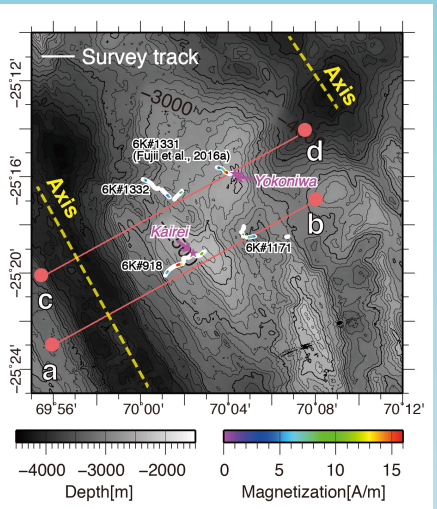
Earth, Planets and Space

Recent Advances in Geo-, Paleo- and Rock- Magnetism



Society of Geomagnetism and Earth, Planetary and Space Sciences (SGEPSS)
The Seismological Society of Japan
The Volcanological Society of Japan
The Geodetic Society of Japan
The Japanese Society for Planetary Sciences

Japan Geoscience Union

Springer Open

Editorial Board (March 2021)

Journal Scope

Earth, Planets and Space (EPS) is the official journal of Society of Geomagnetism and Earth, Planetary and Space Sciences, The Seismological Society of Japan, The Volcanological Society of Japan, The Geodetic Society of Japan, and The Japanese Society for Planetary Sciences.
EPS is a peer-reviewed, open-access journal published under SpringerOpen. It is an international journal covering scientific articles in the entire field of earth and planetary sciences, particularly geomagnetism, aeronomy, space science, seismology, volcanology, geodesy, and planetary science. EPS also welcomes articles in new and interdisciplinary subjects, and technical reports on instrumentation and software.

The journal was launched in 1998 and has since published over 3500 articles. All of them are available for free on SpringerLink:

https://link.springer.com/journal/40623/volumes-and-issues

More information about the journal, its article collections, and the submission process is available on the journal homepage:

https://earth-planets-space.springeropen.com

Submit your next research article to Earth, Planets and Space via:

https://www.editorialmanager.com/epsp

Yours sincerely,

Prof. Takeshi Sagiya
Editor-in-Chief, *Earth, Planets and Space*
eic@earth-planets-space.org

Earth, Planets and Space

Tarduno *et al. Earth, Planets and Space* (2019) 71:68
https://doi.org/10.1186/s40623-019-1043-5

PREFACE

Open Access

Special issue "Recent advances in geo-, paleo- and rock-magnetism"

John A. Tarduno[1,2*], Hirokuni Oda[3], Yuhji Yamamoto[4], Chuang Xuan[5], Ioan Lascu[6] and Koji Fukuma[7]

The special issue of *Earth, Planets and Space* "Recent Advances in Geo-, Paleo- and Rock-Magnetism" was motivated by presentations given in Session S-EM18 "General Contributions in Geomagnetism, Paleomagnetism, and Rock magnetism" held during the Japan Geoscience Union–American Geophysical Union (JpGU–AGU) 2017 Joint Meeting (20–25 May in Chiba, Japan). Contributions span the broad range of topical developments in Earth magnetism including the disciplines of archeomagnetism, paleomagnetism, paleointensity, rock magnetism, crustal magnetism and biogeomagnetism. In addition, several contributions present advances in methods of analysis. These areas are briefly introduced below with an emphasis on the advances represented, current community debates and the motivation the new results provide for further study.

Archeomagnetism and paleomagnetism

Contributions in archeomagnetism and paleomagnetism display the continual advances in the collection of new data recording the history of the geomagnetic field. Kitahara et al. (2018) present Tsunakawa–Shaw paleointensity estimates from a tenth-century kiln from Japan that further demonstrate the viability of this protocol for defining field strength from archeological materials. The field intensity values derived are somewhat lower values than those reported in prior studies in Japan; this should provide motivation for further investigation. Ahn et al. (2018) discuss the potential of sediments from Jeju Island, Korea, for recording young (17–22 kyr) excursions and the challenges of distinguishing these considering rock magnetic complexities. Li et al. (2018) discuss loess and paleosol paleomagnetic records of Brunhes geomagnetic excursions from Central Asia. In particular, they highlight recordings of the Blake and Laschamp geomagnetic excursions.

Global records of the archeomagnetic field and excursions are of crucial importance not only for understanding the past magnetic field but also for providing context on modern changes. Specifically, there is a debate over what excursions tell us about the rapidly diminishing modern dipole field; some analyses of the rate of intensity changes support the idea of an impending reversal or excursion, whereas others argue that the geomagnetic field patterns during recent excursions differ from those of the present-day field. The latter interpretation is highly dependent on the nature of global data coverage. Endeavors of the type defined by Kitahara et al. (2018), Ahn et al. (2018) and Li et al. (2018) can move us closer to global coverage; they are crucial for improving predictions of the future magnetic field and our planetary magnetic shield.

In a Frontier Letter, Kato et al. (2018) present paleointensity results from single silicate crystals separated from Cretaceous granites of Japan. They yield data from plagioclase feldspars that bear on the ongoing debate over the field during Superchrons, periods tens of millions of years long with few (or no) geomagnetic reversals. Numerical simulations, theory and prior paleointensity data from single feldspars argue for a strong field during the Cretaceous Normal Superchron and an inverse relationship between geomagnetic reversal frequency and field strength. However, results from whole rocks fail to show this relationship. The results of Kato et al. (2018) not only highlight the potential of single silicate crystal studies, but also strongly support a high field during the Cretaceous Normal Superchron, representing a major contribution to this fundamental issue.

*Correspondence: john@earth.rochester.edu
[1] Department of Earth and Environmental Sciences, University of Rochester, Rochester, NY 14627, USA
Full list of author information is available at the end of the article

Rock magnetism

Rock magnetism describes the basic physics of rock and mineral magnetic recorders and as such underpins our understanding of paleomagnetism. The Verwey transition, the change from cubic to monoclinic crystal structure in magnetite at 120 K, continues to be a focus of interest in the community. Lindquist et al. (2019) use transmission electron microscope imaging to document domain wall motion across the Verwey transition in a magnetite sample deformed in the laboratory. These authors relate these data to the role stress, and dislocations can play in controlling magnetic properties. In contrast, Dunlop and Özdemir (2018) study magnetite annealed to remove the effects of stress. Their rock magnetic data on size-controlled magnetite allow them to study the degree to which remanence memory occurs when cycling across the transition. While the authors conclude that the results are still too scattered to be useful for magnetic granulometry, these results together with the observations of Lindquist et al. (2019) further define the phenomenology of the Verwey transition and may eventually lead to a better understanding of other observations such as magnetic field controls on low-temperature magnetic properties.

Biogeomagnetism

Biogeomagnetism is an expanding field and one in which many discoveries await further research. In an Express Letter, Oda et al. (2018) offer one such discovery. The authors report the first identification of magnetofossils of magnetotactic bacteria in ferromanganese crust from the Pacific Ocean. The report of this occurrence is surprising and has far-reaching implications. Bacterial magnetite has long been known to be concentrated at the modern redox boundary in pelagic sediments (e.g., studies of the Ontong Java Plateau of the Western Pacific Ocean). The observations of Oda et al. (2018), however, reveal that one should not assume that seemingly fully oxic deep-sea ferromanganese crusts are devoid of magnetotactic bacteria. This should motivate studies to define paleomicroenvironments in these crusts. Moreover, these new observations suggest a greater role of ferromanganese crusts and related deposits for global iron cycling. In a Frontier Letter, Zhang and Pan (2018) review the characterization of magnetite associated with magnetoferritins and magnetotactic bacteria. The former relates to important potential biomedical applications, whereas the latter applies to the continued effort to define modern magnetotactic bacteria populations and magnetofossils in deep geologic time.

