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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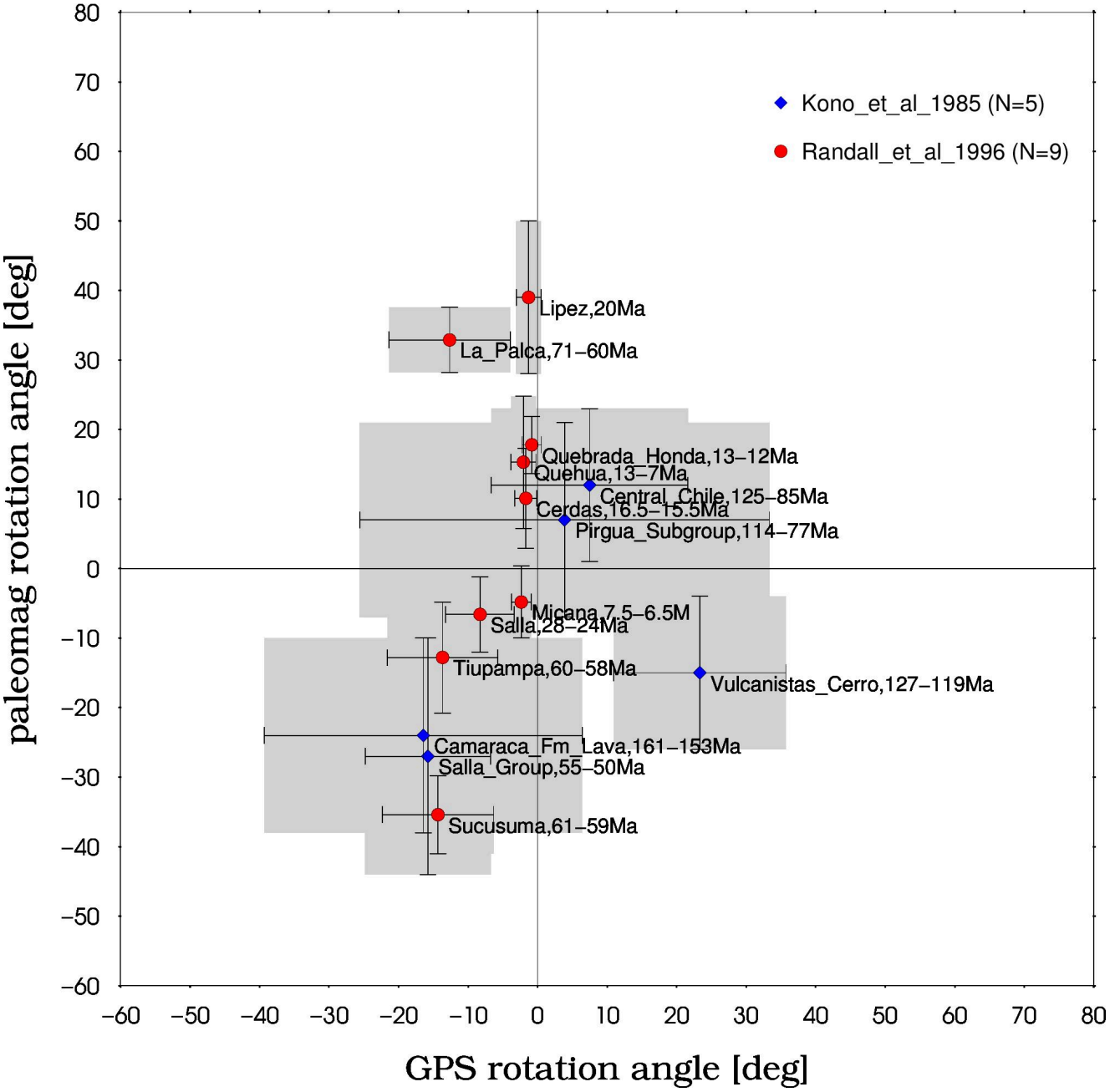
Kawai et al.,2014 JpGU applied a method of Harada and Kato(AGU Fall Meeting 2012), and calculated about 50Ma shape of the south American continent from GPS data, and compared the shape with early tertiary shape of south American continent estimated by paleomagnetic analysis of Kono et al.,1985. The result 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

