High-resolution paleomagnetic and environmental reconstruction from sediments using scanning magnetic microscopy

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High-resolution paleomagnetic and environmental magnetic records from marine and lacustrine sediments play fundamental roles in our understanding of the geomagnetic field and climate change. These data make it possible to reconstruct past changes in Earth's magnetic field and environment on centennial to decadal scales. High-resolution records are often acquired through study of sediments accumulated at high rates (e.g. tens of centimeters to meters per thousand year). In this presentation, we use scanning magnetic microscopy equipped with superconducting quantum interference device (SQUID) to reconstruct high-resolution paleomagnetic records from sediments accumulated at moderate to low rates (e.g. few centimeters per thousand year), taking advantage of the few hundred-micron spatial resolution permitted by the SQUID microscopy. We study the natural remanent magnetization (NRM) of thin sections of sediments from lakes in the UK and Japan as well as from the Japan Sea. NRM of the samples is typically scanned at 100-micron spacing along the surface of thin sections before and after stepwise alternating field (AF) demagnetization. NRM measurements are followed by measurements of laboratory-induced magnetizations including anhysteretic remanent magnetization (ARM) and isothermal remanent magnetization (IRM) before and after the same AF demagnetization steps used for NRM. We will compare the SQUID microscopy-acquired paleomagnetic and environmental magnetic data with those obtained from deconvolved u-channel sample measurements. We will also discuss the potentials and challenges of ultra-high resolution paleomagnetic reconstruction from sediments using SQUID microscopy.

Keywords: scanning SQUID microscopy, paleomagnetism, environmental magnetism, high resolution records

New Palaeosecular Variation Master Records for New Zealand –Applications for Dating and Field Modelling

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We present new palaeosecular variation master records for New Zealand on both archaeological and Holocene timescales. These have been compiled using continuous data from the detrital remanent magnetization of lake sediment cores with high-resolution C-14 based chronology, and are constrained and calibrated using directions and absolute palaeointensities obtained from the thermoremanent magnetizations of archaeological materials and volcanic rocks. All data has been “relocated” to a standard geographical location (40°S, 175°E) using a virtual geomagnetic pole (VGP) transformation. By a reciprocal VGP process, the master records can be used to calculate accurate palaeosecular variation records for all locations within the New Zealand region. The geomagnetic field alternates between active periods of high amplitude swings from 12000 to 8000 BP and over the past 4000 years, and a relatively inactive period between 8000 and 4000 BP. The current field (Dec = 21.5° E, Inc = - 65.4°, F = 55.4 micro T at 40°S, 175°E) represents a rare steep and easterly extreme in direction, but is close to average in intensity. The palaeointensity record mirrors to some extent the variation of the virtual axial geomagnetic moment seen in the global dataset, but shows some notable differences. We also investigate the effect of including the Holocene record in global spherical harmonic-based and regional field models.

Keywords: Palaeomagnetism, Secular variation, New Zealand

Secular variation of inclination with a timescale of tens of thousand years

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Relative paleointensity records of marine sediments revealed that geomagnetic field fluctuations between polarity reversals contain variations with a timescale of tens of thousand years and longer. However, discussion on directional secular variations has been limited for timescale of tens to a few thousand years in general. This is probably because directional variations of the timescale of tens of thousand years are not easy to be detected due to the small amplitude of variations, often close to measurement errors, and difficulty in precise inter-core correlations. Exceptionally, inclination variations of the timescale of tens of thousand years were discussed using sediments from the western equatorial Pacific in terms of possible relations with persistent non-dipole components and orbital forcing (Yamazaki and Ioka, 1994; Yamazaki and Oda, 2002; Yamazaki et al., 2008). We revisited the problem of the long-term inclination secular variations using sediments from the Okhotsk Sea; three piston cores and nine gravity cores adjacent to each other were available. The sediments are of late Pleistocene age, and relative paleointensity was used for the age control. Inclination variations with the timescale of several to tens of thousand years are visible. Further accumulation of datasets for better spatial and temporal distribution is expected for elucidating geomagnetic field behavior of this timescale. For tectonic application of paleomagnetism assuming the virtual geocentric axial dipole field, a period of order of 100 kyr is required to average out secular variations to detect differences of several degrees in paleolatitudes.

Keywords: geomagnetic secular variaiton, inclination, Okhotsk Sea

Paleomagnetic secular variation of deep-sea sediment in Northeast Japan: challenge of dating of sedimentary sequence below CCD for paleoseismology in the rupture zone of 2011 Tohoku-oki earthquake