Marine geology/geophysics

From the earliest definition of the marine magnetic anomalies that were crucial for the plate tectonics scientific revolution, magnetic investigations have been central in marine geology and geophysics. Today there remain unknowns about seafloor magnetization processes. Studies addressing these unknowns take on even greater importance as we look for terrestrial analogs for hydrothermal processes on other planets and satellites. Fujii et al. (2018) discuss the fundamental hydrothermal alteration effects on the magnetic properties of submarine basalts from the Okinawa Trough. Although their data cannot completely exclude effects of alteration-induced self-reversal by ionic recording, available geochemical constraints support a conversion of high magnetic titanomagnetites to non-magnetic phases. Fujii and Okino (2018) combine magnetic mapping with submersible photographic documentation and sampling to study off-axis lava flows of the Central Indian Ridge near hydrothermal fields. This diverse data set allows the authors to draw inferences on the emplacement of altered and less magnetic material versus more highly magnetized recently erupted flows.

Global magnetic field studies and applications

A plethora of new satellite data offer opportunities for analyses of tectonic structure, magnetic anomalies and seismicity. Lei et al. (2018) identify a possible correlation between the vertical component of the lithospheric magnetic field and continental seismicity in Mainland China and surrounding areas and discuss this in terms of lithospheric viscosity and temperature gradients. Roger et al. (2019) discuss the investigation of core flow using Slepian functions. Although the authors conclude that more work is needed to address spectral leakage, potential remains to study features of core flow, including the potential influence of unusual core–mantle features such as large low-shear-velocity provinces that have been proposed to be long-term sites of flux expulsion affecting the most recent and paleofield of the South Atlantic Anomaly region.

Methods

Retrieving pristine rock magnetic and paleomagnetic records from natural samples remains challenging, especially as the discipline seeks records with ever greater spatial and temporal resolution. A number of contributions address advances in techniques of sample preparation and/or data analysis.

Myre et al. (2019) present applications of a fast spatial domain algorithm "TNT-NN" to address the inversion of data sets from scanning SQUID magnetometers (SSMs).

As opposed to ultrasensitive three-component SQUID magnetometers, these magnetometers directly measure only the vertical component on the magnetization, and therefore, the other components must be inferred by an inversion of the data with associated uncertainties. The work of Myre et al. (2019) is an important step forward in providing a robust framework for the analyses of SSM data.

Analyses of data derived from continuous measurements of sedimentary cores using pass-through SQUID magnetometers have also been a target of software development. Yamamoto et al. (2018) present a successful application of a software UDECON (Xuan and Oda 2015) to deconvolve natural remanent magnetization data obtained from such continuous measurements spanning a geomagnetic reversal; tests show that the software can help extract fine-scale features in the data which are in good agreement with discrete paleomagnetic sample measurements.

In technical reports, Hatakeyama (2018) present online plotting options for viewing paleomagnetic and rock magnetic data assisting international collaborations, whereas Anai et al. (2018) discuss a reductive chemical demagnetization approach with the promise of being able to remove secondary minerals and their magnetizations reveals primary recordings of the geomagnetic field from reef limestones and potentially other rock types.

The rock magnetic study of single silicate grains has mainly focused on their use in paleointensity or paleodirections, but their use in provenance studies has only recently been recognized. Usui et al. (2018) present methods of separation and present the first rock magnetic results from quartz and feldspar derived from red clays, presenting their results as a new provenance indicator. Given the areal distribution of red clays, this work opens many new possibilities for future investigations.

Authors' contributions

All authors served as guest editors for this special issue. Lead guest editor John Tarduno drafted the preface which was edited and approved by all authors. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Author details

[1] Department of Earth and Environmental Sciences, University of Rochester, Rochester, NY 14627, USA. [2] Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA. [3] Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki 305-8567, Japan. [4] Center for Advanced Marine Core Research, Kochi University, Nankoku, Kochi 783-8502, Japan. [5] School of Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton, Southampton SO14 3ZH, UK. [6] Department of Mineral Sciences, Smithsonian Institution, National Museum of Natural History, Washington, DC 20560, USA. [7] Department of Environmental Systems Science, Doshisha University, Kyoto, Japan.

Received: 22 May 2019 Accepted: 24 May 2019
Published online: 17 June 2019

References

Ahn H-S, Sohn YK, Lee J-Y, Kim JC (2018) Preliminary paleomagnetic and rock magnetic results from 17 to 22 ka sediment of Jeju Island, Korea: Geomagnetic excursional behavior or rock magnetic anomalies? Earth Planets Space 70:78. https://doi.org/10.1186/s40623-018-0850-4

Anai C, Mochizuki N, Shibuya H (2018) Reductive chemical demagnetization: a new approach to magnetic cleaning and a case study of reef limestones. Earth Planets Space 70:184. https://doi.org/10.1186/s40623-018-0954-x

Dunlop DJ, Özdemir Ö (2018) Remanence cycling of 0.6–135 μm magnetites across the Verwey transition. Earth Planets Space 70:164. https://doi.org/10.1186/s40623-018-0928-z

Fujii M, Okino K (2018) Near-seafloor magnetic mapping of off-axis lava flows near the Kairei and Yokoniwa hydrothermal vent fields in the Central Indian Ridge. Earth Planets Space 70:188. https://doi.org/10.1186/s40623-018-0959-5

Fujii M, Sato H, Togawa E, Shimadaand K, Ishibashi J (2018) Seafloor hydrothermal alteration affecting magnetic properties of abyssal basaltic rocks: insights from back-arc lavas of the Okinawa Trough. Earth Planets Space 70:196. https://doi.org/10.1186/s40623-018-0958-6

Hatakeyama T (2018) Online plotting applications for paleomagnetic and rock magnetic data. Earth Planets Space 70:139. https://doi.org/10.1186/s40623-018-0906-5

Kato C, Sato M, Yamamoto Y, Tsunakawa H, Kirschvink JL (2018) Paleomagnetic studies on single crystals separated from the middle Cretaceous Iritono granite. Earth Planets Space 70:176. https://doi.org/10.1186/s40623-018-0945-y

Kitahara Y, Yamamoto Y, Ohno M, Kuwahara Y, Kameda S, Hatakeyama T (2018) Archeointensity estimates of a tenth-century kiln: first application of the Tsunakawa–Shaw paleointensity method to archeological relics. Earth Planets Space 70:79. https://doi.org/10.1186/s40623-018-0841-5

Lei Y, Jiao L, Chen H (2018) Possible correlation between the vertical component of lithospheric magnetic field and continental seismicity. Earth Planets Space 70:179. https://doi.org/10.1186/s40623-018-0949-7

Li G, Xia D, Appel E, Wang Y, Jia J, Yang X (2018) A paleomagnetic record in loess–paleosol sequences since late Pleistocene in the arid Central Asia. Earth Planets Space 70:44. https://doi.org/10.1186/s40623-018-0814-8

Lindquist AK, Feinberg JM, Harrison RJ, Loudon JC, Newell AJ (2019) The effects of dislocations on crystallographic twins and domain wall motion in magnetite at the Verwey transition. Earth Planets Space 71:5. https://doi.org/10.1186/s40623-018-0981-7

Myre JM, Lascu I, Lima EA, Feinberg JM, Saar MO, Weiss BP (2019) Using TNT-NN to unlock the fast full spatial inversion of large magnetic microscopy data sets. Earth Planets Space 71:14. https://doi.org/10.1186/s40623-019-0988-8

Oda H, Nakasato Y, Usui A (2018) Characterization of marine ferromanganese crust from the Pacific using residues of selective chemical leaching: identification of fossil magnetotactic bacteria with FE-SEM and rock magnetic methods. Earth Planets Space 70:165. https://doi.org/10.1186/s40623-018-0924-3

Roger HF, Beggan CD, Whaler KA (2019) Investigation of regional variation in core flow models using spherical Slepian functions. Earth Planets Space 71:19. https://doi.org/10.1186/s40623-019-0997-7

Usui Y, Shimono T, Yamazaki T (2018) Rock magnetism of quartz and feldspars chemically separated from pelagic red clay: a new approach to provenance study. Earth Planets Space 70:153. https://doi.org/10.1186/s40623-018-0918-1

Xuan C, Oda H (2015) UDECON: deconvolution optimization software for restoring high-resolution records from pass-through paleomagnetic measurements. Earth Planets Space 67:183. https://doi.org/10.1186/s40623-015-0332-x