Paleoenvironmental control on the magnetic mineral assemblage in the Izu rear arc over the last 1 Ma

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During April and May 2014, IODP Expedition 350 drilled a 1806.5 m deep hole at Site U4137 in the Izu-Bonin rear arc, in order to understand, among other objectives, the compositional evolution of the arc since the Miocene and track the missing half of the subduction factory. Mostly fine grained sediments were recovered and variations in magnetic properties and mineralogy are well documented. Routine rock magnetic measurements performed on about 360 samples in the first 120 meters of Hole U1437B showed that pseudo single domain to multidomain (titano-) magnetite is the main carrier of the remanence. The studied interval covers the last 1 Ma, i.e. marine oxygen isotope stages (MIS) 1 to 25. Rock magnetic properties and composition, concentration and grain size variations of the magnetic minerals are compared with the isotopic record in order to investigate the rock magnetic signature of climate changes in the Izu rear arc in the Late Pleistocene. The proxies for magnetic concentration (e.g. magnetic susceptibility, saturation isothermal remanent magnetization) show generally higher values during the interglacials; and lower values during the glacials. This might be partly explained by increasing volcanic activity at the glacial/interglacial transitions as is shown by an increase in the frequency of tephra layers near the time of the transitions. In addition, the composition of the magnetic assemblage also varies with the oxygen isotope record. After the mid Pleistocene transition (1250-700 ka), higher coercivity minerals (such as hematite) dominate the magnetic assemblage in the glacial stages, whereas lower coercivity minerals dominate the interglacial stages. The magnetic assemblage of the Izu rear arc sediments is thus complex with various origins. Ti-magnetite, of detrital and volcanic origins, dominates the interglacials whereas higher coercivity minerals dominate the glacials confirming an increasing supply of Asian dust in the sediments in glacial times. XRF measurements support our observations.

Keywords: Izu rear arc, IODP Exp 350

Microscopic observations of pedogenic nanoparticles causing magnetic enhancement in Chinese loess deposits

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Paleoclimatic signals have been recorded in various ways in Chinese loess-paleosol sequences. Magnetic susceptibility has been used as a reliable proxy for reconstructing Asian summer monsoon intensity because its enhancement is exactly related to paleorainfall through neoformation of magnetic nanoparticles during pedogenesis. However there are no observations which can interpret either formation process or form of such pedogenic nanoparticles exactly.
To investigare this problem, scanning electron microscope (SEM) observations were conducted after some rock magnetic experiments including magnetic susceptibility measurements, IRM composition analysis and thermomagnetic measurements, and we divided bulk samples into three subsamples with different grain size bands (D1: >10 μm, D2: 10~1 μm, D3: <1 μm) in advance so that we can obtain significant informations on grain sizes of pedogenic nanoparticles which may help the microscopic observations. Bulk samples used in this study include less-altered loess and mature paleosol showing extremely low (29 $\times 10^{-8} m^3 kg^{-1}$) and high (116 $\times 10^{-8} m^3 kg^{-1}$) magnetic susceptibility respectively and were selected as specimens from a sequence of loess L8 to paleosol S8 from Lingtai on central part of the Chinese Loess Plateau.
From results of IRM composition analysis and thermomagnetic measurements, pedogenic nanoparticles turned out to be magnetite or maghemite. Besides, results of magnetic susceptibility and its frequency dependence (FD) showed that D2 has the dominant contributions amounting to over 60 % to enhanced magnetic signals in paleosol. Considering FD indicates the total amount of super-paramagnetic (SP) particles whose grain sizes are tens of nm, we can suggest that the detritus grain size band in which pedogenic nanoparticles including some SP particles are concentrated is D2 and such ultra-fine particles exist in detrital particles in the form of inclusions. Based on these results and hypothesis, magnetic extractions were conducted on D2 of both loess and paleosol. A certain amount of particles was obtained from paleosol while particles were hardly obtained from loess, and these magnetically extracted particles from paleosol D2 were subjected to SEM observations. Energy dispersive X-ray spectroscopy (EDS) showed that such magnetically extracted particles include a lot of detritus silicates like chlorite, muscovite and quartz even they are non-magnetic minerals. Watching surface of these silicates with SEM carefully, nanoinclusions of iron oxide were observed. Further results including X-ray diffraction analysis and TEM observation will be shown on the poster.

