Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-01 会場:301B 時間:5 月 26 日 08:30-08:47

Magnetic modeling of fields from internal and external sources at the Earth, Moon and Mars

Magnetic modeling of fields from internal and external sources at the Earth, Moon and Mars

Michael Purucker[1]*
Michael Purucker[1]*

[1]Raytheon at Planetary Geodynamics Lab
[1]Raytheon at Planetary Geodynamics Lab

Effective modeling of spacecraft magnetic field observations presupposes answers to the following questions: 1) is the region source-free?, 2) what is a natural coordinate system for the magnetic field being described? 3) what is the distribution in time and space of the observations? 4) what are the time and space characteristics of the coeval solar wind? Magnetic fields encountered by spacecraft have multiple origins, and each of these fields will often have a natural coordinate system. The origin of these magnetic fields can be classified into the following general categories: 1) spacecraft, 2) magnetopause, 3) magnetotail, 4) field-aligned currents, 5) magnetodisk currents 5) core, 6) lithosphere (remanent and induced), 7) induced fields, 8) motional induction fields. Modeling strategies are either sequential in approach, usually from the largest to smallest fields, or involve coestimation of fields of multiple origins. I will discuss examples from the Moon and Mars.

キーワード: mars, moon, magnetic fields, modeling, earth, spacecraft
Keywords: mars, moon, magnetic fields, modeling, earth, spacecraft

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-02 会場:301B 時間:5 月 26 日 08:47-09:02

全地球海上磁気データセットとその精度向上
Global marine magnetic data set and improvement of its accuracy

石原 丈実 [1*]
Takemi Ishihara[1*]

[1] 産業技術総合研究所地質情報研究部門
[1]Inst. Geology and Geoinformation, AIST

I have been making efforts to expand our digital global marine data set to contribute to the World Digital Magnetic Anomaly Map (WDMAM) project. After creating a data set using digital GEODAS marine track line data stored at the U.S. National Geophysical Data Center together with some European colleagues (Quesnel et al., 2009), we collected new marine magnetic data for areas around Antarctica from the first ADMAP compilation, north Atlantic area compiled by Collette et al. (1984) and various oceanic areas from surveys by the IFREMER, the BGR, the British National Oceanography Centre, Spain, the JAMSTEC, etc. I have also digitized analog GEODAS data for about 30 cruises, and added them to our data set. The compiled data set now consists of about 37 million records from some 3000 cruises. Magnetic anomalies were recalculated using a comprehensive main and external field model CM4 (Sabaka et al., 2004), and were cleaned by careful check and removal of spurious data.

The RMS crossover difference (COD) of the whole data set is 82 nT, significantly greater than a typical observation error. If the accuracy of the reference main and external field model improves, the accuracy of the anomalies also increases. The CM4 model was obtained using satellite and observatory data, which have large gaps in oceanic areas. I investigated possibilities of the improvement of the model in oceanic areas, and tried to calculate corrections of secular variation of the main field model in oceanic areas using COD data of our marine data set. More details on the results are shown.

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-03 会場:301B 時間:5 月 26 日 09:02-09:19

Crustal Magnetism and Effects of Exsolution Lamellae on Magnetic Properties: Importance of Remanent Magnetic Anomalies

Crustal Magnetism and Effects of Exsolution Lamellae on Magnetic Properties: Importance of Remanent Magnetic Anomalies

Suzanne McEnroe[1*], Karl Fabian[1], Peter Robinson[1], Richard Harrison[2], Laurie Brown[3]
Suzanne McEnroe[1*], Karl Fabian[1], Peter Robinson[1], Richard Harrison[2], Laurie Brown[3]

[1]Geological Survey of Norway, [2]Dept. of Earth Sciences, Cambridge UK, [3]University of Massachusetts, USA
[1]Geological Survey of Norway, [2]Dept. of Earth Sciences, Cambridge UK, [3]University of Massachusetts, USA

Magnetic anomalies from crustal sources are measured over a wide range of scales and elevations, from near surface to satellites. Crustal anomalies reflect the magnetic minerals, which respond to the changing planetary magnetic field. Anomalies are influenced by the geometry of the geological bodies, and magnetic properties of the constitutive rocks. Commonly, magnetism of continental crust has been described in terms of bulk ferrimagnetism of crustal minerals, and much attributed to induced magnetization. Though remanent magnetization was crucial for dating the ocean floor, and is important in mineral exploration, its contribution to continental magnetic anomalies is commonly ignored. Over the last decade studying remanent anomalies in crustal rocks we discovered a new type of remanence, which we called 'lamellar magnetism'. This type of magnetization is due to interface layers of mixed Fe2+ / Fe3+ valence at contacts between exsolution lamellae and hosts of ilmenite and hematite.