Yamamoto Y, Yamazaki T, Kanamatsu T (2018) An initial case study to deconvolve natural remanent magnetization of a continuous paleomagnetic sample using the software UDECON. Earth Planets Space 70:160. https://doi.org/10.1186/s40623-018-0931-4

Zhang T, Pan Y (2018) Constraining the magnetic properties of ultrafine- and fine-grained biogenic magnetite. Earth Planets Space 70:206. https://doi.org/10.1186/s40623-018-0978-2

Publisher's Note

FRONTIER LETTER Open Access

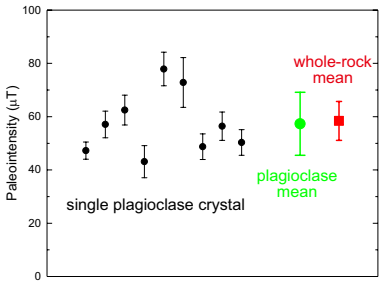
Paleomagnetic studies on single crystals separated from the middle Cretaceous Iritono granite

Chie Kato*, Masahiko Sato, Yuhji Yamamoto, Hideo Tsunakawa and Joseph L. Kirschvink

Earth, Planets and Space 2018, **70**:176 DOI: 10.1186/s40623-018-0945-y
Received: 3 July 2018, Accepted: 25 October 2018, Published: 13 November 2018

Abstract

Investigations of superchrons are the key to understanding long-term changes of the geodynamo and the mantle's controlling role. Granitic rocks could be good recorders of deep-time geomagnetic field behavior, but paleomagnetic measurements on whole-rock granitic samples are often disturbed by alterations like weathering, and the presence of multi-domain magnetite. To avoid such difficulties and test the usefulness of single silicate crystal paleomagnetism, here we report rock-magnetic and paleomagnetic properties of single crystals and compare those to the host granitic rock. We studied individual zircon, quartz and plagioclase crystals separated from the middle Cretaceous Iritono granite, for which past studies have provided tight constraints on the paleomagnetism and paleointensity. The occurrence of magnetite was very low in zircon and quartz. On the other hand, the plagioclase crystals contained substantial amounts of fine-grained single-domain to pseudo-single-domain magnetite. Microscopic features and distinctive magnetic behavior of plagioclase crystals indicate that the magnetite inclusions were generated by exsolution. We therefore performed paleointensity experiments by the Tsunakawa–Shaw method on 17 plagioclase crystals. Nine samples passed the standard selection criteria for reliable paleointensity determinations, and the mean value obtained was consistent with the previously reported whole-rock paleointensity value. The virtual dipole moment was estimated to be higher than $8.9 \pm 1.8 \times 10^{22}$ Am^2, suggesting that the time-averaged field strength during middle of the Cretaceous normal superchron was several times as large as compared to that of non-superchron periods. Single plagioclase crystals which have exsolved magnetite inclusions can be more suitable for identification of magnetic signals and interpretation of paleomagnetic records than the conventional whole-rock samples or other silicate grains.



Graphical abstract

Keywords: Paleointensity, Granite, Single crystals, Feldspar, Zircon

*Corresponding author: Chie Kato, chiekato15@gmail.com

FRONTIER LETTER Open Access

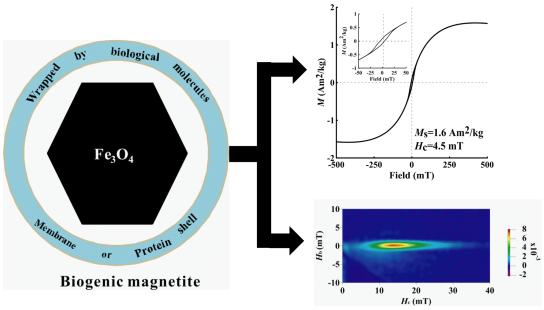
Constraining the magnetic properties of ultrafine- and fine-grained biogenic magnetite

Tongwei Zhang and Yongxin Pan*

Earth, Planets and Space 2018, **70**:206 DOI: 10.1186/s40623-018-0978-2
Received: 2 September 2018, Accepted: 14 December 2018, Published: 24 December 2018

Abstract

Four samples containing ultrafine- and fine-grained magnetite of magnetoferritins and magnetotactic bacteria cells were magnetically characterized at both room and low temperatures. Transmission electron microscopy analysis showed that the biometrically synthesized magnetoferritins (M-HFn) have magnetite cores with a mean size of 5.3 ± 1.2 nm inside protein shells, while *Magnetospirillum gryphiswaldense* MSR-1 cell produced intracellular magnetosome magnetites have a mean size of 29.6 ± 7.6 nm, arranged in a single chain. A pure M-HFn sample (M_1), MSR-1 whole cell sample (M_4) and two samples (M_2, M_3) mixing M-HFn with MSR-1 whole cells in different weight percentages were measured, including hysteresis, temperature dependency of magnetization and remanence and frequency dependence of AC susceptibility at low temperature. At room temperature, the ultrafine-grained magnetite core of M-HFn of M_1 sample has a typical superparamagnetic (SP) behavior. The chain-arranged magnetosome magnetite of MSR-1 cells of M_4 sample shows a stable single-domain (SD) state. At low temperature, the M_2 sample with ~ 16 wt% SD magnetosome magnetite and the M_3 sample with ~ 43 wt% SD magnetosome magnetite behave somewhat similar to the M_1 (pure M-HFn), due to the SP component from M-HFn magnetite. With the dominance of SP magnetite in samples M_1, M_2, and M_3, the coercivity and saturation remanence decrease significantly as temperature increasing from 5 to 20 K. Of note, the magnetization and frequency dependence of AC susceptibility at low temperature are sensitive to SP magnetites in measured samples. The magnetosome magnetite produced by MSR-1 has a Verwey transition temperature at around 100 K, which is consistent with previous observations on magnetotactic bacteria. This study provides useful clues for identification of SP and SD magnetite in sediments, as well as related potential biomedical and biomagnetic applications.



Graphical abstract

Keywords: Superparamagnetism (SP), Magnetoferritins, Magnetosome magnetite, Low-temperature measurements, Biogenic magnetite

*Corresponding author: Yongxin Pan , yxpan@mail.iggcas.ac.cn

FULL PAPER Open Access

A paleomagnetic record in loess–paleosol sequences since late Pleistocene in the arid Central Asia

Guanhua Li*, Dunsheng Xia, Erwin Appel, Youjun Wang, Jia Jia and Xiaoqiang Yang

Earth, Planets and Space 2018, **70**:44 DOI: 10.1186/s40623-018-0814-8
Received: 5 January 2018, Accepted: 7 March 2018, Published: 19 March 2018

Abstract

Geomagnetic excursions during Brunhes epoch have been brought to the forefront topic in paleomagnetic study, as they provide key information about Earth's interior dynamics and could serve as another tool for stratigraphic correlation among different lithology. Loess–paleosol sequences provide good archives for decoding geomagnetic excursions. However, the detailed pattern of these excursions was not sufficiently clarified due to pedogenic influence. In this study, paleomagnetic analysis was performed in loess–paleosol sequences on the northern piedmont of the Tianshan Mountains (northwestern China). By radiocarbon and luminance dating, the loess section was chronologically constrained to mainly the last c.130 ka, a period when several distinct geomagnetic excursions were involved. The rock magnetic properties in this loess section are dominated by magnetite and maghemite in a pseudo-single-domain state. The rock magnetic properties and magnetic anisotropy indicate weakly pedogenic influence for magnetic record. The stable component of remanent magnetization derived from thermal demagnetization revealed the presence of two intervals of directional anomalies with corresponding intensity lows in the Brunhes epoch. The age control in the key layers indicates these anomalies are likely associated with the Laschamp and Blake excursions, respectively. In addition, relative paleointensity in the loess section is basically compatible with other regional and global relative paleointensity records and indicates two low-paleointensity zones, possibly corresponding to the Blake and Laschamp excursions, respectively. As a result, this study suggests that the loess section may have the potential to record short-lived excursions, which largely reflect the variation of dipole components in the global archives.