Keywords: Chinese loess, pedogenesis, magnetic enhancement, SEM observation

Magnetic mineral distributions in surface sediments taken from the northeastern Japan Sea

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In order to understand how magnetic minerals assemblages are affected by the redox state of overlying bottom waters in the northeastern Japan Sea, rock magnetic and chemical analyses were conducted. Undisturbed surface sediments were taken at six sites with a multiple corer during the R/V Shinsei-maru KS-14-13 cruise in 2014. The sediments consist of silty clay, and water depths of the six sites range between 778 to 2709 m. Dissolved oxygen (DO) of bottom waters were measured directly with a DO meter on board immediately after recovering of the multiple cores. Water samples were taken from the cores using by a plastic syringe and were passed through a filter (pore diameter of 0.45 μm), and water samples 30 mL were stored in Teflon bottles. The water samples were treated with 1 mL of special grade nitric acid (1 mol/L concentration), and pH was adjusted below 1 at room temperature for dissolved iron (DI) analysis. DI was measured with a flameless graphite furnace atomic adsorption spectrometer. Dried and powdered sediment samples of approximately 20 mg were used for total organic carbon (TOC) and total nitrogen (TN) measurements with a CNHS analyzer. Thermal demagnetization of composite IRMs were conducted for determination of magnetic minerals in the samples. The dried powder samples (ca 50 mg) were packed in a small quartz cup (5 mm in diameter and 10 mm in height). A magnetic field of 2.5 T was applied along the vertical direction of the cup, and then fields of 0.3 T and 0.07 T were applied along the two remaining perpendicular axes using a pulse magnetizer. Results show that higher values of TN and TOC contents are recognized at sites which has lower DO in bottom water. Thermal demagnetization results for composite IRMs for samples from all site samples, soft (<0.07 T), and medium (0.07-0.3 T) components are demagnetized completely at around 580 degree which is the Curie point of magnetite. Slight thermal decay of the hard components (<2.5 T) is observed at 675 degree which is the Curie point of hematite in all samples. An inflection in demagnetization curves at around 320-400 degree is recognized in samples from all sites. Authigenic greigite which is not expected to be defined magnetic mineral to form under an oxic water column. The inflection suggests the presence of (titano)maghemite. The remanent magnetization intensities decrease at around 80-120 degree which is the Neel temperature of goethite at a most oxic site. DI concentration of the site show highest value, thus it suggest that suspended solids of iron hydroxides (<0.45 um in diameter) area bundantly present in the relatively oxic bottom waters, and goethite is stable under such condition. Magneto fossils were confirmed by TEM observations, and were classified three major morphologies which are elongate, tear drop, and equant. Morphology ratios varies by the redox state of overlying bottom waters.

Keywords: Magnetic mineralogy, Redox state of overlying bottom water, Magneto fossils

Magnetic Detection and Ferromagnetic Resonance Characterization of Magnetic Minerals in Fossil Coral Skeletons in Ishigaki Island, Japan