The mixed-valence contact layers are placed by chemistry between hematite Fe3+ layers and ilmenite Ti 4+ layers, where they help reduce charge imbalance. Placement requires that the uncompensated spin of contact layers on opposite sides of lamellae be magnetically in phase. This produces a net ferrimagnetic moment per lamella of appx. 4uB per formula unit regardless of lamella thickness, thus net moment is greatest with the greatest density of magnetically in-phase fine lamellae. New studies demonstrate that the proportion of magnetically in-phase lamellae are in samples with strong preferred lattice orientation and is highly correlated with the angle of the statistical basal plane (0001) with respect to the magnetizing field at the time of exsolution, thus yielding strong net moments where a = 0 and the weakest moments where a= 90. Sample coercivity is much higher when ilmenite lamellae are in global linkage with an AF hematite host, than when hematite lamellae are in a paramagnetic ilmenite host lacking global linkage.

Lamellar magnetism is responsible most for the remanent continental magnetic anomalies presented here. It may also be an important contributor to deep-seated anomalies. To explore the effects of temperature and pressure on the solvus of the ilmenite-hematite solid solution, piston cylinder experiments were performed. Samples were held for 28 days at 10 kb and 580C. Samples were characterized by electron microprobe and transmission electron microscopy before and after the piston cylinder experiments. Magnetic properties of the natural and heated samples were compared. Microstructures due to the formation of exsolution lamellae appear to control the magnetic properties in both the natural and experimental samples. Because many of these rocks studied have high NRM values, some $>$ 50 A/m we have also postulated lamellar magnetism may be one of the sources of magnetism for Martian rocks.

Studying the nature of lamellar magnetism has provided other surprises. Some samples of titanohematite with very fine lamellae ($<$ 1nm thick) when cooled below the TN of ilmenite showed very large exchange bias, the largest ever observed in any material. This indicates a magnetic interface coupling between lamellar magnetism in the hematite host and the magnetically hard antiferromagnetic ilmenite. Such exchange bias has even been demonstrated using billion-year-old lamellar magnetism, cooled in zero field down to 5 K before the hysteresis experiment. This and other properties of lamellar magnetism may provide templates for modern magnetic storage technology.

キーワード: Lamellar Magnetism, Magnetic Anomalies, hematite-ilmenite, Exchange Bias
Keywords: Lamellar Magnetism, Magnetic Anomalies, hematite-ilmenite, Exchange Bias

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-04 会場:301B 時間:5 月 26 日 09:19-09:36

Mean-field and micromagnetic models for nanoscale magnetism based on ilmenite-hematite solid solutions
Mean-field and micromagnetic models for nanoscale magnetism based on ilmenite-hematite solid solutions

Karl Fabian[1*], Suzanne A. McEnroe[1], Peter Robinson[1], Valera P. Shcherbakov[2]
Karl Fabian[1*], Suzanne A. McEnroe[1], Peter Robinson[1], Valera P. Shcherbakov[2]

[1]Geological Survey of Norway, [2]Geophysical Observatory Borok, Russia
[1]Geological Survey of Norway, [2]Geophysical Observatory Borok, Russia

