, whereas westerly deflection in declination (D=348.5, I=24.7, a95=10.5) is observed around Ratchaburi area. Combining of two directions with those reported from other areas, Umphang Group rocks (Kalaw, Mae Sot, Ratchaburi and North Trang Syncline) reveal variable declinations (between 348.5 and 44.7) for the Sibumasu Terrane. Variable declinations are ascribed to differential deformation in the Sibumasu Terrane, as reflected from sinusoidal shaped features in the Carboniferous-Permian strata and the Cretaceous-Paleogene granites. Observation of such features in the granitic rocks links the occurrences of deformational activities after their intrusion, which took place in a period between 130 Ma and 51 Ma. The Sibumasu Terrane behaved as an independent fragment at a time when the Indochina Block was undergoing through a clockwise rotation and southward displacement as a result of extrusion tectonics after the gigantic India-Asia collision.

小アンティル諸島沖で掘削された火山砕屑性堆積物 (IODP Site U1397, 1398) の堆積過程

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[1] 信大・理; [2] 新潟大・災害・復興研

Emplacement mechanism of marine volcaniclastic sediments (IODP Site U1397, 1398) off Lesser Antilles volcanic arc

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Large numbers of marine volcaniclastic sediments with various origins were recovered from the sites U1397 and U1398 during IODP Expedition 340. They were most likely derived from volcanoes on Martinique and possibly from Dominica, Lesser Antilles volcanic arc. Some volcaniclastic units were transported and deposited as turbidites, some were as thin tephra fall deposits and others show both characteristics. They contain various amounts of bioclastic component, pumice and lithic fragments and hemipelagic mud clasts. Therefore, these volcaniclastic sediments are suitable for investigating transport and emplacement mechanisms of volcanic materials and the resultant sedimentary and petro-facies in marine settings. In this study, we carried out rock magnetic measurements, grain size analysis by the laser diffraction spectrometry and electron microscopic observation. As a result, turbidites and tephra fall deposits showed distinct rock magnetic characters. Grain size distribution and microscopic observation showed consistent results, suggesting various types of depositional processes were recorded on size, sorting, morphology and magnetic signals of marine volcaniclastic sediments. We can estimate the origin of the marine volcaniclastic sediments by using these approaches.

カリブ海の小アンティル火山弧沖で実施された統合国際深海掘削計画 (IODP) の第 340 次航海において，火山弧から供給された火山砕屑物を母材とする多様な堆積物が採取された。数十メートルの厚さからなる火山砕屑性混濁流堆積物 (タービダイト，以下では TB) をはじめ，数センチメートル程度の降下火山灰層などが船上で数多く識別されたが，中には中間的な性質を示し，分類に困るユニットも多く存在した。本研究は，岩石磁気学的手法による磁性鉱物の定量的解析と粒度分析・電子顕微鏡による粒子観察などを基に，多様な火山性堆積物を供給した火山活動について，また水中に流入する火砕物の流動・運搬・堆積機構を解き明かすことを目的としている。

岩石磁気学的測定の結果，層厚 1m を超す厚い TB と層厚数十センチ程度の薄い TB，さらに降下火山灰層で，異なる特徴を示すことが明らかとなった。厚い TB は細粒で帯磁率異方性の比較的強い最上部をもち，中央部は帯磁率異方性が弱く，下部に向かって粒子サイズが大きくなる傾向を示す。厚い TB のベースは帯磁率異方性が比較的強く，帯磁率も大きい。流れの下部では，重い Fe 鉱物の沈降・濃集が起き，底部でのせん断応力を反映して強い帯磁率異方性を示していると考えられる。熱磁気分析からは少なくとも 2 つのキュリー点の異なる磁性鉱物 (おそらく Ti-rich，Ti-poor titanomagnetite) の存在が示され，TB 下部に向かって Ti-rich titanomagnetite の寄与が増加する。また半遠洋性堆積物は Ti-rich titanomagnetite のシグナルをほとんど示さない。このことから Ti-rich titanomagnetite は火山起源であると考えられる。それに対し，薄い TB は Ti-rich titanomagnetite の寄与が小さく，火山起源の重く粗粒な Fe 鉱物を欠いた堆積物であると考えられる。降下火山灰層は，帯磁率が大きく，粗粒で Ti-rich titanomagnetite の寄与が大きいが，火山灰層の上部に連続して堆積する部分は細粒で，Ti-rich titanomagnetite の寄与が小さい。噴火マグマ起源の火山灰が海中を沈降中に粗粒な下部と細粒な上部に分級したと考えられる。