Keywords: Geomagnetic excursion, Blake excursion, Laschamp excursion, Relative paleointensity, Loess, Arid Central Asia

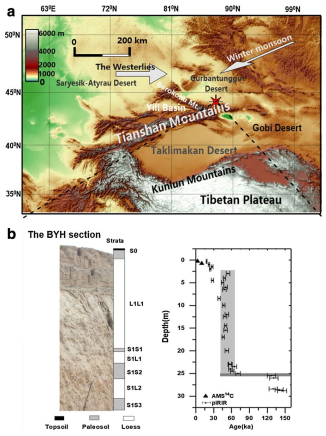


Fig. 1

*Corresponding author: Guanhua Li, ligh1986@gmail.com

FULL PAPER Open Access

Preliminary paleomagnetic and rock magnetic results from 17 to 22 ka sediment of Jeju Island, Korea: Geomagnetic excursional behavior or rock magnetic anomalies?

Hyeon-Seon Ahn*, Young Kwan Sohn, Jin-Young Lee and Jin Cheul Kim

Earth, Planets and Space 2018, **70**:78 DOI: 10.1186/s40623-018-0850-4
Received: 2 January 2018, Accepted: 25 April 2018, Published: 9 May 2018

Abstract

Paleomagnetic and rock magnetic investigations were performed on a 64-cm-thick section of nonmarine unconsolidated muddy sediment from the Gosan Formation on Jeju Island, Korea. This sediment was recently dated to have been deposited between 22 and 17 kyr BP calibrated, with a sedimentation rate of 13–25 cm/kyr, based on many radiocarbon ages. Interestingly, stepwise alternating field (AF) demagnetization revealed characteristic natural remanent magnetizations with anomalous directions, manifested by marked deviations from the direction of today's axial dipole field, for some separate depth levels. On the other hand, stepwise thermal (TH) demagnetization showed more complex behavior, resulting in the identification of multiple remanence components. For all TH-treated specimens, consistently two different components are predominant: a low-temperature component unblocked below 240–320 °C entirely having normal-polarity apparently within the secular variation range of the Brunhes Chron, and a high-temperature component with unblocking temperatures (Tubs) between 240–320 and 520–580 °C that have anomalous directions, concentrated in the ~ 13–34-cm-depth interval (~ 17–19 ka in inferred age) and possibly below ~ 53 cm depth (before ~ 20 ka). Rock magnetic results also infer the dominance of low-coercivity magnetic particles having ~ 300 and ~ 580 °C Curie temperature as remanence carriers, suggestive of (titano)maghemite and/or Ti-rich titanomagnetite and magnetite (or Ti-poor titanomagnetite), respectively. A noteworthy finding is that AF demagnetizations in this study often lead to incomplete separation of the two remanence components possibly due to their strongly overlapping AF spectra. The unusual directions do not appear to result from self-reversal remanences. Then, one interpretation is that the low-temperature components are attributable to post-depositional chemical remanences, associated possibly with the later formation of the mineral phase having Tub ~ 300 °C, whereas the high-temperature components are of primary detrital origin that survived later chemical influence. Accordingly, the unusual directions might record geomagnetic instability within the ~ 17–22 ka period manifested by multiple excursional swings, partly associated with the Tianchi/Hilina Pali excursion. However, further work is needed to verify this interpretation and distinguish it from alternative explanations that invoke rock magnetic complexities as the cause of the unusual directions.

Keywords: Gosan formation, Jeju Island, Paleomagnetism, Rock (sediment) magnetism, Geomagnetic instability, Tianchi excursion, Hilina Pali excursion, 17–22 ka period

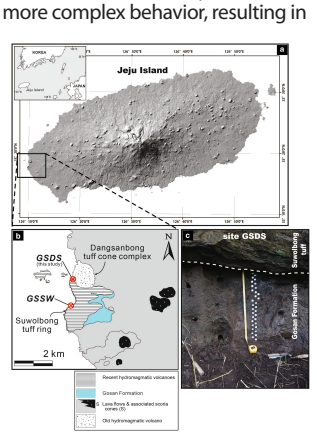


Fig. 1

*Corresponding author: Hyeon-Seon Ahn, mitsuki_ahs@hotmail.com; hs.ahn@gnu.ac.kr

FULL PAPER Open Access

Archeointensity estimates of a tenth-century kiln: first application of the Tsunakawa–Shaw paleointensity method to archeological relics

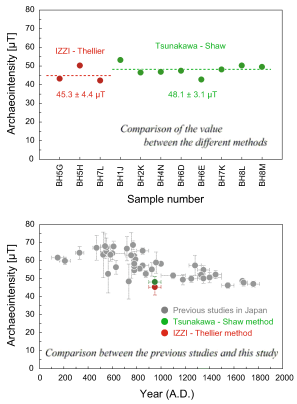
Yu Kitahara*, Yuhji Yamamoto, Masao Ohno, Yoshihiro Kuwahara, Shuichi Kameda and Tadahiro Hatakeyama

Earth, Planets and Space 2018, **70**:79 DOI: 10.1186/s40623-018-0841-5
Received: 3 January 2018, Accepted: 14 April 2018, Published: 9 May 2018

Abstract

Paleomagnetic information reconstructed from archeological materials can be utilized to estimate the archeological age of excavated relics, in addition to revealing the geomagnetic secular variation and core dynamics. The direction and intensity of the Earth's magnetic field (archeodirection and archeointensity) can be ascertained using different methods, many of which have been proposed over the past decade. Among the new experimental techniques for archeointensity estimates is the Tsunakawa–Shaw method. This study demonstrates the validity of the Tsunakawa–Shaw method to reconstruct archeointensity from samples of baked clay from archeological relics. The validity of the approach was tested by comparison with the IZZI-Thellier method. The intensity values obtained coincided at the standard deviation (1σ) level. A total of 8 specimens for the Tsunakawa–Shaw method and 16 specimens for the IZZI-Thellier method, from 8 baked clay blocks, collected from the surface of the kiln were used in these experiments. Among them, 8 specimens (for the Tsunakawa–Shaw method) and 3 specimens (for the IZZI-Thellier method) passed a set of strict selection criteria used in the final evaluation of validity. Additionally, we performed rock magnetic experiments, mineral analysis, and paleodirection measurement to evaluate the suitability of the baked clay samples for paleointensity experiments and hence confirmed that the sample properties were ideal for performing paleointensity experiments. It is notable that the newly estimated archaomagnetic intensity values are lower than those in previous studies that used other paleointensity methods for the tenth century in Japan.

Keywords: Archeointensity experiment, Sueki kiln in Japan, Tsunakawa–Shaw method



Graphical abstract

*Corresponding author: Yu Kitahara, 3gs15005w@s.kyushu-u.ac.jp

FULL PAPER Open Access

Rock magnetism of quartz and feldspars chemically separated from pelagic red clay: a new approach to provenance study

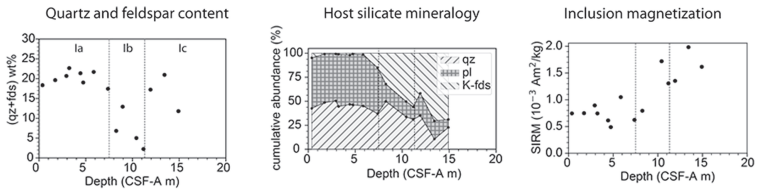
Yoichi Usui*, Takaya Shimono and Toshitsugu Yamazaki

Earth, Planets and Space 2018, **70**:153 DOI: 10.1186/s40623-018-0918-1
Received: 8 May 2018, Accepted: 5 September 2018, Published: 26 September 2018

Abstract

Magnetic mineral inclusions in silicates are widespread in sediments as well as in igneous rocks. Because they are isolated from surrounding environment, they have potential to preserve original magnetic signature even in chemically altered sediments. Such inclusions may provide proxies to help differentiating the source of the host silicate. We measure magnetism of quartz and feldspars separated by chemical digestion of pelagic red clay. The samples are from the upper 15 m of sediments recovered at Integrated Ocean Drilling Program Site U1366 in the South Pacific Gyre. The quartz and feldspars account for 2.3–22.7 wt% of the samples. X-ray diffraction analyses detect both plagioclase feldspar and potassium feldspar. Plagioclase is albite-rich and abundant in the top ~ 7.4 m of the core. Potassium feldspar mainly occurs below ~ 10.4 m. The dominance of albite-rich plagioclase differs from a previous investigation of coarser fraction of sediments from the South Pacific. Saturation isothermal remanence (SIRM) intensities of the quartz and feldspars are 7.45×10^{-4} to 1.98×10^{-3} Am^2/kg, accounting for less than 1.02% of the SIRM of the untreated bulk samples. The depth variations of the silicate mineralogy and the previously reported geochemical end-member contributions indicate that quartz and/or plagioclase above 8.26 m is likely to be Australian dust. In contrast, the relative abundance and the magnetic properties of quartz and feldspars vary below 10.42 m, without clear correlation with geochemical end-member contributions. We consider that these changes trace a subdivision of the volcanic component. Our results demonstrate that magnetism of inclusions can reveal additional information of mineral provenance, and chemical separation is an essential approach to reveal the environmental magnetic information carried by magnetic inclusions.