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The remanent magnetization of corals has been one of attractive archives because coral frameworks may provide us high-resolution paleomagnetic records from pre-observatory times, due to their high growth rates. The coral skeletons, mainly composed of aragonite, have following two advandages in the reconstruction of the geomagnetic field: 1) they can be dated by radiocarbon and uranium-thorium dating method, 2) a paleomagnetic standard 1-inch core sample gives an avaraged orientation for two-three years because they grow up at a rapid rate. Especially, the annual banded skeleton of *Porites* might have a great potential as a high-resolution paleomagnetic recorder due to their continuous growths through hundreds of years at a growth rate 11–20 mm-yr. Because of these characteristics, they may be able to record short-term geomagnetic paleosecular variation in a decadal or centennial scale, which are difficult to reconstruct with previus samples (e.g., lava flows, burnt archeological artifacts, lake or marine sediments, and speleothems). Unfortunately, in spite of the enormous possibility for paleomagnetic reconstruction, most coral skeletons have shown an extremely weak magnetization, and their magnetic origin has not been determined. However, a measureable magnetization has been reported in deceased coral tsunami boulders along the shorelines of Ishigaki Island where the coral reefs are grown on bedrock of Ryukyu limestone and Jurassic schist, even using a conventional spinner magnetometer. It is necessary to determine the characterization of magnetic assembladges in this coral skeleton to utilize them as a reliable paleomagnetic recorder, because paleomagnetic records are affected not only by past geomagnetic field variations but also by lithologic factors of samples, such as mineralogy, concentration, and grain size of the magnetic phases. Therefore, by using first-order reversal curve (FORC) measurements, ferromagnetic resonance (FMR) spectroscopy and petrological observations by FE-SEM of acid-treated residuals of our corals, we found that the magnetic mineral assemblage consists of a dominant biogenic-origin single-domain magnetite and a minor detrital component. From AF demagnetization of recently-ceased *Porites* coral skeletons, we also found that the characteristic remanence directions of almost all samples are relatively stable with some fluctuations. However, some samples exhibit obviously different remanence directions from its average, suggesting the rotation by a past tsunami event. Our findings suggest that *Porites* coral framework samples have a potential use as a high-resolution paleomagnetic recorder with careful examination of past rotations.

Keywords: rock magnetism, coral skeletons, ferromagnetic resonance

Analyzing the early 19th century's Geomagnetic declination in Japan from Tadataka Inoh's San-Tou-Houi-Ki,10th report.

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The Santou-Houi-Ki is a national treasure of Japan 67 volumes magnetic survey ledger recorded by cartographer Tadataka Inoh in 1800 to 1816,consist of approximately 200,000 magnetic compass land survey azimuth data accuracy of 0 degree 5 min, from the coast of eastern Hokkaido to Yakushima Island in Western Japan. We restarted the analysis stopped after only one analysis in 1917,which done about the magnetic compass survey azimuth data at known position of the retirement home of Tadataka Inoh at Fukagawa in Edo (Tokyo) in 1802-1803,by interdisciplinary simultaneous analysis across geomagnetism, survey science, historical cartography and local history. We can increase precise evidence to verify the real azimuth, geomagnetic declination and the reference point where magnetic compass survey was executed, or survey target points recorded in the Santou-Houi-Ki,than traditional way of study separated in each field. (1) Procedure of analysis. Use the recreation software of scenery and digital map of GSI Japan Denshi Kokudo to know the latitude and longitude accuracy sec of particular survey target points, and the outline position of survey reference point to grasp the outline of each real azimuth from the survey reference point to survey target points. Geomagnetic declination=Real azimuth-Magnetic compass survey azimuth recorded in the Santou-Houi-Ki. Calculate backward the precise position of the survey reference point should be adjusted to the position in accuracy 0.001sec.in latitude and longitude, where all of geomagnetic declination unit of 0.01sec. Calculate from the magnetic compass survey azimuth to each different targets at the reference point are approximately equal to each other. Calculate the average value of each declination unit of 0.001sec.and express it as the geomagnetic declination unit of 1min.on the day and point Tadataka Inoh's magnetic compass survey was executed. To use the consecutive formula of Excell for speed up and Keep accuracy. If it possible to go to the field of the survey reference point, confirm the real scenery and the longitude and latitude by GPS transmitter and recalculate the value of geomagnetic declination. (2)It is able to change Japan as the concentrated area of data
in early 19th century from insufficient area of data and supply data to north east Asia. Total number of analyzed points exceeded 197. (3) The outline of isogonic line in Japan archipelago and the distribution of the declination in every 15 min in western Japan coast in those days. begin to appear. Compare the isogonic line of declination in those year's Japanese archipelago by analysis of The Santou-Houi-Ki,with the Historical Magnetic Declination map by NOAA(1800,1805,1810,1815)is the NOAA's pace of variation West is almost 5 years later than the analysis of the Santou-Houi-Ki in western Japan. (4)However, from the analysis of Santou-Houi-Ki, we can recognise the magnetic declination supposed as the local geomagnetic declination anomaly in southern coast of eastern Hokkaido, some part of Noto Peninsula, Mt. Asama in Ise, Nobeoka city in Kyushu Island etc., impossible to drew in Historical Magnetic Declination map by NOAA. (5)It is able to restore the precise position of survey reference points where Tadataka Inoh's magnetic compass survey was executed the accuracy of less than sec in latitude and longitude ,valuable in local history. It is so accurate as impossible to achieve by other way of study. The analysis is developed from the coast area of Japanese archipelago to the inland area of Honshu island.