レーザー粒度分析の結果と電子顕微鏡による粒子観察の結果も岩石磁気学的測定結果と調和的であった。TB の本体部分は淘汰が良く，粒度分布のカーブは粗い粒子に鋭いピークを持つユニモーダルなカーブを示す。TB の最上部や降下火山灰層の上部層は半遠洋性堆積物に似て，なだらかでピークが細かい粒子の方に触れた粒度分布カーブを示し，鏡下でも淘汰が悪く，粗粒な粒子に細かい粒子がたくさん付着している様子が観察された。降下火山灰層は TB ほど淘汰が良くなく，細かい粒子も多く見られた。これは厚さが同程度の TB とは全く異なる結果である。降下火山灰層が海中を沈降中に被る分級作用は TB ほど強くないことが示唆される。

北西太平洋ニューファンドランド沖の IODP Site U1408 から掘削された海底堆積物の古地磁気・岩石磁気学的研究（予察）

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Preliminary paleomagnetic and rock magnetic studies on the sedimentaty sections from IODP Site U1408 in the Northwest Atlantic

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We have conducted preliminary paleomagnetic and rock magnetic measurements on the sedimentary sections recovered from Integrated Ocean Drilling Program (IODP) Site U1408 in the Northwest Atlantic, off Newfoundland. Principal purposes are to establish an age model of the sediments and to investigate variation of the geomagnetic field in geologic past.

Stepwise alternating field (AF) demagnetizations (20-80 mT) on natural remanent magnetizations (NRMs) revealed that characteristic components of the sediments mainly resulted in (1) inclination between -60 and -30 degree and declination between -45 and 0 degree, and (2) inclination between 30 and 60 degree and declination between 120 and 180 degree. The intervals showing the components (1) obviously recorded normal polarity while those showing (2) recorded reversed polarity. In total we could identify nine polarity reversals in the studied interval (20-160 mcd; meter composite depth) of the sediments.

We correlated the obtained reversal pattern with the geomagnetic polarity time scale by Gradstein et al. (2012) (Geologic Time Scale 2012), with referring the shipboard biostratigraphy (Norris et al., 2014). The correlation suggested that the studied interval covered Chrons C17n.2n to C20r (approximately 38-43 Ma), and provided an age model which infer sedimentation rate of about 2-4 cm/kyr during these chrons. However, we could not find nor identified the interval correlatable to Chron C19n (41.154˜41.390 Ma), suggesting some possible mis-splice at around 100 mcd.

After the measurements of NRMs, we imparted anhysteretic remanent magnetizations (ARMs, 50 micro-T biasing field with 80 mT AF) and isothermal remanent magnetizations (IRMs, 800 mT). Ratios of ARM to SIRM (ARM/SIRM) resulted in either about 0.20 or 0.05 for majority of the studied interval. The intervals showing the ratio 0.20 seem to be potentially suitable for relative paleointensity estimation, while those showing the ratio 0.05 are probably originated from diagenetic dissolution of fine magnetic particles.

船上三成分磁力計による地磁気観測に基づいた北西太平洋の中生代磁気異常縞模様

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Mesozoic magnetic lineations in the northwestern Pacific Ocean using shipboard three component magnetometers

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We present the Mesozoic magnetic anomaly lineations identified using geomagnetic data by the shipboard three component magnetometer (STCM) mounted on deck of R/V MIRAI in the northwestern Pacific Ocean. Mesozoic magnetic anomaly lineation map was made by Nakanishi et al. (1989; 1992). The map comprises several blank areas where no magnetic anomaly lineations were identified because of lack of geomagnetic data. Additional geomagnetic measurements have been necessary to complete the map. However, measurements of total forces with towed magnetometer such as a proton precession magnetometer have been not very often carried out in recent years unlike before the 1980s.

