Paleomagnetic study on baked earth from Izumo-Sugisawa ruins

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In Japanese archaeomagnetic direction study, there are few case examples reported with age till the establishment of Sue-wares (Sueki potteries) which were well baked under the anoxic condition in the closed kiln, because baked earths before Yayoi era were in an open atmosphere and in low temperature, and their chronology have large uncertainty.
Here we report paleomagnetic and rock magnetic results for samples obtained from red colored and bake earths two fire pits in a middle Yayoi era (around the begging of AD1C) constructions of Izumo-Sugisawa archaeological site. In the paleomagnetic results, the intensity of remanent magnetization was too low to detect in a spinner magnetometer then all measurements were conducted by a SQUID magnetometer. The natural remanent magnetization of these samples are still low and unstable in many specimens. We could obtain stable direction from a few specimens, and it is hard to extract the characteristic components.
From the results of saturated magnetization (Js) with respect to the temperature in a vacuum condition show an alternation of magnetic minerals above 400C. This is a representative of insufficient heating
at that time of operation. On the other hand, one specimen which has a stable ChRM shows smaller discrepancy of Js between heating and cooling process, so that the place where this specimen was sampled is likely the most baked part in the pit.

Keywords: Archaeomagnetism, Paleomagnetism, Yayoi Era

Reliability of paleomagnetic directions of the Ichi-no-megata Marr sediments as a secular variation record

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Sedimentary paleomagnetic data is crucial for modeling of paleomagnetic secular variation (PSV) in global scale. As currently available Holocene paleomagnetic database contains inconsistent PSV records even from close areas, it is necessary to further improve quality and distribution of the sedimentary paleomagentic records. Here, we report paleomagnetic directions of multiple cores from Ichi-no-megata Marr located in Oga peninsula, Akita Prefecture, and evaluate their validity as a Holecene PSV record.
In 2006 and 2013, two series of core samples (IMG06; 37 m long, IMG13; 118 m long) were recovered from multiple holes in central part of the lake. The core sediments were mostly composed of laminated clay or silt, partly intercalating sandy turbidite layers. We have made pass-through measurements of natural remanent magnetization (NRM) of u-channel samples from these cores. We also made discrete measurements of $7cm^3$ cubic samples from two piston cores (IMG13P-1; 5.9 m long, IMG13P-2; 6.2 m long) collected in 2013. A precise age model has been constructed for the IMG06 core by means of Bayesian modelling constrained by event free depth (Bronk Ramsey et al., 2012).We applied this age model for the other cores based on lithological correlations and matching of magnetic susceptibility data.
Although stepwise AF demagnetizations showed that the NRM is essentially composed of a single stable component, a turbidite layer of 20-30cm thick, dated at about 120 year BP provided inclination values inconsistent between the 3 cores. This is likely explained by deformation of the sandy sediments during the core recovery or sub-sampling. Excepting such intervals, the inclination and the relative declination showed consistent variations between multiple cores, which are also resemble the PSV record from Lake Biwa (Ali et al., 1999). It is thus suggested that the paleomagnetic data from Ichi no-megata Maar can be regarded as a reference PSV record for the global modeling.

Keywords: remanent magnetization, paleomagnetic secular variation, Ichi-no-megata Maar, Holocene

Palaeointensities from Pliocene lava sequences in Iceland: Emphasis on the problem of Arai plot with two linear segments

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Palaeointensity experiments were carried out to a sample collection from two sections of basalt lava flow sequences of Pliocene age in north central Iceland (Chron C2An) to further refine the knowledge of the behaviour of the palaeomagnetic field. Selection of samples was mainly based on their stability of remanence to thermal demagnetization as well as good reversibility in variations of magnetic susceptibility and saturation magnetization with temperature, which would indicate the presence of magnetite as a product of deuteric oxidation of titanomagnetite. Among 167 lava flows from two sections, 44 flows were selected for the Konigsberger-Thellier-Thellier experiment in vacuum.

In spite of careful pre-selection of samples, an Arai plot with two linear segments, or a concave-up appearance, was often encountered during the experiments. This non-ideal behaviour was probably caused by an irreversible change in the domain state of the magnetic grains of the pseudo-single-domain range. This is assumed because an ideal linear plot was obtained in the second run of the palaeointensity experiment in which a laboratory thermoremanence acquired after the final step of the first run was used as a natural remanence. This experiment was conducted on six selected samples, and no clear difference between the magnetic grains of the experimented and pristine sister samples was found by scanning electron microscope and hysteresis measurements, i.e. no occurrence of noticeable chemical/mineralogical alteration, suggesting that no change in the grain size distribution had occurred.