Keywords: geomagnetic declination , Tadataka Inoh, Santou-Houi-Ki, Survey reference point, Survey target point, interdiscplinary

Mineral inclusions and magnetic properties of single zircon crystals from the Tanzawa tonalitic pluton

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Geomagnetic field paleointensity data provide critical information about the evolution of the core and mantle, and the state of the geomagnetic field are closely related to the condition of surface environment (Tarduno et al. 2014, 2015). Although it is essential to understand the variations in geomagnetic field intensity through the Earth history, data are still scarce to a resolve billion year-scale geomagnetic field variation. This is mainly due to the lack of well-preserved rocks for older eras, which often results in unsuccessful paleointensity experiments. To overcome this problem, recent investigates has focused on paleointensity experiments using single silicate crystals, which often accompany magnetic mineral inclusions, such as plagioclase (Tarduno et al. 2006), quartz phenocryst (Tarduno et al. 2010), pyroxene (Muxworthy and Evans 2012), olivine (Tarduno et al. 2012), and zircon (Tarduno et al., 2015, Sato et al., 2015).
Tarduno et al. (2015) demonstrated that paleointensity data of early Archean to Hedean zircons bearing magnetic inclusions from the Jack Hills conglomerate could be used to reconstruct the early geodynamo, and Sato et al. (2015) reported the rock-magnetic properties of the single zircon crystals sampled from the the Tanzawa tonalite (4-5 Ma). Sato et al. (2015) demonstrated that the various rock-magnetic properties such as natural remanent magnetization (NRM), isothermal remanent magnetization (IRM), hysteresis parameters, and transition temperature could be measured using the standard magnetometers (SQUID magnetometer, MPMS, and AGM). During their rock-magnetic measurements, many of single zircon crystals are below the limits of the sensitivity of the magnetometers employed, but for the 80 in 1037 zircons had values of M NRM $\geq 4 \times 10^{-12}$ Am^2 and M IRM $\geq 4 \times 10^{-12}$ Am^2, containing enough magnetic minerals to be measured in the DC SQUID magnetometer. According to the rock magnetic parameters, the main remanence carriers seem to be nearly pure magnetite and pyrrhotite, while direct identification of mineral inclusions in those zircons are not yet acquired.
In this study, we investigate mineral inclusions in Tanzawa zircons reported in Sato et al. (2015), with an optical microscope, Laser-Raman microspectroscopy and scanning electrom microscope equipped with EDS system. It is confirmed that zircon crystals with strong NRM intensity contain titano-magnetite and pyrrhotite. Significantly, titano-magnetite inclusions display fine exsolution lamellae indicating single- or pseudo-single-domain size. In this presentation, we will discuss the relationship between rock-magnetic properties and magnetic mineral inclusions in the Tanzawa zircons.