To break through the current difficulties, we are utilizing geomagnetic data obtained by STCM and bathymetric data obtained by multibeam echo-sounders. The results of multibeam data will be shown in the presentation by Nakanishi in this meeting.

Several research vessels of Japan Agency for Marine-Earth Science and Technology (JAMSTEC) continuously measure the geomagnetic field by the STCM in the transit of the survey areas. We are trying to identify magnetic anomaly lineations using geomagnetic data obtained by the STCM mounted on deck of R/V Mirai. The precision of STCM data is less than that by towed magnetometers, but it is useful to find strikes of magnetic anomaly lineations.

We processed the STCM data collected during the cruises of R/V Mirai from 2009 to 2013 on basis of the methods proposed Isezaki (1986) and Korenaga (1995). We examined critical values of intensity of spatial differential vector (ISDV) in the areas where magnetic anomaly lineations have been already identified by previous works. On base of our examination of ISDV, we newly identified magnetic anomaly lineations in the blank areas, especially near the Izu-Ogasawara and Mariana trenches.

伊能忠敬の山島方位記から 19 世紀初頭の地磁気偏角と郷土地理を解析する。

辻本 元博 [1]
[1] なし

Analyzing the geomagnetic declination and the local geography in early 19 century from Santou-Houi-Kirecorded by Tadataka Inoh.

Motohiro Tsujimoto[1]
[1] none

The Santouhouiki is a national treasure of Japan recorded by the cartographer Tadataka Inoh in 1800 to 1816, consist of 67 volumes survey ledger. In the Santouhouiki approximately 200,000 magnetic compass survey

azimuth data by 0 deg 5 min to 10 min unit,with name or short description of reference point and target points are recorded. We executed interdisciplinarity and simultaneous analysis of geomagnetic declination,and real azimuth, precise position of the survey reference point,confirm with the survey diary,Inoh maps, the survey map in today or local source books.

We analyze the position of reference point,less than 1 sec in latitude and longitude, where the value of magnetic declination subtracting the magnetic survey azimuth from the true azimuth, to any target points are similar or approximate. We cannot read the presice content of national treasure Santouhouiki without this interdisciplinarity and simultaneous analysis. We analyzed geomagnetic declination at 180 points in Japan mainland. The distribution of magnetic declination in early 19 century is gradually elucidated. When we compare those result with gufm1 global isogonic map in 1800 by Andrew Jackson,we can find some differences not only in the area of geomagnetic disorder in eastern Hokkaido volcanic belt. I refer to the ciircumstance of popularization of magnetic compass without the correction of magnetic declination from 17 to 19 century in Japan.

日本の国宝「山島方位記」は地図作成者伊能忠敬により 1800 年から 1816 年に記録された測量台帳であり、測量実施地点及び測量対象地点の地名と短い記述付きの 0 度 05 分〜0 度 10 分単位の推計約 20 万件の磁針測量方位角を記録した 67 巻の台帳でなっている。測量地域は北海道東部から西日本の屋久島に及ぶ。測量基点や測量対象地点に付された地名、短い記述と伊能の日記、近代の測量地図、現代の測量地図、郷土史料と照合し、地磁気偏角、真方位、測量基点の詳細位置と測量対象地点 (緯度経度 1 秒単位以下) の位置の学際の同時解析をした。いずれの測量対象地点への真方位からも磁針測量方位角を差し引いた地磁気の偏角の数値が一定或いは近似になる測量基点の詳細な位置を逆算した。この学際同時解析以外では国宝「山島方位記」の詳細な内容を解読できない。180 地点で地磁気偏角を解析し、19 世紀初頭の日本列島の地磁気偏角の分布が順次判明し始めた。これらの結果をアンドリユー・ジヤクソンの Gufm1 の地球の地磁気永年変化図 (1800) と比較すると北海道東部の火山帯の地磁気異常地域以外にも相違が見つかる。

17 世紀から 19 世紀の日本での偏角無補正の羅針盤使用の背景に言及する。

R-SCHA2Dを用いた地磁気ジャークの検出：20世紀後半の東アジアにおける解析事例

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Detection of the geomagnetic jerks over East Asia in the latter half of the 20th century using R-SCHA2D method

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SCHA(Spherical Cap Harmonic Analysis) is a method that models a potential field on a spherical cap of a sphere.This method was originally developed by Hains [1985] and improved by Thebault [2006].Paticularly R-SCHA2D(Revised SCHA2D) elaborated by Thebault [2008] is suitable for analyses of site distribution where the altitude diffrence can be ignored.We applied this method to geomagnetic data over East Asia in the latter half of the 20th century and created regional geomagnetic models for the area in the era.