Hence, the two-segment Arai plot was not caused by the reversible multidomain/pseudo-single-domain effect in which the curvature of the Arai plot is dependent on the grain size. Considering that the irreversible change in domain state must have affected data points at not only high temperatures but also low temperatures, $f_v >= 0.5$ was adopted as one of the acceptance criteria where f_v is a vectorially defined fraction of the linear segment. A measure of curvature k' was also used to check the linearity of the selected linear segment. It was avoided, however, to reject the result out of hand by the large curvature k' of the entire data points because it might still include a linear segment with a large fraction.

Combining with the results of Shaw's experiments, 52 palaeointensities were obtained out of 192 specimens, or 11 flow means were obtained out of the 44 lava flows. Most of the palaeointensities were from the upper part of the lava section (Chron C2An.1n) and ranged between 30 microT and 66 microT. Including two results from the bottom part of the lava section, the mean virtual dipole moment for 2.5–3.5 Ma is 6.3 +/- 1.4 10^{22} Am^2 (N=11), which is about 19% smaller than the present-day dipole moment.

Keywords: Palaeointensity, Rock and mineral magnetism, basalt lava, Iceland

Relative paleointensity variation in the Middle Eocene estimate to the marine sediment cores recovered from IODP Site U1403

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From the Cretaceous to the present, geomagnetic reversal frequency is known to increase from zero to five times in 1 million year (e.g. Merrill et al., 1996). The characteristic of the geomagnetic polarity change for such a long term is elucidated. However, the paleomagnetic intensity continuous variation are elucidated in detail in the past only for about 2-3 million years (e.g. Valet et al., 2005; Channel et al., 2009; Yamazaki & Oda, 2005), and reversal frequency and the relationship of plaeointensity do not become clear. 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. We conduct paleomagnetic/rock magnetic measurements of marine sediment cores drilled from Site U1403 (25-160 mcd: meter composite depth), and estimate the relative paleointensity (RPI) in Paleocene to the Eocene.

It was estimated that 25-160 mcd covered 40.145 Ma (chron C18n.2n/C18r) to 49.344 Ma (C22n/C22r) from the paleomagnetic polarity stratigraphy based on the result of the natural remanent magnetization (NRM) measurement. As a result of Anhysteretic remanent magnetization (ARM), Isothermal remanent magnetization (IRM), ARM/SIRM and S-ratio (-0.1, -0.3 T), 50-101 mcd (40.145 Ma (C18n.2n/C18r) to about 44 Ma (C20r)) interval is considered relatively homogeneous rock magnetic property. Thus, we estimated RPI of this interval.

According to the RPI variation, the shows the minimum on the chron boundary and variation with the big amplitude within chron. In three chron (C18r/C19n, C19n/C19r, C19r/C20n) boundary before and after showed that the intensity decreased with a reversal gently for about 50 ka and the intensity suddenly increased and recovered for about 10 ka. These characteristics are similar to a characteristic to be seen in the RPI of the past 2 million years and the five times reversal boundary during this period (Valet et al., 2005). The reversal frequency of middle Eocene was about half of the present (Merrill et al., 1996). It is suggested that these characteristics are common to paleointensity, regardless of the reversal frequency, continuous middle Eocene to the present.

Keywords: paleomagnetism, marine sediment core, relative paleointensity

Integrated magnetostratigraphy and biostratigraphy of the Upper Triassic bedded chert sequences from Inuyama area, central Japan

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The Late Triassic was characterized by several catastrophic events, such as widespread eruption of the Central Atlantic Magnmatic Province flood basalts, and large extraterrestrial impacts. The stratigraphic record of these events has been recently reported from the Triassic bedded chert successions in Japan, deposited within a Paleo- Pacific (Panthalassa) deep basin. However, the ages and durations of these events are uncertain because the magnetostratigraphic studies and the conodont biostratigraphic studies of chert sequence in Japan are not well known, and the radiolarian biostratigraphy of Sugiyama (1991) established in the chert sequence is not correlated with the Tethyan biostratigraphy.
Here we present Carnian to Rhaetian magnetostratigraphy and biostratigraphy (conodont and radiolaria) of the Upper Triassic bedded chert successions from the Mino belt, Inuyama area, central Japan. 416 oriented samples were collected at four sections (Section H, N, Q, R) where Sugiyama (1997) investigated the radiolarian biostratigraphy. All samples were thermally demagnetized and analyzed at the paleomagnetic laboratory of Center for Advanced Marine Core Research, Kochi Univ.
Based on detailed study of the conodont biostratigraphy from the study sections, seven conodont zones are recognized and calibrated with the Sugiyama's radiolarian zone. Thermal demagnetization showed four distinct remanent magnetization components from the cherts. The highest blocking temperature component shows positive reversal test and is regarded as the primary remanent magnetization, which produced a magnetostratigraphy of the Carnian to Rhaetian. Paleomagnetic polarity reversals observed at the vicinity of Carnian/Norian boundary and middle Norian/upper Norian boundary are correlated with those of Tethyan marine sections (Pizzo Mondello and Silickà Brezovà). Assuming that the rocks in the two Tethyan marine sections were deposited in the Northern Hemisphere, the magnetostratigraphic correlation indicates that the bedded chert of Inuyama area was deposited in the Northern Hemisphere. The mean inclination of the last demagnetized component suggests the bedded chert originated in an equatorial area.