Keywords: Rock-magnetism, Zircon, inclusion

Rock-magnetic properties of single zircon crystals sampled from the Yangtze River

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Geomagnetic field paleointensity data provide critical information about the thermal evolution of the Earth, and the state of the geomagnetic field is closely related to the surface environment. While it is pivotal to understand the variations in geomagnetic field intensity throughout the history of the Earth, data are still too scarce to resolve billion-year-scale geomagnetic field variation. This is primary because of the lack of geological samples for older eras, which often result in unsuccessful paleointensity experiments.
We focus on a paleointensity experiment using single zircon crystal. Zircon crystals play an important role in paleomagnetic studies because they have several mineralogical advantages: (1) they commonly occur in crustal rocks, (2) precise age determinations with U-Th-Pb and (U-Th)/He analyses are possible, and (3) they have highly resilient responses to alterations and metamorphism.
Recently Sato et al. (2015) reported the rock-magnetic properties of the single zircon crystals sampled from the Nakagawa River, which crosses the Tanzawa tonalitic pluton in central Japan. They demonstrated that the various rock-magnetic properties such as natural remanent magnetization (NRM), isothermal remanent magnetization (IRM), hysteresis parameters, and transition temperature could be measured using the standard magnetometers (SQUID magnetometer, MPMS, and AGM). Combining these rock-magnetic parameters, they proposed the sample selection criteria for paleointensity experiments using single zircon crystals.
In this study, we conducted rock-magnetic measurements for single zircon crystals sampled from the Yangtze River. NRM intensity (M_{NRM}) was first measured for the 1034 grains of zircon crystals. Then, low-temperature demagnetization (LTD) treatment was further conducted for 85 grains with M_{NRM} values larger than 5 x10^{-12} Am^2, and the memory (NRM intensity after LTD treatment; $M_{NRM-LTD}$) was measured. For the 85 samples, we also carried out alternating field demagnetization (AFD) treatment at 10 mT, and the memory (NRM intensity after AFD treatment; $M_{NRM-AFD}$) was measured. After the NRM measurements, IRM was imparted with a field of 1 T using pulse magnetizer for the 1034 crystals, and the resultant IRM intensity was measured (M_{IRM}). Subsequently, IRM intensity after LTD treatment ($M_{IRM-LTD}$) and AFD treatment ($M_{IRM-AFD}$) were measured for the sample with M_{NRM} values larger than 5 x10^{-12} Am^2.
M_{NRM} values of the single zircon crystals varied from 10^{-13} to 10^{-10} Am^2, and 101 crystals (9.8%) had M_{NRM} larger than 4 x10^{-12} Am^2. M_{IRM} values of the single zircon crystals also varied by five orders of magnitude, and 402 crystals (38.9 %) showed M_{IRM} larger than 4 x10^{-12} Am^2. The ratios of M_{NRM}/M_{IRM}, $M_{NRM-LTD}/M_{IRM-LTD}$, and $M_{NRM-AFD}/M_{IRM-AFD}$ varied 0.003-2.0, 0.005-2.4, and 0.005-2.4. There were several samples with the $M_{NRM-AFD}/M_{IRM-AFD}$ less than 0.1, which could be suitable for paleointensity experiment. Combining the rock-magnetic parameters, we will discuss the feasibility of the paleointensity experiment using single zircon crystals from the Yangtze River.