Geomagnetic jerks are known as a phenomenon of rapid geomagntetic secular variations.It is seid that jerks do not occur at the same time over the globe and there are a few years delay from region to region (Pinheiro, Jackson and Finlay [2011]).Various kinds of method such as statistical analyses, wavelet analyses, spherical harmonic analyses have been applied to detect the geomagnetic jerks.Among them,Thebault′s [2008] regional analysis is a good example of applying R-SCHA2D to detection of the jerks.He made a series of geomagnetic models over France int hte latter half of the 20th century in order to identify the geomagnetic jerks of the region.

We used our regional geomagnetic models in East Asia so as to detect the jerks,and compared the result with that of Thebault [2008]. In the presentation, we illustrate our regional models, and discuss R-SCHA2D as a useful method for detection of the geomagnetic jerks.

SCHA（Spherical Cap Harmonic Analysis）は球面上の一部領域でのポテンシャル場をモデル化する手法である。Hains[1985] により提唱され、Thebault[2006] などにより改良が重ねられてきた。中でも Thebault[2008] で示された R-SCHA2D という方法は、高度の差が無視できる地上地磁気観測網データに基づく広域地場モデル構築に適した手法である。本研究では、この手法を用いて 20 世紀後半の東アジア地域における地球地場モデルを作成した。

地磁気ジャークは地磁気永年変化の急変現象として知られている。全球で同時に起こる現象ではなく、その発生には地域により数年の差があるとも言われている（Pinheiro, Jackson and Finlay[2011]）。地磁気ジャークの検出には統計解析、ウェーブレット解析、球面調和関数解析など様々な手法が用いられてきた。その一つに、20 世紀後半のフランスの地磁気観測データを R-SCHA2D によりモデル化し、同地域内での地磁気ジャークを同定した Thebault[2008] の例がある。

そこで本研究では、作成した東アジアの地磁気モデルからその永年変化を求めて東アジアでの地磁気ジャークを同定した。また、解析結果を他地域での先行研究と比較した。本発表では、モデル化による地磁気ジャーク同定の成果を紹介すると共に、地磁気ジャークの解析手法という観点から R-SCHA2D についても議論する。

野島断層ガウジの地震性すべり面にみられる磁化した波状褶曲: 摩擦熱による間隙水圧上昇の証拠

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[1] 東北大・理・地学; [2] 東北大・理・地学

Magnetic billow-like wavy folds in a seismic slip plane of Nojima fault gouge: evidence for thermal pressurization

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There is an enigma whether steadily creeping fault could trigger a big earthquake. Recent study suggests that a key mechanism would be an infiltration by hot geological fluids into fault zones, acting as a lubricant to occur a big slip. Therefore, it is very useful for a fault gouge as a fossilized slip zone to seek evidence of frictional heating associated with geological fluids in the fault zone. Nojima fault gouge is one of best materials with a laminated breccia of incohesive grayish gouges and cohesive blackish gouges, including a sharp slip zone, turbulent disordered textures and billow-like wavy folds. Our previous rock magnetic studies provide cohesive blackish gouges experienced at least a 400 degrees heating during its formation from the incohesive grayish gouges, because of the magnetite formation through thermal decomposition of siderite in the grayish gouge.Our scanning Magneto-Impedance magnetic microscope observation shows the billow-like wavy folds and sharp slip zone are strongly magnetized, indicating these two zones had been experienced a frictional heating (over 400 degrees). The billow-like wavy folds are very similar to Kelvin-Helmholtz (KH) instability pattern in nature. Conspicuous examples of KH-instability are the cloud-atmosphere interface, Jupiter and Saturn’s atmosphere and cold-warm interface at the ocean current. This instability generated at the interface between two fluids of different densities shearing at different velocities (Thorpe 2005).Spectral analysis of square amplitude against wave numbers of wavy folds indicates a good correlation (R^2=0.9) with power law form. The index of the power law was -1.9, agreeing well with the previous results.This leads us to consider that our billow-like wavy folds were surely produced by KH-instability, suggesting that the cohesive blackish gouges deformed as fluids. The preservation of this KH texture suggests that a part of the blackish gouge mixed with hot fluids and a granular dense layer flew with a less dense layer at different velocity. This result suggests that shear-induced thermal turbulence in the fault gouge decrease a frictional strength along the billow-like wavy folds during earthquake slip dynamics.This provides the geological evidence for thermal pressurization.In this presentation, the X-ray computed tomography (CT)-based three dimensional analysis of our billow-like wavy folds in a slip zone will also be shown to determine slip orientation of the fault.