Keywords: Late Triassic, magnetostratigraphy, biostratigraphy, bedded chert, Mino belt, Panthalassa

Lock-in depth of pDRM Acquisition on Marine Sediments of the Western Equatorial Pacific Ocean

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On reconstructing past geomagnetic-field variations from marine sediments, lock-in depth of post-depositional remanent magnetization (pDRM) acquisition has been controversial for a long time. By direct comparison of relative paleointensity (RPI) and ^{10}Be flux, Suganuma et al. (2010, 2011) proposed a lock-in depth of ~15 cm, whereas Valet et al. (2014) reported ~0 cm. We studied lock-in depth of pDRM using a marine sediment core obtained from the West Caroline Basin in the equatorial Pacific Ocean (R/V “MIRAI” MR14-02 cruise, core PC01). RPI and ^{10}Be flux did not show obvious constant shift around the onset of the Olduvai subchron and the Gauss-Matuyama transition. This implies a negligibly small lock-in depth for the studied core. We also examined the lock-in depth of the PC01 core by comparing δ^{18}O based ages of recorded polarity boundaries and GPTS ages, and by comparisons of RPI records among PC01, MD982187 (Yamazaki and Oda, 2005) and IODP Site U1314 (Ohno et al., 2012), which have different sedimentation rates. The results were consistent with the negligibly small lock-in depth of the PC01 core. This contrasts to the ~15 cm lock-in depth of the MD982187 core (Suganuma et al, 2010, 2011), which was obtained from the same area. Furthermore, Horiuchi et al. (in press) obtained lock-in depths of ~6 cm and ~10 cm from two cores in the same area. Lock-in depth may depend on lithology and depositional processes of each core.

Keywords: paleointensity, lock-in depth, 10Be

Paleomagnetic re-examination of ca. 3.46 Ga dacite in the Pilbara Craton: a positive field test?

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Dacite and basalt from the Duffer Formation in the Pilbara Craton were used in a positive fold test for ca. 3.46 Ga remanence (McElhinny and Sananayake, 1980). This has been the oldest paleomagnetic field test, only tied by recent conglomerate tests from the Barberton Greenstone Belt (Usui et al., 2009; Biggin et al., 2011). However, the reliability of the fold test was questioned because of the potentially complex deformation in the area. To better understand the remanence of the Duffer Formation, we conducted paleomagnetic study on dacitic agglomerates apparently overlying the dacite lava. Typically, agglomerates yielded three remanence components, similarly to the lavas measured by McElhinny and Sananayake (1980). However, the so-called “magnetite component”, which was reported to pass the fold test, and the “hematite component”, which did not pass the fold test, both revealed directional difference between the agglomerates and the lavas. On the other hand, multiple clasts taken from single outcrops yielded different directions. This possibly reflects relatively low temperature deposition of the agglomerates and effectively forms a positive conglomerate test. Alternatively, the clasts may be remagnetized to various extents. Further rock magnetic investigation is necessary to distinguish these two possibilities.