Lamellar magnetism was proposed as a new type of magnetic remanence, carried by uncompensated magnetic layers at interfaces between nanoscale exsolution structures of antiferromagnetic (AFM) hematite and paramagnetic ilmenite. A first experimental proof that the natural remanent magnetization (NRM) of a rock from Modum, Norway, is due to lamellar magnetism, resulted from cooling grains with the original NRM to 5 K, and then measuring their hysteresis loop. The observed large shift of the hysteresis curves showed that exchange bias develops from the untreated NRM. Therefore, the moments which carry the NRM participate in the exchange coupling at the hematite-ilmenite interfaces. The development of physical models to understand the detailed mechanisms of exchange bias and other unusual magnetic properties within homogenous or exsolved minerals of the ilmenite-hematite solid-solution series IlmX (X FeTiO3 (1-X) Fe2O3) is an important research topic. In a general case of isolated nanoparticles embedded in an antiferromagnetic matrix the mechanism of exchange bias originates from the formation of a (quasi)spherical domain wall inside the AF matrix when the particle moment rotates under the influence of an external magnetic field. Micromagnetic calculations show that for isolated nanodots the energy of this domain wall increases nearly quadratically with the deflection angle of the nanodot moment. By introducing the corresponding quadratic energy term in a modified Stoner-Wohlfarth model, a two-parameter family of hysteresis loops is obtained, depending on scaled anisotropy energy and field direction. In case of pure solid solutions, geometric mean-field models implement the varying Fe and Ti concentrations, and the random distribution of Fe ions in the solid solutions. The models either use statistical interactions between sites, whereby they effectively average over all possible configurations, or they describe specific random configurations. Statistical mean-field models are successful in predicting the ferromagnetic (FM) Curie temperatures TC and Ms(T) curves of the IlmX solid solutions. The results depend on the choice of interaction coefficients, which either have been determined by neutron diffraction measurements (Samuelson and Shirane, 1979), by Monte Carlo model fits (Harrison, 2006), or by density-functional theoretic calculations (Nabi et al., 2010) . A special class of mean-field modelling has been suggested by Ishikawa (1957), to estimate the size of interacting clusters in IlmX beyond the FM percolation threshold ($X > 87$), where global ferrimagnetic order breaks down, and only finite ferrimagnetically ordered clusters generate a pseudo-Langevin magnetization curve at temperatures between the FM Curie temperature and the antiferromagnetic Neel temperature TN. Using a numerical inversion method, it is possible to fit measured hysteresis loops of synthetic IlmX samples (X= 92, 97) by improved theoretical pseudo-Langevin curves which depend on cluster-size- and exchange-interaction- distributions. Due to frustrated exchange interactions, the IlmX system can show magnetic spin-glass behaviour at low temperatures, which cannot be modeled by mean-field methods. At T=0, however, the Heisenberg hamiltonian of the spin system has only a finite number of possible values and can be minimized by combinatorial optimization. This at least makes it possible to gain some limited insight into the magnetic behaviour at very low temperatures.

Apart from statistical mean-field models, it is also possible to investigate specific atomic configurations, each corresponding to some fixed Ilm X. These models contain several tens to hundreds of ilmenite unit cells (e.g. 3x3x3 or 5x5x5) with periodic boundary conditions. Their main advantage is that they permit visual inspection of the geometric configuration in relation to the magnetic behaviour.

キーワード: lamellar magnetism, micromagnetic modeling
Keywords: lamellar magnetism, micromagnetic modeling

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-05 会場:301B 時間:5 月 26 日 09:36-09:53

Muon spin radiography of sediments
Muon spin radiography of sediments

田中 宏幸 [1*]
Hiroyuki Tanaka[1*]

[1]University of Tokyo
[1]University of Tokyo

In this paper, we propose a method to use muon spin radiography as a non-destructive testing method to evaluate the magnetic properties of materials. Muon particles have the ability to penetrate matter ranging from a few mm to a few km, depending on the energy levels. Gigantic objects, such as volcanoes [1], have been imaged using muon absorption radiography by measuring the internal density distribution of the structure. This technique exploits very high energy muons in cosmic rays. It is also possible to produce muons artificially in particle accelerators. These produced muon particles are inadequate (in terms of energy) to penetrate structures as thick as a volcano. However, a higher degree of control over both momentum and polarization is possible and this advantage can allow new applications of muon radiography to be developed. By controlling the momentum of the muon particles, we can control the depth of penetration with greater precision. As a next step, we can also create a three dimensional scan of a specimen by employing a fabricated muon beam with a collimated, narrow spatial spread. Another possibility is to combine muon spin spectroscopy with the mentioned three dimensional scan in order to obtain information about the magnetic properties, also in three dimensions. Muon spin spectroscopy is conducted by using muon beams that have nearly perfect spin alignment in relation to the beam direction. Since muons experience local magnetic fields in their surroundings when they stop in the specimen, they can provide useful information on the local structure of the magnetic domain. This principle is similar to nuclear magnetic resonance, however in this case we implant muons (light protons) instead of using protons that already exist in the material. One of the benefits of muon spin radiography in contrast to conventional techniques is that information is collected from within the structure of the specimen instead of from the outside. In this forum, we demonstrate how muon spin radiography works for a specimen from a banded iron formation (BIF) as the first step application. This can be a good target because the local domain structure of hematite grains in BIF could potentially record the past geomagnetic field. In order to strictly control the muon momentum, a surface muon beam was used in this experiment. The surface muons are produced via decay of pions at rest, therefore they have a momentum of 30 MeV/c. We can calculate the range at which the muon stops and decays to be 0.3 g/cm2 for rock by using the muon energy range relationship. As a result, muon spin asymmetry was measured at this specific depth of the BIF specimen and rapid spin precession due to the internal magnetic field was measured. Results were consistent with the fact that the hematite has parasitic ferromagnetism. The amounts of non-magnetic substances or local magnetic alignments can be calculated by comparing these results with Fe to measure the amount of the non-relaxation component. With the reasonable success of this experiment, there is the potential to extend this concept to applications such as three dimensional tomographic measurements of local magnetic alignments.