Keywords: Magnetic inclusions, South Pacific Gyre, Eolian dust, Environmental magnetism



Quartz and feldspar in pelagic clay reveal changing mineralogy and magnetism.

Graphical abstract

*Corresponding author: Yoichi Usui, yoichi@jamstec.go.jp

FULL PAPER Open Access

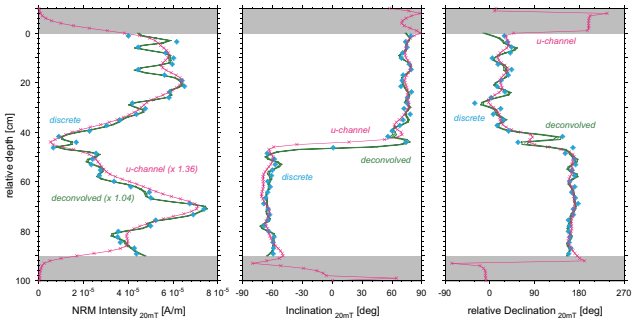
An initial case study to deconvolve natural remanent magnetization of a continuous paleomagnetic sample using the software UDECON

Yuhji Yamamoto*, Toshitsugu Yamazaki and Toshiya Kanamatsu

Earth, Planets and Space 2018, **70**:160 DOI: 10.1186/s40623-018-0931-4
Received: 14 June 2018, Accepted: 30 August 2018, Published: 1 October 2018

Abstract

Previous studies have compiled relative paleointensity data for the last 2–3 Ma from individual paleomagnetic records obtained from marine sediment cores. These records have mostly been obtained by pass-through measurements, which are known to smooth and alter magnetic signals. Among many efforts, a standalone open-use graphical software UDECON has been developed to deconvolve pass-through measurement data. As an initial case study to assess the applicability of the software to deconvolve natural remanent magnetization (NRM) of a continuous paleomagnetic sample, we chose 40 discrete samples from a piston core recovered in the northeast Pacific. We measured NRMs after alternating field demagnetization at 20 mT for both discrete samples and a simulated continuous sample, made by connecting the discrete samples. The discrete samples show centimeter-scale variations in NRM. Such variations are smoothed out and mostly disappear in the results of the simulated continuous sample. However, after using the software to deconvolve the data, the variations are almost completely restored. Good agreement between the discrete sample data and the deconvolved data indicates that the deconvolution by the software is very successful. We observe detailed features of a directional reversal in the data from the discrete samples and in the deconvolved data but not in the data from the simulated continuous sample. This emphasizes that the deconvolution analysis by the software is a powerful tool to extract detailed features from continuous paleomagnetic records obtained by pass-through measurements.



Graphical abstract

Keywords: Superconducting rock magnetometer, Deconvolution, Reversal

*Corresponding author: Yuhji Yamamoto, y.yamamoto@kochi-u.ac.jp

FULL PAPER Open Access

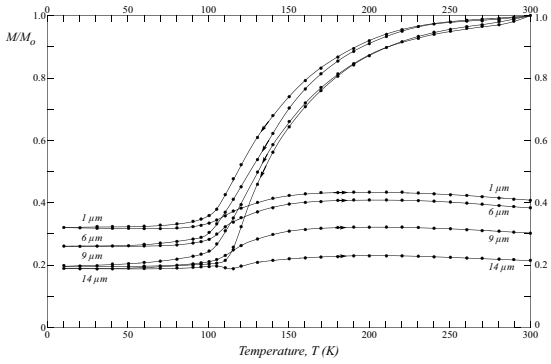
Remanence cycling of 0.6–135 μm magnetites across the Verwey transition

David J. Dunlop* and Özden Özdemir

Earth, Planets and Space 2018, **70**:164 DOI: 10.1186/s40623-018-0928-z
Received: 11 July 2018, Accepted: 18 September 2018, Published: 4 October 2018

Abstract

We report zero-field low-temperature cycling of saturation remanence (SIRM) produced at 300 or 10 K for crushed natural magnetites in nine size fractions from 0.6 to 135 μm, one set annealed to reduce stress, the other unannealed. Coercivities of isothermal remanence increase tenfold between 300 and 10 K, possibly explaining an apparent transition near 50 K. 300-K SIRM decreases continuously on cooling, losing 60–80% by $T_V = 120$ K (Verwey transition), is constant from 120 to 10 K, then recovers a small memory in warming through T_V to 300 K. A dip and recovery of remanence near T_V for larger (> 15 μm) annealed grains is probably due to memory of cubic domain structures by monoclinic magnetite below T_V, permitting partial recovery of initial remanence. In warming, 10-K SIRM is little affected until lost catastrophically near T_V. A small memory is recovered in cooling to 10 K. The contrasting behaviors of 300-K and 10-K SIRMs result from the contrasting anisotropies and domain structures of cubic and monoclinic magnetite. Memories of initial remanences after full temperature cycles are attributed to monoclinic magnetite providing a template for partially regenerating initial cubic domain structures on the second passage through T_V. Memory ratios as a function of grain size for our magnetites are too scattered to be granulometrically useful.



Graphical abstract

Keywords: Magnetite, Verwey transition, Saturation remanence, Low-temperature cycling

*Corresponding author: David J. Dunlop, dunlop@physics.utoronto.ca

FULL PAPER Open Access

Possible correlation between the vertical component of lithospheric magnetic field and continental seismicity

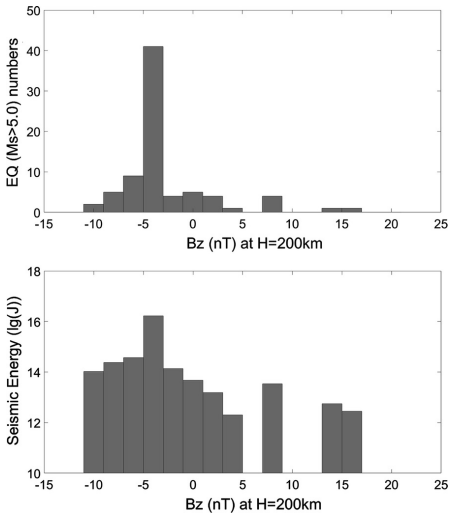
Yu Lei, Liguo Jiao* and Huaran Chen

Earth, Planets and Space 2018, **70**:179 DOI: 10.1186/s40623-018-0949-7
Received: 8 April 2018, Accepted: 1 November 2018, Published: 16 November 2018

Abstract

Recent magnetic satellite missions facilitate new birth of large-scale geomagnetic field models and their applications to tectonics. Here, we directly compare the global geomagnetic field models NGDC-720 with the tectonics and seismicity in Mainland China and surroundings. It is found that the tectonics and seismicity in this area show remarkable correlation with the vertical component of lithospheric magnetic field (B_z) calculated at an altitude of 200 km. Previous thought was that earthquakes are more likely to occur in zero B_z belts or in obvious anomaly gradient belts. On the contrary, we find that more than half (53.2%) of the earthquakes occurred in areas with B_z of -5 to -3 nT or in areas with a relatively small horizontal gradient of B_z in the same time interval with the satellite data. The percentage seismic energy in these areas (-5 nT $< B_z < -3$ nT) is even as high as 94.6%. We explain this unexpected result with a two equivalent source dipole model, arguing that the viscosity difference caused by the temperature gradient within the lithosphere likely accounts for the correlation between magnetic anomalies and seismicity.