阿蘇火山中央火口丘群における完新世溶岩流の古地磁気学的研究

望月 伸竜 [1]; 渋谷 秀敏 [2]; 弥頭 隆典 [3]; 宮縁 育夫 [4]
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Paleomagnetic study on Holocene lava flows from post-caldera central cones of Aso Volcano

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We have conducted a paleomagnetic study on Holocene lava flows from post-caldera central cones of Aso Volcano. Paleomagnetic sampling was made at 25 sites of seven units. Nineteen out of 25 sites gave reliable mean paleomagnetic directions, which had a 95% confidence circle of lower than 5 degree. Different sites from a few lavas, which had been treated as a single unit in the geological map of Aso Volcano (Ono and Watanabe, 1985), gave different mean paleomagnetic directions at 95% confidence level. For Kishimadake lava, Ojodake lava, and Nakadake young volcanic edifice lava, two different mean directions were obtained from multiple sites of each flow. These differences in mean paleomagnetic direction indicate that multiple flows were extruded with a temporal gap of the order of 10 or 100 years. We also found that Kamikomezuka scoria, two sites of Kishimadake lava, two sites of Ojodake lava gave identical mean directions at 95% confidence level. The concordance of the mean directions suggests that the multiple vents erupted simultaneously, in a time interval of the order of 10 years, and these lavas were extruded over a wide area of the post-caldera central cones. In this presentation, we report new data from a couple of sites. On the basis of all the paleodirectional data, combined with geological evidences, we discuss the stratigraphic relationships and distributions of Holocene lava flows from post-caldera central cones of Aso Volcano.

本研究では阿蘇火山の噴火活動史研究に利用できる基礎データを与えることを念頭に、阿蘇火山中央火口丘群の溶岩流の古地磁気学的研究を進めている。鬼界アカホヤテフラ（7300 年前）以降に流出した溶岩流 7 ユニットに対して、25 サイトをもうけて定方位サンプリングを行った。全 25 サイトのうち 19 サイトからは 95%信頼限界が 5 度未満の精度の良い古地磁気方位が得られた。阿蘇火山地質図（小野・渡辺，1985）においては、各中央火口丘に対応するように杵島岳溶岩・往生岳溶岩・中岳新期溶岩と区分されていたが、得られた古地磁気方位に基づくならば、これらの溶岩は数十年から数百年間の時間間隙をもつ複数回の溶岩流を含むことが明確になりつつある。また、上米塚スコリアの 1 サイト・杵島岳溶岩の 2 サイト・往生岳溶岩の 2 サイトから得られた古地磁気方位は 95%信頼限界の範囲で一致する。この結果は、複数の火口から同時期（数十年以内）にこれらの溶岩流が流下した可能性を示唆する。今回の発表では、新たに測定を行ったサイトの測定結果を含めて、古地磁気方位データの総括を行い、阿蘇火山の完新世火山岩（溶岩流）の層序関係・分布を整理する。

考古地磁気データの時間軸に関する考察

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Study on evaluation of archaeological date applied to archaeomagnetic temporal axis

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We have produced an archaeomagnetic database with gathering Japanese archaeomagneitc data and made a new geomagnetic secular variation curve for the past 2000 years. Here we discuss the archaeological dating due to the type morphology of the potteries baked in the kilns whose floors are used for archaeomagnetic studies, which is often applied to the temporal axis of the geomagnetic secular variation models. There is a conflict in the date between archaeological type age and paleomagnetic age. The former has a period when the potteries of this type were made, whereas the latter show the date of the final output of the potteries in the kiln, which is based on the view of the thermoremanent magnetization. Here we estimate the archaeomagnetic mean direction for each interval with using a new window filters due to those conditions. We will also discuss the distribution of the archaeomagnetic direction with these windows, which should be biased toward older ages and would be necessary to be treated with different statistics as Fisher and Bivariate Fisher.