References

[1] H.K.M. Tanaka et al., High resolution imaging in the inhomogeneous crust with cosmic-ray muon radiography: The density structure below the volcanic crater floor of Mt. Asama, Japan, Earth and Planetary Science Letters 263 (2007) 104.

キーワード: muon, spin, radiography, geomagnetism, sediments
Keywords: muon, spin, radiography, geomagnetism, sediments

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-06 会場:301B 時間:5 月 26 日 09:53-10:10

磁気光学イメージング（MOI）の岩石磁気学への応用と開発
Development and application of magneto-optical imaging (MOI) for rock magnetism

植原 稔[1*], ジェローム　ガタチェッカ[2], コーネリウス　ジャコミニュス　ヴァン　デア　ベック[3], ユグ　ルルー[4], ダミアン　ジャコブ[4]
Minoru Uehara[1*], Jerome Gattacceca[2], Corrnelis Jacominus van der Beek[3], Hugues Leroux[4], Damien Jacob[4]

[1] ポールセザンヌ大学, [2] 欧州地球科学環境研究教育センター, [3] エコール　ポリテクニーク, [4] リール第１大学
[1]Universite Paul-Cezanne, [2]CEREGE, [3]Ecole Polytechnique, [4]Universite des Sciences et Technologies

Magneto-optical imaging (MOI) technique measures the magnetic flux threading a magneto-optically (MO) active film, which rotates the polarization direction of transmitted light (Faraday rotation), directly placed on the sample. Through the analyzer of a reflected light microscope, the vertical component of surface magnetic field of the sample is observed. Owing to the thin MO film (5 um) and the small sample-to-film distance (~100 nm), internal structures within metallic grains in meteorites carrying saturation isothermal remanent magnetization is successfully imaged with a spatial resolution better than 10 um. In addition to its high spatial resolution, this technique offers a direct comparison of magnetic and reflected light images, making it a very powerful tool to map and identify the carriers of magnetic remanence in rock samples.

We present results of an integrated study of metallic grains in meteorites, combining MOI, petrography, FE-SEM, TEM, microprobe analyses, and DC demagnetization. Metallic Fe-Ni grains in meteorites have microscopic structures due to Ni diffusion during slow cooling subsequent to metamorphism on their parent body. Previous magnetic studies suggested that tetrataenite (ordered FeNi) is the stable magnetic carriers in these meteorites. On the other hand, mineralogical studies showed that tetrataenite is intimately mixed with other Fe-Ni phases (kamacite and taenite, that contain less than 10 wt% and around 30 wt% Ni, respectively), and forms complex microstructures (see below). However, due to the typical spatial resolution of classical bulk magnetic measurements (~1 mm), it has been so far difficult to isolate the contribution of these different Fe-Ni minerals.

We studied equilibrated ordinary chondrites. Optical and electron microscopies showed two types of micron- to submicron-scaled tetrataenite-bearing microstructures: (1) Zoned taenite particles that consist of a taenite core, surrounded by a "cloudy zone" (20-150 nm large tetrataenite granules embedded in taenite matrix), and a 1-10 um thick tetrataenite rim. (2) Zoneless plessite particles that consist of $<$ 10 um large tetrataenite grains embedded in a kamacite matrix. MOI of saturation remanence showed that only the nm-sized tetrataenite granules in cloudy zone carry very strong remanence. Micron-scale mapping of coercivity of remanence (B_{cr}), by means of DC demagnetization coupled with MOI, combined with FE-SEM and TEM study showed that this cloudy zone has zoning in Ni composition, tetrataenite grain size, and B_{cr}. The center part has finer tetrataenite (20 nm), lower bulk Ni composition (30 wt %) and higher B_{cr} values (up to 1 T) than the outer part (150 nm, 55 wt %, and 400 mT respectively). This result shows good agreement with B_{cr} distribution of bulk ordinary chondrite. Therefore, tetrataenite in the cloudy zone is a potential very stable carrier of extraterrestrial remanence. Moreover, even in weathered meteorites, we can observe natural remanence of metals separated from magnetic signature from oxides. This result demonstrates that MOI is a hopeful technique to discriminate the primary magnetization from altered samples.