Keywords: Lithosphere magnetic field, Satellite, Tectonics, Continental seismicity, Mainland China



Graphical abstract

*Corresponding author: Liguo Jiao, lgjiao@cea-igp.ac.cn

FULL PAPER Open Access

Near-seafloor magnetic mapping of off-axis lava flows near the Kairei and Yokoniwa hydrothermal vent fields in the Central Indian Ridge

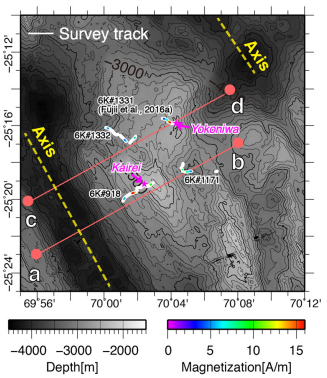
Masakazu Fujii* and Kyoko Okino

Earth, Planets and Space 2018, **70**:188 DOI: 10.1186/s40623-018-0959-5
Received: 17 April 2018, Accepted: 13 November 2018, Published: 4 December 2018

Abstract

The Kairei (KHF) and Yokoniwa hydrothermal fields (YHF) are hosted in mafic as well as ultramafic rocks distributed at an off-axis volcanic knoll of the Central Indian Ridge. Despite intensive investigations, their geological and geophysical background is still debated. Here, we show the results of near-seafloor magnetic anomaly surveys conducted using a submersible. We investigated the bulk magnetization of the hydrothermally altered zone and the surrounding lava flows and evaluated their intensities compared with previously reported values at axial areas of seafloor spreading environments. The KHF is characterized by low coherence between observed and modeled anomalies and low values of magnetization. This result suggests that magnetic minerals within basaltic lava flows were likely altered by hydrothermal fluid circulation. The variation pattern in the observed magnetic anomalies above the lava flows is in phase with that of the modeled magnetic anomalies for the simple assumption that the magnetization direction is parallel to the geomagnetic field. This result suggests that these lava flows preserve normal magnetic polarity corresponding to the Brunhes Chron. The estimated magnetic-anomaly-derived absolute magnetizations show a reasonable correlation with the natural remanent magnetizations of rock samples collected from the seafloor of the same region; their relationship is consistent with previously reported datasets from the Mariana Trough and Mid-Atlantic Ridge. The estimated magnetization intensity reaches 20 A/m in the study area, which is clearly greater than those of previously reported off-axis areas, suggesting that recent volcanic eruption may have occurred in these off-axis areas. The high magnetization distributions are commonly observed at the bottoms of the western slope from the KHF and YHF. This finding provides new insight into the distribution of highly magnetized lava flows in the off-axis areas and indicates the distribution of recent off-axis volcanic activities, which is potentially linked to the sub-seafloor hydrothermal circulation.

Keywords: Seafloor hydrothermal system, Marine magnetic anomaly, Off-axis lava flow, Central Indian Ridge, Kairei site, Yokoniwa site



Graphical abstract

*Corresponding author: Masakazu Fujii, fujii.masakazu@nipr.ac.jp

FULL PAPER Open Access

Seafloor hydrothermal alteration affecting magnetic properties of abyssal basaltic rocks: insights from back-arc lavas of the Okinawa Trough

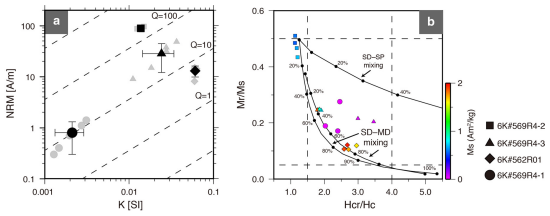
Masakazu Fujii*, Hiroshi Sato, Eri Togawa, Kazuhiko Shimada and Jun-ichiro Ishibashi

Earth, Planets and Space 2018, **70**:196 DOI: 10.1186/s40623-018-0958-6
Received: 7 April 2018, Accepted: 13 November 2018, Published: 13 December 2018

Abstract

Seafloor hydrothermal systems in the back-arc region of the Okinawa Trough have been viewed as a modern analogue to the Kuroko-type volcanogenic massive sulfide deposits. Detection of magnetic signatures is widely utilized and assumed to facilitate the understanding of geological controls on hydrothermal system genesis. However, the magnetic properties of seafloor volcanic rocks are still poorly understood because of the difficulties of sample acquisition. Here, we report rock magnetic data along with linked geochemical and petrological data of volcanic rock samples obtained from the Irabu knolls of the southern Okinawa Trough. Both fresh and hydrothermally altered basaltic andesites were successfully obtained from the seafloor via submersible. A fresh sample, with single-domain titanomagnetite grains, is strongly magnetized with NRM intensity of up to 100 A/m. Minute skeletal and dendritic titanomagnetite grains are also observed. A second fresh sample, with multi-domain titanomagnetite grains, contains a greater amount of titanomagnetite grains, but exhibits NRM intensity ~ 10 A/m at most. In contrast to the fresh samples, hydrothermally altered samples show extremely low NRM intensities along with low saturation magnetization and certain contribution of paramagnetic minerals. Grain assemblages of pyrite and chalcopyrite grains appear along cracks in the groundmass. Our results indicated that fine titanomagnetite grains in groundmass within back-arc lava flows are altered due to hydrothermal processes. The recorded primary remanent magnetization of the lava flows is thus partly removed by hydrothermal alteration. Magnetization reduction related to hydrothermal activity produces local crustal magnetization lows and thus enables us to detect hydrothermal alteration zones by utilizing magnetic field measurements in space. In particular, the lavas we examined (via their resultant basaltic andesites) have high Curie temperatures greater than 400 °C, which is significantly higher than those indicated by mid-ocean ridge basalts, suggesting that the thermal effect for crustal magnetization may be less in back-arc settings.

Keywords: Magnetic properties, Hydrothermal alteration, Titanomagnetite, Back-arc basaltic andesite, Okinawa Trough



Graphical abstract

*Corresponding author: Masakazu Fujii, fujii.masakazu@nipr.ac.jp

FULL PAPER Open Access

The effects of dislocations on crystallographic twins and domain wall motion in magnetite at the Verwey transition

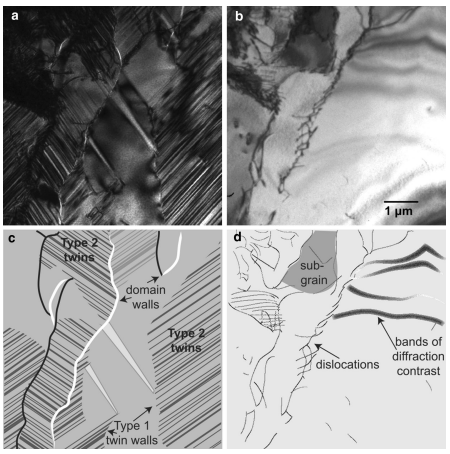
Anna K. Lindquist*, Joshua M. Feinberg, Richard J. Harrison, James C. Loudon and Andrew J. Newell

Earth, Planets and Space 2019, **71**:5 DOI: 10.1186/s40623-018-0981-7
Received: 15 August 2018, Accepted: 24 December 2018, Published: 15 January 2019

Abstract

Pure magnetite experiences a first-order phase transition (the Verwey transition) near 120–125 K wherein the mineral's symmetry changes from cubic to monoclinic. This transformation results in the formation of fine-scale crystallographic twins and is accompanied by a profound change in magnetic properties. The Verwey transition is critical to a variety of applications in environmental magnetism and paleomagnetism because its expression is diagnostic for the presence of stoichiometric (or nearly stoichiometric) magnetite and cycling through the Verwey transition tends to remove the majority of multidomain magnetic remanence. Internal and external stresses demonstrably affect the onset of the Verwey transition. Dislocations create localized internal stress fields and have been cited as a possible source of an altered Verwey transition in deformed samples. To further investigate this behavior, a laboratory-deformed magnetite sample was examined inside a transmission electron microscope as it was cooled through the Verwey transition. Operating the microscope in the Fresnel mode of Lorentz microscopy enabled imaging of the interactions between dislocations, magnetic domain walls, and low-temperature crystallographic twin formation during the phase transition. To relate the observed changes to more readily measurable bulk sample magnetic behavior, low-temperature magnetic measurements were also taken using SQUID magnetometry. This study allows us, for the first time, to observe the Verwey transition in a defect-rich area. Dislocations, and their associated stress fields, impede the development of monoclinic magnetite twin structures during the phase transition and increase the remanence of a magnetite sample after cooling and warming through the Verwey transition.