これまで我々は、過去2000年間分の地磁気永年変化の様子を明らかにするために、考古地磁気学データを集めてデータベース化し、そこから曲線モデルを作成してきた。本研究では、いわゆる「考古学年代値」を考古地磁気学で取り扱う場合の考察をし、それが周辺にどのような影響を与えるか議論する。考古地磁気方位測定で多く用いられる古窯跡の床面は、床を張り替えたり嵩増ししたりして数年〜数十年使用されるが、そこから得られた試料が持つ熱残留磁化の「時間」は、最後に熱を受けた時、すなわち、最終床面を最後に使用した時のものとなる。一方で、窯で作成された同時代の土器（古地磁気強度推定にも用いられる）は形式ごとに数十年単位で分類されている（形式編年）。形式編年において各々の土器とそれを作成した窯には通常幅のある年代値が与えられるが、その中である１つの窯の古地磁気学的な年代（＝最終焼成の年代）は確率的には幅の後ろ側になることが期待されるはずである。さらに、この幅のある年代値というのは、自然科学的な視点では中心±誤差であるかのように取り扱いがちであるが、あくまで「幅」であってσではないものである。今回はこれらの点を考慮した時間別の重み関数を作成し、これまでのデータに対するウィンドウとは異なる平均方位を作成し比較した。また分布についても従来の Fisher 的なものや Bivariate Fisher 的なものとも異なる、年代値の古い側に広がる分布を考える必要がある。本講演では、このような年代値の取り扱いおよびデータベースとしての表し方について議論する。

Magnetic mineral distributions from the red soil on land to offshore sediments: a case study of northeastern Okinawa Island.

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The red soil called Kunigami Margi is distributed in the northeastern part of Okinawa Island northeastern part. Coral reefs in Okinawa Island are damaged by red soil which is transported rivers in the short steep slope. In order to investigate the red soils distribution in the nearshore marine sediments, rock magnetic analysis was conducted in this study. The samples were taken from the natural beach to continental slope in the northeastern part of Okinawa Island. The red soil and nerashore sediments have significantly low S-ratio values, while the value shows high in the offshore sediment samples. The value low-temperature magnetometry shows the Morin transition at around 250 K in the red soil samples. This suggests that the magnetic carrier of the red soils is hematite. The offshore samples have a slight decrease in IRM at about 100 K. This decrease is interpreted to be the Veywey transition of magnetite, and its suppression is indicative of oxidation (maghematization) of magnetite. These thermomagnetic results suggest that hematite is distributed from the land, and the principal magnetic minerals are maghemized from nearshore to offshore sediments.

沖縄県羽地内海堆積物の磁気特性：赤色土壌流入と続成作用の検討

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Magnetic properties of a piston-core sample from Haneji-naikai: Effects of the red soil erosion and reductive diagenesis

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We investigated the magnetic properties of a sediment core sample of 286 cm long, which was recovered from the Haneji-naikai bay in Okinawa Island. Pass-through measurements of u-channel samples show a gradual down-core decrease of low-field magnetic susceptibility, followed by sharp decrease of anhysteretic remanent magnetization (ARM) of about two orders of magnitude at about 150 cm below seafloor. Measurements of isothermal remanent magnetization (IRM), made on discrete cubic specimens, revealed that the proportion of low-coercivity magnetic minerals (S-ratio) shows variation consistent with the ARM. It is also found that high-coercivity component of IRM (HIRM) is enhanced at the topmost part of the core (above 80 cm), corresponding to the variation of the color indices (a∗and b∗) measured on the split core surface. IRM acquisitions and thermal demagnetization experiments on selected samples suggest occurrence of goethite and hematite as high-coercivity minerals and titanomagnetite and magnetite as medium to low coercivity minerals. These results suggest that a loss of fine-grained magnetite have occurred in the lower interval due to reductive diagenesis and that inflow of the red soils from the watershed increased after ca. 500 year BP.