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We examined the potential for obtaining detailed ages from the turbidites sequences recovered from deep-sea basins close to the rupture zones of the 2011 and past earthquakes off Tohoku, Japan using paleomagnetic secular variation records. Although it is generally difficult to obtain a detailed stratigraphy from deep-sea sediments below Calcium Compensation Depth (CCD), we found the sediments possess excellent paleomagnetic secular variation records. Sediment cores were recovered from a slope break at 4000-6000 m water depth, off Tohoku. The cores are mainly composed of diatomaceous clay-silt intercalated with sand layers of various thicknesses. The thickness of the coarse beds and laminae are generally a few cm, and rarely more than 10 cm. Occasionally the cores involve tephra layers spreading in historical time from the Japan Island, which are used for tie-points for establishing the stratigraphy. Samples for paleomagnetic study were collected continuously using standard paleomagnetic plastic cubes without gap. Natural remanent magnetization (NRM) intensities of samples before alternating field demagnetization (AFD) ranges from 10^{-5} to 10^{-6} kA/m. Maximum angular deviation (MAD) angles calculated from NRM vectors in AFD steps show that NRM vectors are stable single components, which are generally less than 2°. Major magnetic carrier is recognized as magnetite by themo-magnetic analysis. The ages obtained from the tephra layers, and the core tops calibrated with excess 210Pb permit to correlate our data to the references such as an archaeomagnetic field model, and a lacustrine data set back to ca. 9,000 ka. Variations in magnetic records obtained show systematic changes in the cores with remarkable similarity in all the studied cores in spite of a wide distribution with 200 km. Especially their declination patterns are similar to those of the references, while obtained inclination profiles seem to be less amplified in various degree than that of references. We infer the shorter frequency in the obtained inclination is subject to the filtering effects of post-depositional remanent magnetization. Paleomagnetic pattern matching with tephra tie points of well defined age reveal offsets in depth between our data and those of references. We consider these are corresponding to “lock-in depth” of post-depositional remanent magnetization process. These facts suggest age determinations by the pattern matching will produce some time offsets. We can estimate those offsets using depth of tephra horizons and geomagnetic directional variations. Measured offsets are in the range of a few tens of cm’s. Our study reveals that more detailed age control is possible by taking into consideration the lock-in depth, and this information is useful to understand the detailed recurrence of earthquake in Tohoku and can potentially be applied to sediments from other subduction boundaries located below the CCD.

Keywords: Paleomagnetic secular variation, 2011 Tohoku earthquake, Lock-in depth, deep sea-sediment

Archaeomagnetism in Japan: a historical review and new perspectives

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Archaeomagnetism, a branch of paleomagnetism aimed at archaeological relics and antiquities, provides the highest-precision geomagnetic data in all paleomagnetic targets. In Japan, researches of archaeomagnetism for paleodirection and paleointensity would begin in 1940s and have achieved a certain goal in 1970s and 1980s. Although for a quarter century after that a lot of measurements of archaeomagnetic direction have been conducted to give date estimates to few thousand baked earth sites such as old kilns, archaeomagnetic results in Japan brought out almost no new contribution and feedback to geomagnetic secular variation study. Here we refer the history and the current status of archaeomagnetism in Japan, and we also introduce our recent efforts to build a new archaeomagnetic database and secular variation curve in Japan and recent measurements carried out by the Japanese paleomagnetic community.

Keywords: Archaeomagnetism, Paleomagnetism, Geomagnetic Secular Variation, Geochronology

Paleomagnetic Study of Four Geomagnetic Records of the last 15,000 years: Insights From Hawaiian Lavas, Ecuadorian Archaeomagnetic Artefacts and Soft Sediments From the Baltic Sea

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Paleomagnetic data are the unique source of observations to understand the geomagnetic variations and hence the geodynamo processes involved in field generation. During the last three decades, great interest has been concentrated on the investigation of the Secular Variation (SV) of the Earth's magnetic field in different parts of the world. Several reference SV curves have been constructed at the local and/or the regional level mainly based on the paleomagnetic data from lava flows, soft sediments and archaeological artifacts. Such reference curves are particularly important for improving our knowledge about the non-dipole variations of the geomagnetic field, the geodynamo processes and the particular characteristics of the field behavior. Based on these secular variation records, particular interest has been recently concentrated on the short-term variations of the direction and intensity of the Earth's magnetic field evidenced from local SV curves. Recent archaeomagnetic and geomagnetic observations from studies in western Europe, the eastern Mediterranean, South America and Hawaii indicate that periodic changes of ~500 to 1000 years in the secular variation of the geomagnetic field over the last 1000 to 15000 years have been truncated by sudden so-called “archaeomagnetic jerks,” which apparently have taken place at irregular intervals of time. Here, we present results of 15000 years of PSV investigations derived from Hawaiian lavas and from two widely separated archaeological sites in Ecuador spanning ~3000 years of PSV, from Valdivia coastal Ecuador spanning ~6000 years of PSV, and two sites from IODP Expedition 347 Sites M0059 and M0060 in the Baltic Sea that cover ~9000 years and 510-15145 years of PSV. We will show correlations of all these PSV results with the regional and global geomagnetic field models.