Keywords: Verwey transition, Magnetite, Dislocations, Domain wall, Transmission electron microscopy, TEM, Low-temperature demagnetization, Oxidation, Phase transition



Graphical abstract

*Corresponding author: Anna K. Lindquist, alindqu1@macalester.edu

FULL PAPER Open Access

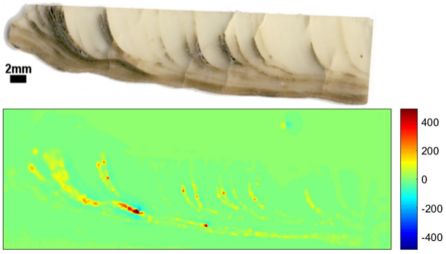
Using TNT-NN to unlock the fast full spatial inversion of large magnetic microscopy data sets

Joseph M. Myre*, Ioan Lascu, Eduardo A. Lima, Joshua M. Feinberg, Martin O. Saar and Benjamin P. Weiss

Earth, Planets and Space 2019, **71**:14 DOI: 10.1186/s40623-019-0988-8
Received: 11 August 2018, Accepted: 10 January 2019, Published: 4 February 2019

Abstract

Modern magnetic microscopy (MM) provides high-resolution, ultra-high-sensitivity moment magnetometry, with the ability to measure at spatial resolutions better than 10^{-4} m and to detect magnetic moments weaker than 10^{-15} Am^2. These characteristics make modern MM devices capable of particularly high-resolution analysis of the magnetic properties of materials, but generate extremely large data sets. Many studies utilizing MM attempt to solve an inverse problem to determine the magnitude of the magnetic moments that produce the measured component of the magnetic field. Fast Fourier techniques in the frequency domain and non-negative least-squares (NNLS) methods in the spatial domain are the two most frequently used methods to solve this inverse problem. Although extremely fast, Fourier techniques can produce solutions that violate the non-negativity of moments constraint. Inversions in the spatial domain do not violate non-negativity constraints, but the execution times of standard NNLS solvers (the Lawson and Hanson method and Matlab's *lsqlin*) prohibit spatial domain inversions from operating at the full spatial resolution of an MM. In this paper, we present the applicability of the TNT-NN algorithm, a newly developed NNLS active set method, as a means to directly address the NNLS routine hindering existing spatial domain inversion methods. The TNT-NN algorithm enhances the performance of spatial domain inversions by accelerating the core NNLS routine. Using a conventional computing system, we show that the TNT-NN algorithm produces solutions with residuals comparable to conventional methods while reducing execution time of spatial domain inversions from months to hours or less. Using isothermal remanent magnetization measurements of multiple synthetic and natural samples, we show that the capabilities of the TNT-NN algorithm allow scans with sizes that made them previously inaccesible to NNLS techniques to be inverted. Ultimately, the TNT-NN algorithm enables spatial domain inversions of MM data on an accelerated timescale that renders spatial domain analyses for modern MM studies practical. In particular, this new technique enables MM experiments that would have required an impractical amount of inversion time such as high-resolution stepwise magnetization and demagnetization and 3-dimensional inversions.



Graphical abstract

Keywords: Magnetic microscopy, Rock magnetism, Non-negative least-squares

*Corresponding author: Joseph M. Myre, myre@stthomas.edu

FULL PAPER Open Access

Investigation of regional variation in core flow models using spherical Slepian functions

Hannah F. Rogers*, Ciarán D. Beggan and Kathryn A. Whaler

Earth, Planets and Space 2019, **71**:19 DOI: 10.1186/s40623-019-0997-7
Received: 16 June 2018, Accepted: 1 February 2019, Published: 18 February 2019

Abstract

By assuming that changes in the magnetic field in the Earth's outer core are advection-dominated on short timescales, models of the core surface flow can be deduced from secular variation. Such models are known to be under-determined and thus require other assumptions to produce feasible flows. There are regions where poor knowledge of the core flow dynamics gives rise to further uncertainty, such as within the tangent cylinder, and assumptions about the nature of the flow may lead to ambiguous patches, such as if it is assumed to be strongly tangentially geostrophic. We use spherical Slepian functions to spatially and spectrally separate core flow models, confining the flow to either inside or outside these regions of interest. In each region we examine the properties of the flow and analyze its contribution to the overall model. We use three forms of flow model: (a) synthetic models from randomly generated coefficients with blue, red and white energy spectra, (b) a snapshot of a numerical geodynamo simulation and (c) a model inverted from satellite magnetic field measurements. We find that the Slepian decomposition generates unwanted spatial leakage which partially obscures flow in the region of interest, particularly along the boundaries. Possible reasons for this include the use of spherical Slepian functions to decompose a scalar quantity that is then differentiated to give the vector function of interest, and the spectral frequency content of the models. These results will guide subsequent investigation of flow within localized regions, including applying vector Slepian decomposition methods.

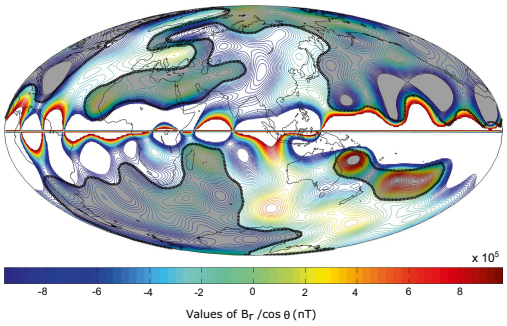


Fig. 1

Keywords: Spherical Slepian functions, Outer core flow, Geostrophic flows, Tangent cylinder

*Corresponding author: Hannah F. Rogers, h.f.rogers@sms.ed.ac.uk

EXPRESS LETTER Open Access

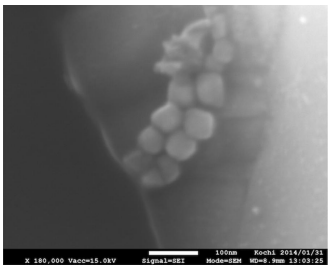
Characterization of marine ferromanganese crust from the Pacific using residues of selective chemical leaching: identification of fossil magnetotactic bacteria with FE-SEM and rock magnetic methods

Hirokuni Oda*, Yoshio Nakasato and Akira Usui

Earth, Planets and Space 2018, **70**:165 DOI: 10.1186/s40623-018-0924-3
Received:2 August 2018, Accepted: 15 September 2018, Published: 5 October 2018

Abstract

Hydrogenetic ferromanganese crusts (hereafter referred to as "crusts") on Pacific seamounts are formed by the precipitation of iron–manganese oxides from seawater on volcanic and biogenic substrate rocks. As crusts grow continuously and have very slow growth rates of between 1 and 10 mm/m.y., they can potentially be used as records of the Neogene paleoceanographic and paleoclimatic conditions. Crusts can be considered as compressed sediment cores containing biogenic, volcanogenic, and terrestrial particles that include eolian dusts and the partly weathered products of substrate acquired during its growth. In this study, selective leaching experiments were conducted on a sample of ferromanganese crust, which had been obtained from the Federated States of Micronesia at a water depth of 2262 m. Chemical leaching experiments were conducted using oxalic acid buffered with ammonium oxalate on the crushed crust samples, which is an optimization of previously proposed sequential leaching procedures. The applied method was found to be effective in separating the major mineral phases of crusts from associated metallic components, thereby providing concentration of the residual fraction for use in analysis following the leaching experiment. Using this method, polygenetic particles were extracted from the crust and identified using optical and electron microscopes. They were found to be of various origins and included volcanogenic, biogenic, terrestrial, and extraterrestrial material. In addition, well-sorted prism-shaped chained magnetic particles were observed in residual fractions. Rock magnetic experiments support the idea that the magnetic particles are magnetites and originated from fossil magnetotactic bacteria. The fossil magnetotactic bacteria might have been living on the crust at the time of crust formation. Alternatively, fossil magnetotactic bacteria could have been transported by deep sea currents from the sediment where magnetotactic bacteria originated.