羽地内海は沖縄県本島半部の付け根に位置する内湾で，国頭マージと呼ばれる周辺の赤色土壌が流入することが知られている．本研究では，羽地内海の中央部（水深 9.2 m）においてマッケラス・サンプラーを用いて採取された長さ 286 cm のコア試料（OHU10-1）について磁気測定を行い，赤色土壌の混入について検討を行った．このコアの深度 253 cm から採取された植物片について，1890+/-50 yr BP の 14C 年代が得られており，約 2000 年前から現在にかけての環境変遷の記録が得られる可能性がある。

今回の研究では，まず U-チャネル試料の初磁化率，自然残留磁化（NRM）と非履歴残留磁化（ARM）の測定を行った。初磁化率の測定には Bartington MS-2 とコアロギングセンサー MS2C，NRM と ARM の測定および交流消磁にはパススルー型超伝導磁力計（2G Enterprises 755R）を用いた。次に，U-チャネル試料から体積 1 cm^3 キューブ試料を採取し，初磁化率と ARM の測定を行った後，等温残留磁化（IRM）の段階的付加（1.0 T まで）と逆方向の磁場（-0.3 T）の付与を行った。キューブ試料の初磁化率の測定にはカッパブリッジ（AGICO KLY-3S），IRM の着磁にはパルスマグネタイザー（ASC IM-10）を用いた。さらに，深度 20 cm，110 cm，245 cm の 3 層準については，パルスマグネタイザーのコイルを強磁場用のもの（IM-30）に交換し，4.5 T まで段階的に IRM の付加を行った。また，深度 12 cm，110 cm，235 cm の堆積物を石英ガラスのシリンダーに充填し，直交する 3 軸方向に 1.0 T，0.4 T，0.12 T の順に付与した IRM の段階熱消磁実験（Lowrie, 1990）を行った。

初磁化率は深度 35 cm でピークを示し，深度 160 cm まで減少し，それ以深はほぼ値に変化はなかった。80 mT で付与した ARM の強度は深度 100 cm までほぼ一定で，深度 140〜160 cm にかけて急激に減少し，それ以深では大きな変化を示さなかった。IRM に占める低保磁力成分（0.3 T 以下）の割合（S-ratio）はコア最上部から深度 80 cm にかけて 0.9 から 1.0 に近づいた後，深度 140〜160 cm で急減，それ以深では 0.7 以下の低い値を示した．IRM の高保磁力成分（0.3 T 以上；HIRM）はコア最上部でピークを持ち，深度 80 cm にかけて減少した。

IRM の着磁曲線は，深度 0〜30 cm（0.1〜1.0 T でほぼ飽和），40〜140 cm（0.1 T まででほぼ飽和），160〜260 cm（1.0 T まで飽和がみられない）で異なる振る舞いを示した。4.5 T までの着磁では，３層準の試料とも 1.0〜4.5 T の間も IRM が増加する傾向が見られた。３軸 IRM の熱消磁実験からは，３層準の試料すべてにおいて 80 ℃と 710 ℃付近で高保磁力成分の強度が減少することが明らかになり，すべての層準にゲーサイトとヘマタイトが存在することが示唆された。また，上部２層準の試料について， 580 ℃付近と 200 ℃で中保磁力成分と低保磁力成分の強度が減少することから，チタノマグネタイトとマグネタイトの存在が示唆された。

HIRM の値が深度 80 cm から増加することは，コアの半割面で測定された色相と彩度を示す色度（a∗，b∗）の変化とも調和的であり，ゲーサイトとヘマタイトの増加によるものと考えられる。増加開始の年代は約 600 年前と推定され，この時期から赤色土壌の浸食流入が始まった可能性がある。一方，深度 150 cm 付近に認められた磁性鉱物含有量の変化は，還元的続成作用による細粒マグネタイトの溶解によるものと考えられる。