Keywords: Paleosecular Variation, Hawaiian Lavas, Ecuadorian archaeomagnetic artefacts

A Power Spectrum for the Geomagnetic Dipole Moment

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Fluctuations in the geomagnetic field offer insights into convective processes deep inside the liquid outer core. We show that quantitative information can be recovered from a time series of fluctuations in the dipole moment when the underlying process is represented by a stochastic differential equation. Slow changes in the dipole moment are described by a deterministic term (sometimes called the drift term), whereas short-period fluctuations are represented by a random noise term. Our description of the dipole moment in terms of a stochastic differential equation provides a framework for evaluating the power spectrum in frequency. We show that the power spectrum has the form A f^{-n}, where the exponent n takes even integer values n = 0, 2, and 4, over a prescribed range of frequency, f. The low frequency behavior (n = 0) changes to n = 2 at intermediate frequencies. The transition frequency corresponds to the average decay time of dipole fluctuations. Numerical geodynamo simulations suggest that dipole fluctuations inside the core can be represented by the first few dipole decay modes, so the appropriate decay time for the power spectrum is a weighed average of the eigenvalues for the decay modes. A second transition from n = 2 to n = 4 at higher frequency is set by the correlation time of the noise term. When the correlation times are recovered from a geodynamo model we obtain values that are consistently less than the convective overturn time. However, changes in the relative amount of heat flow across the top and bottom boundaries can produce systematic variations in the correlation time. Similarly, a change in the style of convection can affect the spatial structure of dipole fluctuations, which alters the first transition frequency. Consequently, the transition frequencies in the power spectra contain quantitative information about the underlying convection. We use these results to interpret recent paleomagnetic estimates of the power spectrum.

Keywords: geodynamo simulation, spectrum analysis

Long-term secular variation in dynamo simulations

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Geomagnetic secular variation provides a way to characterize dynamo processes in the Earth's outer core. Thanks to recent developments in paleomagnetic and rock magnetic measurement technique, some models of global paleosecular variation have been constructed, although uneven distribution of data in terms of location and age should be kept in mind. In contrast, numerical dynamo simulation has advantages regarding such matters. Here we use numerical dynamo modeling to offer interpretation of geomagnetic paleosecular variation and its connections with dynamo action in the core. Since we primarily focus on statistical behavior of paleosecular variation, long-term (typically longer than 1 Myrs) dynamo simulations are required. However, it is extremely difficult and time-consuming to carry out such a long-term dynamo simulation with state-of-the-art parameters. To handle this problem, we have to adopt a higher value of Ekman number (E) by compromise. Some of the parameter values used in this study are fixed at E = 3.25 x 10^{-3}, Pr (Prandtl number) = 1, Pm (magnetic Prandtl number) = 20, whereas Ra (Rayleigh number) is varied to see effects of flow vigor. We will report our preliminary analysis of secular variation in numerical dynamos.

Keywords: secular variation, dynamo, core

Vector archeomagnetic secular variation for the past 400 years from Miyakejima volcanic rocks in Japan

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Full vector archeomagnetic secular variation for the past 400 years was obtained from volcanic rocks in Miyakajima, Japan. Recent archeomagnetic studies have revealed the temporal variation of geomagnetic direction and intensity for the several thousands years. The archeomagnetic variation for the past centuries, which is closely related to the directly measured geomagnetic variation, is rather difficult to be obtained due to poor age constraints. Volcanic eruptions in Miyakejima occurred intermittently about every 50 years for the last 400 years. The basaltic lava flows are extremely well dated based on the ancient documents, therefore essentially no age error is needed to be considered. We collected drilled cores oriented with several azimuthal methods by using back-sighting and magnetic, sun and GPS compasses. The archeomagnetic directions were obtained based on the cross-checked azimuth so that the orientation error should be minimized. Thellier paleointensity measurements were performed for primarily the clinker and scoria samples that give much more reliable paleointensities than the solid part of lavas. An automated spinner magnetometer with thermal demagnetizer *TSpin* was utilized for all the Thellier measurements. We will discuss our archeomagnetic direction and intensity results by comparing with the geomagnetic field model *gufm1.*

Keywords: archeointensity, Thellier method, paleomagnetism

Paleointensity study on lava flows of Fuji Volcano and implications for the atmospheric ^{14}C variation for the last 30 kyr

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The atmospheric ^{14}C production rate is considered to be controlled by the solar activity and geomagnetic field intensity. The ^{14}C variation of timescale of the order of 10-100 years is mainly caused by the solar activity, while the ^{14}C variation of longer timescales is probably related to the geomagnetic field intensity change. We can recognize a decreasing trend in the atmospheric ^{14}C for the last 30 kyr and an increasing trend in paleointensity data in the database for the same period. However, a quantitative evaluation on the relationship between the geomagnetic dipole moment and the atmospheric ^{14}C has been difficult, because the paleointensity database shows a very large scatter. The present study attempts to obtain reliable paleointensities from ^{14}C dated lava flows and then discuss the relationship between absolute paleointensity and the atmospheric ^{14}C. We sampled seven lava flows of 4-30 ka ^{14}C ages of Fuji and Aso Volcanoes in Japan. These ages were reported from the charred material in/below the lava flows or organic sediment below the lava flows in previous studies. Sixty-three samples were subjected to the LTD-DHT Shaw paleointensty experiment (Tsunakawa-Shaw experiment), and forty-six of them passed the selection criteria. These paleointensity data and the ^{14}C data reported for the same lava flows give a constraint on the relationship between virtual axial dipole moment and the atmospheric ^{14}C.

Keywords: paleointensity, 14C, Fuji Volcano