Keywords: Archean, paleomagnetism

Past continental shape inferred from GPS data part 2

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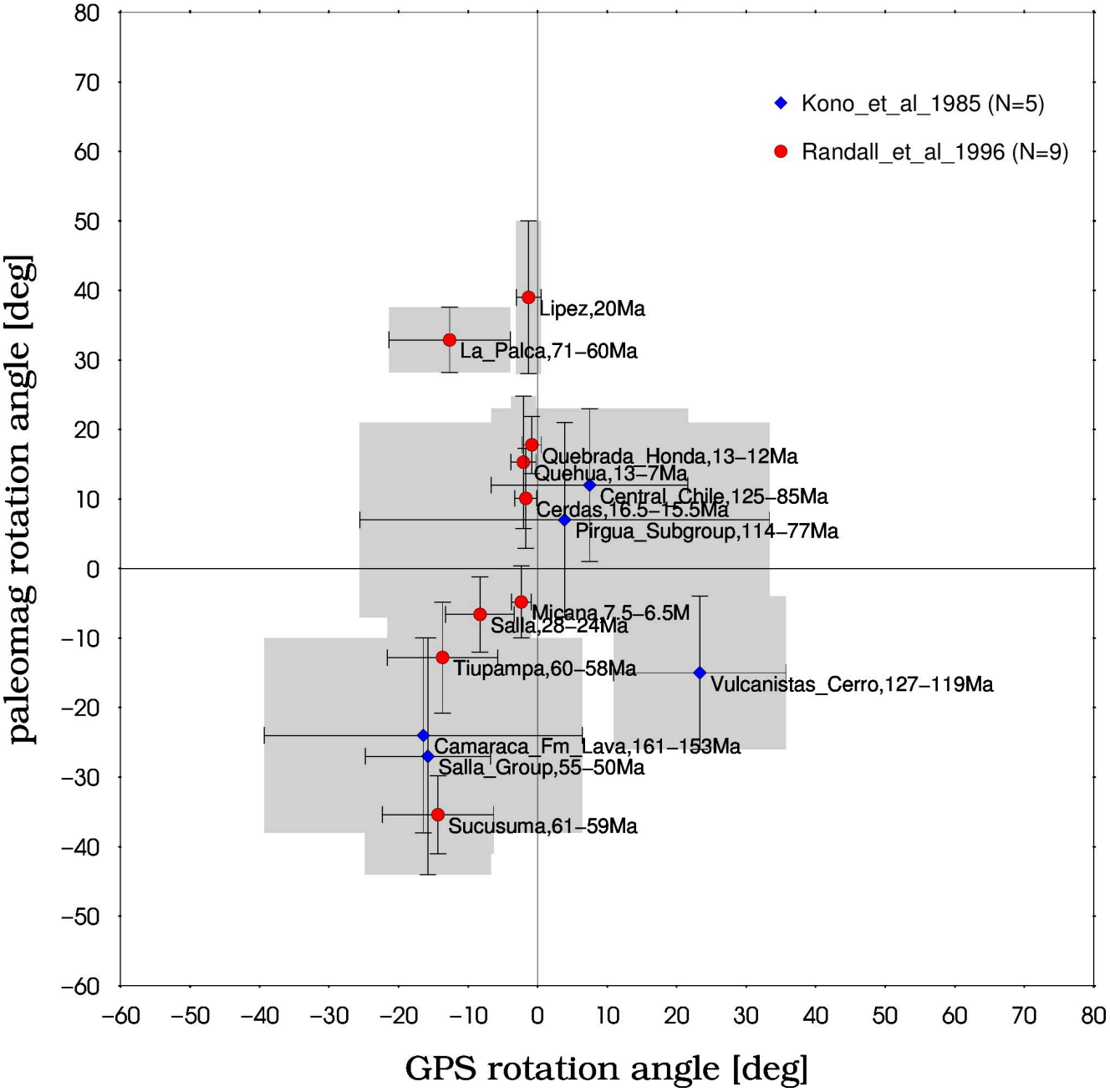
Kawai et al.,2014 JpGU applied a method of Harada and Kato(AGU Fall Meeting 2012), and calculated about 50Ma shape of the south American continent from GPS data, and compared the shape with early tertiary shape of south American continent estimated by paleomagnetic analysis of Kono et al.,1985. The result was quite similar with each other and this implies 20 years of GPS data is comparable with million year scale crustal deformations.
We applied a same method as Kawai et al.,2014 with more GPS data and calculated past and future shapes of all continents of earth.
For quantitative examination of the results above, we used about 14 paleomagnetic data from Kono et al.,1985 and Randall et al.,1996 and compared the rotation angles with calculated rotations from GPS data at same age and locations.
Although the error sizes for GPS extrapolation and ages of paleomagnetic data are large, a positive correlation between paleomagnetic and GPS rotations are shown in this study. This also implies 20 years of GPS data is comparable with million year scale continental deformations. However, 3 out of 14 paleomagnetic data we used have a negative correlation between paleomagnetic and GPS rotations. This may show that there are some limits for our methods of analysis and that GPS data is incomparable to paleomagnetic data at certain time ago or at certain locations.

Keywords: GPS, Past continental shape, Paleomagnetic data



Spatial and temporal variation of vorticity at the core surface estimated from geomagnetic field data

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Fluid motion near the Earth's core surface provides useful information on core dynamics, and it can be estimated from spatial and temporal distributions of the geomagnetic field. Most of core surface flow models rely on the frozen-flux approximation, in which the magnetic diffusion is neglected for a large-scale magnetic field with time scales much shorter than magnetic diffusion time. It should be noted, however, that there exists a viscous boundary layer at the core-mantle boundary (CMB), where the magnetic diffusion may play an important role in secular variations of geomagnetic field. Keeping this in mind, a new approach to estimation of core surface flow has been devised by Matsushima (2015). That is, the magnetic diffusion is explicitly incorporated within the viscous layer, while it is neglected below the boundary layer.