Graphical abstract

Keywords: Ferromanganese crust, Magnetotactic bacteria, Terrestrial, Extraterrestrial, Eolian, Cosmic spherule, Titanomagnetite, Chemical leaching, Rock magnetism

*Corresponding author: Hirokuni Oda, hirokuni-oda@aist.go.jp

TECHNICAL REPORT Open Access

Online plotting applications for paleomagnetic and rock magnetic data

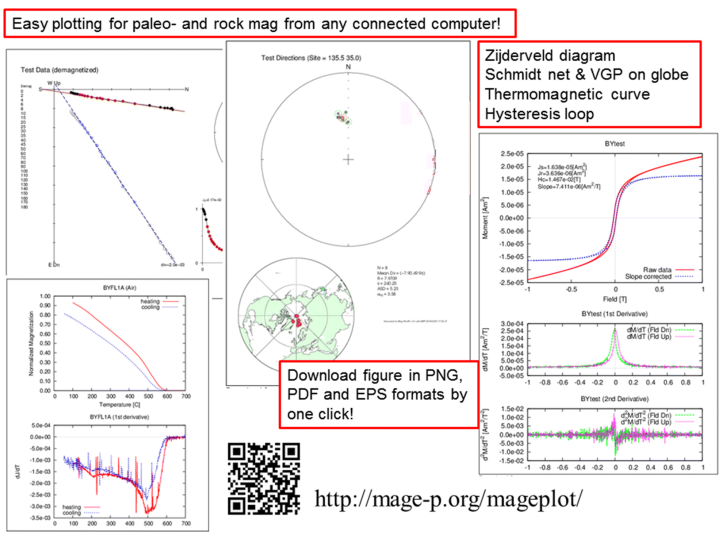
Tadahiro Hatakeyama

Earth, Planets and Space 2018, **70**:139 DOI: 10.1186/s40623-018-0906-5
Received: 5 April 2018, Accepted: 10 August 2018, Published: 23 August 2018

Abstract

This paper describes the development and release of a series of web-based services to generate plots of paleomagnetic and rock magnetic data. All plotting services require a World Wide Web browser as the user interface. The use of online plotting services facilitates rapid and easy sharing of work of analysis and preliminary results with collaborators who use different platforms and operating systems. To implement these routines, two paleomagnetic data types (stepwise demagnetization and paleodirection) are formally defined. These have been popular among researchers for many decades.

Keywords: Paleomagnetism, Rock magnetism, Drawing applications, Online services



Graphical abstract

Corresponding author: Tadahiro Hatakeyama, hatake@center.ous.ac.jp

TECHNICAL REPORT Open Access

Reductive chemical demagnetization: a new approach to magnetic cleaning and a case study of reef limestones

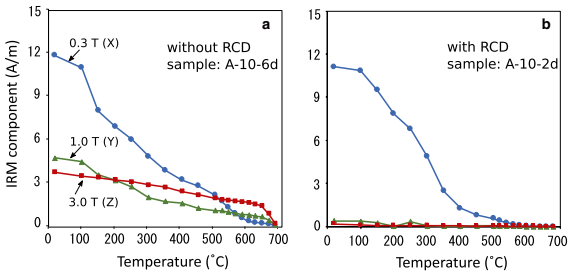
Chisato Anai*, Nobutatsu Mochizuki and Hidetoshi Shibuya

Earth, Planets and Space 2018, **70**:184 DOI: 10.1186/s40623-018-0954-x
Received: 15 April 2018, Accepted: 12 November 2018, Published: 26 November 2018

Abstract

Chemical demagnetization is not preferred as a demagnetizing method in paleomagnetism because strong acids are cumbersome to handle and require considerable time compared to alternating field and thermal demagnetizations. Particularly, for rocks with carbonate minerals, strong acidic solutions are not applicable. This study presents a new method, termed reductive chemical demagnetization (RCD), using ascorbic acid solution as a reductive etchant. Ascorbic acid is a strong reductive agent and converts Fe^{3+} ions of secondary magnetic minerals to water-soluble Fe^{2+} ions, which facilitate chemical demagnetization of carbonate rocks. The carbonate frame can remain intact if the pH of the solution is buffered at approximately 7 with sodium bicarbonate. This etchant is more suitable than strong acid in terms of handling in a paleomagnetic laboratory, particularly in a magnetic field free room. To reduce the required time, a technique of dripping the etchant on the sample was also devised. This helps the fresh etchant flow through the voids between the grains of rocks to rapidly remove dissolved Fe^{2+} ions. As a case study of RCD, reef limestone samples were examined. The results showed that the dripping experiments with 5% ascorbic acid solution were the most effective. It took 72 h to reach the remaining isothermal remanent magnetization (IRM) constant. Thermal demagnetizations of 3-component IRM indicate that RCD removed the high coercivity remanences carried by hematite and goethite. These magnetic minerals were considered to be precipitated between the grains of the rock, and thus they were dissolved by the RCD treatment. A chemical remanent magnetization (CRM), acquired by secondary magnetic minerals, can easily mask the primary remanence for sedimentary rocks of weak magnetization, and the coercivity or unblocking-temperature spectra of the primary remanence and secondary CRM overlap; however, RCD can effectively remove the secondary CRM. RCD prior to alternating field or thermal demagnetization has the potential to improve paleomagnetic demagnetization of sedimentary rocks.

Keywords: Reductive chemical demagnetization, Reductive etchant, Ascorbic acid, Reef limestone



Graphical abstract

*Corresponding author: Chisato Anai, chisato@kumamoto-u.ac.jp

Information for Contributors

General

1. Manuscripts should be submitted through the journal's Editorial Manager system (https://www.editorialmanager.com/epsp/default.aspx).
2. Only papers not previously published will be accepted, and the emphasis is on the originality of concept or observation.
3. Five varieties of article types are available.
   - 3.1 "Full Paper" without word limit.
   - 3.2 "Express Letter" has a limit of 5000 words including the main text, figure legends and table legends. The sum of the number of figures and tables should be less than or equal to 5.
   - 3.3 "Frontier Letter" can be submitted upon invitation by the Editor-in-Chief.
   - 3.4 "Technical Report" describes the technical development of instrument or software.
   - 3.5 "Comment" is a substantial re-analysis of a previously published article in the journal. "Comment" should not exceed 1000 words.
4. Authors retain the copyright, and distribution of articles is free under the CC BY license.

Technical

1. Manuscripts should be written in English with double spacing.
2. Each manuscript should be organized in the following order: title, authors' names, affiliations, abstract, key words, main text, acknowledgement, appendix, references, and supplementary materials. A graphical abstract image must be uploaded during submission which should provide the reader with a visual description of the topic covered in the article.
3. The corresponding author should be clearly indicated.
4. The abstract is limited to 350 words and should be informative and include principal findings and conclusions. Please avoid abbreviations.
5. The main text can have multiple free headings.
6. High-resolution figures should be provided in the following format; PDF (preferred format for diagrams), PNG (preferred format for photos or images), EPS ,TIFF, JPEG, BMP. The graphical abstract should be approximately 920×300 pixels and should be uploaded as a JPEG, PNG or SVG file.
7. References must follow the Springer Basic style.

Correspondence

If you have any questions, please contact info@springeropen.com.

A Grant-in-Aid for Publication of Scientific Research Results (19HP1001) from Japan Society for the Promotion of Science is used for printing.

Contents

Cover image: Fujii, M. *et al.*, *Earth, Planets and Space* 2018, **70**:188 DOI: 10.1186/s40623-018-0959-5