Keywords: Rock-magnetism, Zircon, Paleointensity

Abusolute Paleointensities of about 30Ma from Ethiopian flood basalts

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The Ethiopian traps, distributed in Ethiopia and Yemen, are flood basalts erupted about 30Ma related to the activity of the Afar hot plume, and form about 2000-m-thick sequence of lava flows at the Ethiopia plateau. Rochette et al. (1998) performed paleomagnetic and geochronological studies on samples from 42 lave flows in Lima-Limo and Wegel Tena section at the Ethiopia Plateau. Based on obtained $^{40}Ar/^{39}Ar$ ages of 28-30Ma, they corresponded paleomagnetic polarity changes obtained from the lave sequence to Chron C11r-C11n.2n-C11n.1r in Geomagnetic Polarity Time Scale (GPTS) of Huestis and Acton (1997), and argued that the period of the Ethiopian trap volcanism is about 1Myr or less. In order to reveal detailed geomagnetic variations at about 30 Ma recorded in the Ethiopian traps, we have been performing paleomagnetic analyses on samples collected from 94 lava flows in Lima-Limo sections. In addition to the polarity changes reported by Rochette et al. (1998), we found polarity changes with short intervals and some directional variations like geomagnetic excursion (Ahn,2015). We have been also estimating paleointensities from the samples by using the double heating technique of the Shaw method with low temperature demagnetization (LTD-DHT Show method: Yamamoto et al., 2003). Paleointensity data between 6.3 and 29.1μT are obtained form 11 specimens of 10 flows. A mean of specimens providing higher latitude of Virtual Geomagnetic Pole (VGP) above 45° is 17.6μT, and the value of one specimen with lower VGP latitude is 6.3μT. The mean intensity is lower than the present geomagnetic intensity at Ethiopia (35μT). It is implied that the geomagnetic intensity at about 30Ma is lower than the present, which may be compatible with that a mean VADM between 0.3 and 300Ma is about 60% of that between 0 and 0.3 Ma (Plenier et al., 2003). A weaker intensity of the sample with lower VGP latitude might have represented a temporal feature in geomagnetic excursion or polarity change.

Keywords: Ethiopian trap, geomagnetic polarity change, absolute paleointensity

Orienting paleomagnetic drill cores using a GPS compass

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Azimuths of paleomagnetic drill cores are usually determined with magnetic compasses, and sometimes verified with sun compasses and back-sighting. Weather condition or geographical obstacles often do not allow to perform these subsidiary measurements. Strongly magnetized volcanic rocks can generate local magnetic field that deflects magnetic declination from the regional value. This time we tested a compact GPS compass that is directly mounted on a orientation device and cross-checked the azimuth values of volcanics drill cores by several orienting methods. When placing the GPS compass in a location with good visibility, the azimuth measurement showed excellent performance with the RMS of 0.44 degrees and the angles deviation with the sun compass were less than 2.5 degrees. To achieve such a high precision, we needed to wait about 5 minutes for initializing the RTK measurement and to ensure no obstacle in an angle of elevation more than 35 degrees. Actually orienting drill cores, the azimuths of the GPS compass were consistent with those of the sun compass and back-sighting, although an outcrop itself often acted as an obstacle for the GPS compass. The magnetic compass also provided accurate azimuths after correcting regional magnetic declination, but sometimes showed relatively large deviations more than 5 degrees. The amounts of deviation were variable from sample to sample even within a same single site. When collecting volcanic rocks for archeomagnetic studies, we need to verify the azimuth of each drill core by using a orienting method other than a magnetic compass.

Keywords: paleomagnetism, archeomagnetism, GPS compass

Estimation for rotation history of tsunami boulders in Hachijo Island, by using viscous remanent magnetization

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In Hachijo Island, there are some huge volcanic-origin tsunamigenic boulders. These are about over 3000kg in weight without any sign of organic carbon, such as fossils. Because such huge boulders are mainly moved by extreme tsunami events, they are paid attentions as a key to understanding of past disaster events. If they are the coral boulders, we can estimate the date of past tsunami by using radiocarbon dating. However, we cannot estimate the date by using this theory for the volcanic boulders without any organic fossils. One of an alternative way to date volcanic boulders is the cosmogenic nuclide exposure dating because it simply accumulates on boulder surface. But, the cosmogenic dating can not apply to the boulders if the boulder had experienced multiple rotations. We applied paleomagnetic approach to these volcanic-origin boulders and tried to examine the age of tsunami event, and rotation history of these boulders. This method is useful for all boulders with a bit of magnetic grains regardless of its lithology, and we can determine multiple rotations. Boulders acquire the secondary magnetic component, called viscous remanent magnetization (VRM) after tsunami. This secondary viscous remanence is acquired to the original magnetic vector after the boulder has been removed from the original state. By using Neel's thermal activation theory, the magnetization at low temperature for a long time can be demagnetized at high temperature in a short time. Thus, we can count backward to the age when VRM was acquired (i.e. the past tsunami event). And we can understand how they emplaced, by displacement of direction of magnetization.