A core surface flow model between 1840 and 1990 has been derived from a geomagnetic field model, gufm1 (Jackson et al., 2000). Temporal variations of the flow model contain information on phenomena in relation with core-mantle coupling, such as the LOD (length-of-day), and spin-up/spin-down of core flows. In particular, core surface flows inside the viscous layer at the CMB may reveal an interesting feature in relation with Earth's rotation.

In this paper, we have examined time series of the LOD, kinetic energy of core surface flow, and vorticity derived from the flow model. We could not find any clear correlation between the LOD and kinetic energy of core flow within the boundary layer, and rates of changes in the LOD and the kinetic energy. Also the z-component of global vorticity calculated from core surface flows inside and below the boundary layer was turned out to have little correlation to the LOD. By focusing on a specific longitude or latitude, however, the z-component of local vorticity reveals moderate correlation to the LOD. This result may be explained in terms of conservation of the potential vorticity.

Keywords: vorticity, core surface flow, geomagnetic field

Thermal structure of the inner core boundary in numerical dynamos

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Seismic anisotropy through alignment of crystal lattices suggests aspherical growth of the inner core. Slow viscous deformation of the inner core and latent heat distribution by flow motion are expected to be the origin of the aspherical growth of the inner core. A number of dynamo simulations has been performed with prescribed boundary conditions at ICB to take into account the inner core heterogeneity. In the present study, we perform geodynamo simulations with considering the heat equation in the inner core. To compare the results with the simulation without considering the inner core, we assume that the inner core is electrically insulated and co-rotate with mantle. In addition, we set the same thermal diffusivity for the inner core and outer core, and introduce a constant heat source in the inner core to keep the average temperature in the outer core through the simulations. We also set a homogeneous heat flux at the outer boundary of the shell as a thermal boundary condition at CMB. We compare the simulations results with the simulations results using fixed heat flux or temperature condition at ICB. The results show that the time averaged thermal structure at ICB is likely to the homogeneous heat flux boundary conditions. The time averaged lateral temperature variation is approximately 26% of the average temperature difference between ICB and CMB, while lateral heat flux variation is only 6% of the average heat flux at the ICB. We also observe small scale temperature and heat flux variations; however, these components vary with time. In addition, the length scale of the heat flux variation is smaller than the temperature variation at ICB.

Keywords: geodynamo simulations, Inner core boundary

Regional mapping of the Martian magnetic anomalies on the surface with the SVM method

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The Mars shows strong magnetic anomalies of more than 100 nT at 400 km altitude by the Mars Global Surveyor (MGS) observation during 1997-2006 (e.g. Acuña et al., 1998). The magnetic anomalies indicate existence of the ancient Martian dynamo at about 4Ga, although the present Mars has no global magnetic field. Several previous studies have mapped the magnetic anomalies using the MGS observations at about 400 km altitudes of the mapping phase and at about 120-400 km altitudes of the aerobraking phase. The mapping results show characteristic features: the E-W elongated magnetic anomalies of about 15 degree width, and magnetic reduction/demagnetization at some large craters (e.g. Acuña et al., 1998; Purucker et al., 2000; Connerney et al., 2005; Lillis et al., 2008). However, it is difficult to detect fine structures of the crustal magnetic fields on the maps normalized at high altitudes, since short wavelength components are attenuated. In the present study, we have applied the Surface Vector Mapping (SVM) method (Tsunakawa et al., 2014, 2015) to the Terra Cimmeria region and several craters on the Mars.
Terra Cimmeria is a part of the high land region on the southern hemisphere and one of the strongest magnetic anomaly regions on the Mars. Applying the regional SVM method to the MGS observations in 2005 (30-60 S, 150-180 E; -0.4 ~ 3 km in topographic elevation), the surface magnetic field is estimated to be more than 10000 nT at some areas of the Terra Cimmeria region. The SVM maps show elongated magnetic anomalies with about 5 degree width on the surface, which is much shorter in wavelength than those on the previous maps. These short wavelength components are recognized with relatively smaller amplitudes in the observed magnetic fields. We also have analyzed the magnetic fields observed in 2001. Comparison of the SVM maps between 2005 and 2001 datasets indicates good internal consistency. Based on the SVM results, we have calculated the magnetic field along the pass of about 125-375 km altitudes during the aerobraking phase in 1998, resulting in good agreement of the calculated fields with the observed fields. Thus the Martian magnetic anomalies in the Terra Cimmeria region are successfully mapped on the surface in the present study.
One of the remarkable features on the SVM maps of the Terra Cimmeria region is that total intensities of more than 14000 nT on the surface are restricted at areas with about 2-3 km topographic elevations. The diagram of surface total intensity vs. topographic elevation shows that maximum intensity increases with the elevation in range of -0.4 ~ 2 km. These features suggest that magnetic anomaly sources in this region may be distributed in relatively thin layer near the surface. We also have applied the SVM method to several craters and their surrounding regions. Most of these crater regions show correlations between the the surface total intensity and the topographic elevation, similar to the Terra Cimmeria region. The results from the Terra Cimmeria and crater regions imply that the Martian magnetic anomalies seem to be carried mainly by crustal magnetization of a layer with several kilometer depth.

Keywords: Mars, magnetic anomaly, mapping, crust

Rock-magnetic studies concerning source of the Martian magnetic anomaly

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Mars Global Surveyor observed the magnetic field of Mars, and revealed that there are many strong magnetic anomalies. The strong magnetic anomalies suggest an active core dynamo of early Mars (about 4 billion years ago), and some mechanism of crustal formation in the dynamo field. Since magnetic properties of crustal rocks depend critically upon the mineralogical form of magnetic particles, the strong magnetic anomalies can give crucial information about the chemical composition and oxidation state prevailing in the early Martian crust. However, source of the Martian magnetic anomalies, which are originated from thick magnetized layers within the crust, have been poorly understood yet because of the lack of basic information concerning magnetic properties of deep crustal rocks. Here, we report the results of rock-magnetic studies to interpret the source of the Martian magnetic anomaly.

To determine magnetic domain state of the source, we conducted in-situ magnetic hysteresis measurement of magnetite under high pressure up to 1 GPa. The results show that magnetite exhibits various pressure dependences of coercivity with respect to magnetic domain states: multidomain (MD) magnetite (linearly increase with pressure at a rate of +91%/GPa), pseudo-single-domain (PSD) magnetite (increases with pressure as a quadratic function), acicular single-domain (SD) magnetite (constant up to 1 GPa), and equidimensional SD magnetite (decrease with pressure at a rate of −15%/GPa). Taking into account these pressure dependences, relaxation time of remanent magnetization in the Martian crust was calculated as a function of depth and age. Remanent magnetizations carried by MD and PSD magnetites have been demagnetized within 4 billion years, except very shallow crustal part. On the other hand, the SD magnetite can stably retain its magnetization in the entire crust. Therefore, the source of the Martin magnetic anomaly is fine-grained SD magnetite.

As the mechanism that crystallize and maintain fine-grained SD magnetite in the deep crustal rocks, we focus on a plagioclase crystal with magnetite inclusions. The plagioclase crystal with magnetite inclusions is ubiquitous in mafic and intermediate terrestrial plutonic rocks, and should play an important role in controlling the magnetic properties of deep crustal rocks. To evaluate the role of the plagioclase crystal, we prepared plagioclase crystals from gabbroic anorthosite of the Duluth complex at Forest Center, Minnesota, USA, and magnetic measurements combined with microscopic observation and synchrotron radiation study were conducted for the single grain plagioclase crystals. The magnetic hysteresis parameters resulted in SD and PSD range on the Day plot. The low-temperature remanence curves showed pronounced remanence reductions at around 100–120 K, indicating that the plagioclase crystals contained nearly pure magnetite. The magnetite contents ranged from 40 to 680 ppm with an average of 270 ppm in weight, which could be sufficient to the source of strong magnetic anomalies. On the basis of the experimental results, we will discuss the chemical composition and oxygen state in the Martian crust, which was suited for bearing fine-grained SD magnetite.

Keywords: Rock-magnetism, Martian magnetic anomaly

Improvements in Signal-to-Noise Ratio for SQUID microscope

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We have been developing scanning SQUID (superconducting quantum interference device) microscope for geological samples. In this presentation, we will demonstrate improvements in our scanning SQUID microscope system. We introduce external magnetic shielding by thin shield film outside of a double-layered PC permalloy magnetic shield box surrounding scanning SQUID microscope. We also develop internal magnetic shield just outside of scanning SQUID microscope with five layered shield film for AC and DC shielding. With this set-up, we also introduce a reference SQUID sensor inside liquid helium dewar in order to compensate noise originated from environmental magnetic field. Resulting signal-to-noise ratio is going to be analyzed and reported. In addition, we show a calibration procedure for our scanning SQUID microscope in terms of its sensitivity and deviation from vertical axis.