As a result, some samples from these boulders have acquired VRM components. Especialy, andesitic boulder located on 20m above sea level, showed multiple VRM components, suggesting subsequent tsunamis. However, calculated age was older than geological age of Hachijo island. Thus, combination with other dating method such as cosmogenic nuclide dating, is required to verify a gap of tsunami age, and improve accuracy of paleomagnetic dating method.

Assessment of inhomogeneity of remanent magnetization by measurements with a magneto-impedance spinner magnetometer

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A new version of spinner magnetometer using magneto-impedance (MI) sensor was developed which has a wider dynamic range (10^{-1} to 10^{-6} mAm^2) and a tunable low-pass filter with two (6 Hz and 20 Hz) cut-off frequencies. These new functions allowed the measurement of the fundamental signal (5 Hz) plus the second- (10 Hz) and third-order harmonics (15 Hz). To test how the multipole moments affect the measured waveforms, we measured a set of synthetic samples to simulate the off-centered dipole by changing their direction and offset. The results agreed well with the theoretical waveforms calculated by the offset dipole models. For comparison these synthetic samples were also measured with a conventional, fluxgate spinner magnetometer. It turned out that there are small but significant differences between the results from the two spinner magnetometers. We consider the possible causes for these inconsistencies in terms of theory and instrumentation, and propose the advantage of the MI spinner that can detect the presence and effect of the multipole moment, especially for the case where it is equivalent in the first approximation to the offset dipole model.

Keywords: spinner magnetometer, inhomogeneity of remanent magnetization, multipole moment

The empirical mode analysis of the decadal variations in the geomagnetic Gauss coefficients

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Decadal geomagnetic field oscillations are often considered to be caused by waves in the Earth's outer core. The waves often used in interpreting decadal variations are torsional oscillations and axisymmetric Magnetic-Archimedes-Coriolis (MAC) waves (Braginsky 1993; Buffett, 2014). Both waves are characterized by axisymmetric flows, but decadal variations can, in principle, be explained in terms of non-axisymmetric waves. In order to extract such non-axisymmetric wave components from the Gauss coefficients, we first apply the empirical mode analysis to extract decadal components, and then subtract variations caused by axisymmetric flows.
We use the time series of the last 150 years of the Gauss coefficients with degrees up to 4, from 1865 to 2014. We combine the data from gufm1 model (Jackson, 2000), IGRF-12 and CHAOS-5 model (Finlay, 2015), and apply the empirical mode decomposition (EMD) (Huang et al., 1998) to time series of the Gauss coefficients.
The decomposition shows that the equatorial antisymmetric components of Gauss coefficients have periods of 40 and 80 years. The g-h plots of these components show linearly polarized oscillations, which indicate either forced oscillations, or advection by oscillating flows.
Next we subtract the components which can be caused by advection by axisymmetric flows. The results will be shown at the conference.

Keywords: geomagnetic decadal variations, Gauss coefficients, outer core, torsional oscillations, empirical mode decomposition

Constraint of magnetic models using seismic tomography in Taiwan

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Uncertainty is often one of the sufferings when underlying structure models are constructed by using unitary geophysical data retrieved from field survey. Velocity-susceptibility models are constructed using velocity retrieved from seismic tomography transferring into susceptibility through characteristics of minerals and/or rocks determined by (Vp) together with (Vp/Vs ratio). Simulated values are computed from the models through 2D forward methods to compare with magnetic anomalies processed after field prospection. Two profiles with intense undulation of geomagnetic anomalies over sediment areas in central-west Taiwan and complex geological structures at the rim of the subduction zone in north Taiwan are used to examine consistency between the simulated values and magnetic anomalies. The consistent results suggest that rocks with high susceptibility can be identified in sediment areas and complex geological areas by using velocity tomography. Those models with two-parameter constraints shed light on understanding underlying magnetic structures through more confidence.

Keywords: Magnetic anomaly, Velocity tomography, Magnetic susceptibility