Keywords: scanning SQUID microscope, noise, magnetic shielding, signal-to-noise ratio, calibration

Comparison of magnetic relaxation-time distributions derived from measurements in frequency-domain and time-domain

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Dynamic magnetization variations in short period of time were measured for a set of volcanic rocks in time domain and frequency domain. The frequency domain measurements were performed with MPMS to measure low-field AC magnetic susceptibility over 1 Hz to 1 kHz in 10 K to 300 K. These frequency spectra showed in common the Debye relaxation pattern indicating a narrow distribution of relaxation time. These susceptibility spectra were analyzed with a least-square inversion algorithm to derive their relaxation time spectra. The relaxation time spectra at low temperature were extrapolated to room temperature based on the Neel's relaxation time theory. Measurements in time domain were performed using the pulsed-field method (Kodama, 2015) to determine a decay constant by fitting the relaxation curve. The estimated relaxation times are in the range of 10^{-5} sec in agreement with those at room temperature determined from the frequency domain data. Additionally, numerical transformation of the frequency domain data into time domain and vice versa were made by digital filters based on linear response theory. The narrow distribution of relaxation time derived from these direct and indirect methods is most likely ascribed to the grain-size distribution of SP particles, the magnetic structure and dynamics of domain walls in PSD and MD particles. Applications of these new experimental and theoretical methods to rock magnetism will be proposed.

Keywords: magnetic relaxation time, frequency spectrum, inversion

Viscous remanent magnetitization of tsunamigenic boulders and the age of tsunami events

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Along some coastlines in Japan, there are erratic boulders apparently emplaced by tsunamis. The key to understanding of past tsunami events is the ability to accurately date the emplaced age of boulders. Although radiocarbon is one of powerful tools for dating boulders, subsequent movements and non-organic rocks (sedimentary rocks and volcanic rocks) cannot be dated. To overcome this problem, we use viscous remanent magnetization (VRM). Viscous remanent magnetization (VRM) partially overprints original magnetization in rocks displaced by paleotsunami events. If a magnetic-mineral bearing rock is moved or re-oriented, the magnetism of the smaller magnetic grains re-aligns to the direction of the ambient magnetic field with time. This phenomenon is well known as Neel's (1949, 1955) single-domain (SD) relaxation theory. Pullaiah et al. (1975) derived a time-temperature (t-T relation) relation by assuming Neel's theory of magnetite. In principle, an experimental combination of short relaxation time and high temperature for removing VRM can determine the unknown relaxation time (tsunami age) at room temperature. We tested this hypothesis to tsunamigenic boulders consisted of coral limestone in Ishigaki Island, sand stone in Beppu bay and welded tuff in Sanriku coast. The demagnetized paths of all samples have VRM turning points, and their demagnetization temperatures are compatible or higher value of the Neel's hypothesis.

Keywords: tsunamigenic boulder, viscous remanent magnetization, time-temperature relation

Examination on natural remanent magnetization and its origin of single grains extracted from the Ito pyroclastic flow deposits

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There are many widespread tephras around Japan and various earth science studies on them have been carried out. In paleomagnetic and rock magnetic studies, measurements are typically done on an assemblage of tephra grains and thus targets are macroscopic remanent magnetization. However, there seems a possibility that an individual grain acquired thermoremanent magnetization (TRM) as natural remanent magnetization (NRM) during its formation at eruption producing the tephras. In this study, we have extracted 20-30 mesh size (595-841 micro-m) grains from unwelded parts of the Ito pyroclastic flow deposits and performed paleomagnetic and rock magnetic measurements to examine origin of the NRM.
NRM intensity measurements were conducted on 646 grains extracted from the Ito pyroclastic flow deposits. These grains could be classified into six different groups: block-type volcanic glass, pumice-type volcanic glass, black rock fragment, green rock fragments, pyroxene, and feldspar or quartz. Seventy-nine grains (12.2%) showed intensities more than 10 times higher than averages of blank measurements (8-17 $pAm^{2)}$. One or two grains were selected from the six groups and subjected to stepwise alternating field demagnetization (AFD) experiments. The experiments revealed that the grains from the groups of block-type volcanic glass, pumice-type volcanic glass, black rock fragment, and green rock fragment have stable remanent magnetization. Rock magnetic measurements were conducted for these grains and they indicated that main remanence carriers of the stable magnetization are single domain magnetites with high coercivity.
The grains with stable remanent magnetization also showed stable behaviors against stepwise AFD of anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM). Excepting some samples, cases ratios of NRM/ARM and NRM/IRM resulted in 1.24-4.07 and 0.024-0.0475, respectively. These values agree with the ratios of TRM/ARM with 2.60+/-1.32 and TRM/IRM with 0.0362+/-0.0128 reported by Yu (2010) for SD and PSD magnetites at a one standard deviation level, suggesting that NRMs of these grains are TRMs in origin.

Changes of magnetic minerals in reductive chemical demagnetization.

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Demagnetizations are important processes in paleomagnetism studies. Alternating Field demagnetization(AFD) and Thermal demagnetization (ThD) are two of the most popular techniques used. However, there are samples that those techniques would not work for erasing secondary magnetizations. In such a case, Chemical Demagnetization(CD) could be applied. It is widely used for paleomagnetic studies of redbeds, as the post-dated magnetic minerals may dissolve earlier. So it shall be effective for demagnetization of rocks with chemical remanent magnetization (CRM). Chemical demagnetization in most paleomagnetic studies has been performed using concentrated HCl solution, by leaching specimens for several months or for several days in high temperature. Those procedures have not been widely used because the handling of the high temperature HCl is difficult or time consuming for the room temperature. In addition, they destroy limestone samples and any other sedimentary rocks cemented by carbonate materials. In order to apply CD for limestones, we examined reductive etchant of neutral pH under the room temperature.
The magnetstratigraphy of reef limestone (Ryukyu Group) using the Reductive Chemical Demagnetization(RCD) is already reported in the 138th Society of Geomagnetism and Earth, Planetary and Space Sciences. Here we focus on the magnetic mineral changes in RCD, and magnetic properties of the minerals charring characteristic remanent magnetization.
The reductive etchants tried are potassium iodide (KI) solution and ascorbic acid (C6H12O6) solution. The solutions are prepared in 5-20%, and for ascorbic acid (pH is about 2.4) the pH is buffered to 6.0-6.5 with sodium hydrogen carbonate(NaHCO3). The redox potential of those cases is -150_-10mv. This condition falls in the domain of stable iron ion Fe2+ in the pH-pE diagram shown in Henshaw and Merrill(1980). After the leaching experiment in this condition, we perfomed various rock magnetism measurements.
As we wrote above chemical demagnetization in room temperature is very time consuming, drip-feeding of etchant is also tested. Drips of etchant is supplied from the top of the sample, and flows out from the bottom. The solvent (water) removes the solved Fe2+ faster.
We performed three experiments:
1) RCD of IRM: We compare the efficiency varying the etchants, concentrations and exposure method, in eight kind of solution(KI:5,10,15,20% ascorbic acid:5,10,15,20%) which supplied by dripping and dipping. The IRM is measured every 12 hours. The dripping enhances the demagnetization speed significantly, and shortens the duration up to a 9th of dipping RCD. In the eight kinds of solutions, the ascorbic acid 5% + NaHCO3(pH=6.52,ORP=-107mv) is the fastest, and the demagnetization is completed in 72 hours. Those experiments indicate RCD dipping the reductive etchant is most effective at least for those limestones.
2) IRM acquisition: The comparison of the IRM acquisition curves between before and after RCD indicate that the significant increase in saturating field, 3T and 1T, respectively, by RCD. It suggest that the RCD removes hematite and/or goethite, and remains magnetite intact.
3) Thermal demagnetization of a three-component IRM: Samples before and after RCD are exposed in 3T, 0.3T and 0.1T in each orthogonal direction, and then thermally demagnetized. It showed that a high coercivity magnetic minerals was demagnetized by RCD. This indicate that at least considerable portion of the component demagnetized by RCD is carried by hematite.
These results showed that the RCD is effective for carbonate rocks. We think that the reductive

etchant make CD more versatile, as the ascorbic acid is easy to handle in the laboratory.

Keywords: chemical demagnetization, reductive etchant

Paleomagnetism and AMS of a slumped fine-grained volcanic ash bed

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A slumped fine-grained volcanic ash bed in central Japan provides an opportunity to investigate the paleomagnetic directions and AMS (anisotropy of magnetic susceptibility) of a slumped deposit. The ash bed, named the Otani volcanic ash, is about 3.6 m thick at its type locality and stratigraphically dated at about 4 Ma. The majority of the bed comprises a lahar deposit that has suffered syn-sedimentary slumping. Oriented cores were taken at five sites at the type locality where attitudes of lamination are significantly different from each other. Rock magnetic experiments show that magnetite is the main magnetic mineral. All samples were subjected to alternating field or thermal stepwise demagnetization, and most have reverse polarity characteristic remanent magnetization components that form a moderate to tight cluster at each site in the geographic (in situ) coordinates, hence failure of a fold test. The magnetization was therefore acquired after slumping, possibly as a post-depositional DRM. Our results suggest that slumped fine-grained volcanic ash beds can be a subject of paleomagnetic directional study. On the other hand, the orientation of AMS principal axes differs significantly between sites both before and after unfolding. This indicates that the alignment of magnetization-carrying magnetites does not control the AMS of the samples and that the AMS has been affected by slumping. Determination of the lahar flow direction is not possible for the Otani ash bed from the AMS results.

Keywords: Slumping, volcanic ash, tephra, paleomagnetism, anisotropy of magnetic susceptibility, AMS