キーワード: 磁気顕微鏡, コンドライト隕石, 金属, テトラテーナイト
Keywords: Magnetic Microscope, Meteorite, Metal, Tetrataenite, Magneto-optical imaging

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

SEM001-07 会場:301B 時間:5 月 26 日 10:10-10:27

Limits of Paleomagnetic Detection: Low-temperature, Helium-free Ultra-high Resolution Scanning SQUID Microscopy

Limits of Paleomagnetic Detection: Low-temperature, Helium-free Ultra-high Resolution Scanning SQUID Microscopy

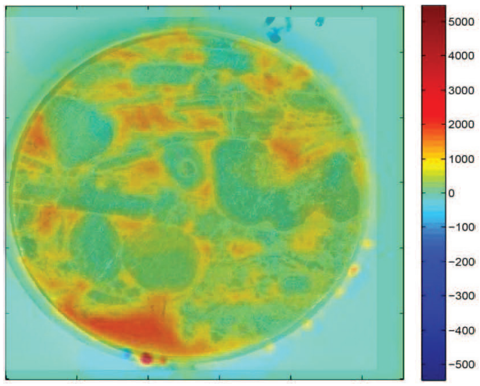
Joseph Kirschvink[1*], Timothy D. Raub[1], Theresa M.D. Raub[1], Woodward W. Fischer[1], Isaac A. Hilburn[1], Nathan L. Donnellan[1]
Joseph Kirschvink[1*], Timothy D. Raub[1], Theresa M.D. Raub[1], Woodward W. Fischer[1], Isaac A. Hilburn[1], Nathan L. Donnellan[1]

[1]Calif. Institute of Technology, 170-25
[1]Calif. Institute of Technology, 170-25

Despite the extraordinary sensitivity of helium-temperature SQUID magnetic sensors, most of their use in geophysics has been in moment magnetometers for paleomagnetic and rock magnetic studies. However, developments in the past decade at Vanderbilt University, Caltech, and at MIT have incorporated them into what is now called the Ultra-High Resolution Scanning SQUID Microscope (UHRSSM). The extreme sensitivity of these instruments ? in some cases capable of imaging the magnetic moment of a single magnetotactic bacterium ? arises from engineering that allows a superconducting sensor in a high vacuum, held at $<$ 5 K, to come within a few tens to hundreds of micrometers from the surface of a room-temperature sample at ambient temperature and pressure. Separating these two regimes, a sapphire window thins to ˜ 25 um near the sensor, and elaborate radiation shielding blocks all but the sensor tip from background heat. By scanning samples in a micron-scale grid beneath the sensor, a map or image of the magnetic field is generated, similar to, but at much smaller scale than, those produced by aeromagnetic surveys. Unlike a magnetic-force microscope, where a magnetized needle is tapped over a small area of a sample, the UHRSSM does not expose the sample to strong magnetic fields and can operate over a much larger area ? from steps only 5 um in size to cover areas up to ˜ 5 x 5 cm. For NRM measurements, the entire assembly must be housed in a mu-metal shielded system with background fields $<$ 10 nT.

Early versions of these instruments were cumbersome to use, requiring separate Dewars for liquid helium and nitrogen. They also needed an elaborate lever mechanism in the vacuum for adjusting the distance of the SQUID sensor from the sapphire window and sample. At Caltech we modified our UHRSSM to operate from a two-stage pulse-tube system manufactured by Cryomech, Inc., which is capable of cooling the sensor to 3.6 K in about two hours. (The same pulse-tube system now is standard on new 2G? magnetometers.) This modification freed us from use of both liquid nitrogen and helium, and minimized the thermal contraction problem to the point where the vacuum lever assembly was not needed. On the other hand, we discovered that the pulse tubes do generate an ˜ 1 Hz magnetic noise of up to 1000 nT amplitude; this is due to their use of rare-earth ferrites with paramagnetic to ferromagnetic transition temperatures $<$ 20 K. This required the addition of a superconducting lead shield to block this noise, and for high-sensitivity measurements, the addition of a second SQUID sensor chip in a gradiometer configuration with real-time noise cancellation.

Applications of the UHRSSM are diverse. It can establish ca. 10,000 independent-grain paleointensity estimates per conventional paleomagnetic sample that offer insight into the dispersion of intra-unit, between-sample paleointensity results. It can assess a conglomerate test on a sandstone or igneous/extraterrestrial (meteoritic) breccia. It can function as a geochemical prospecting tool, discriminating the most pristine from the least-desirable among multiple sulfide paragenetic textures and phases in Archean black shales. And applied to biomagnetic problems, the UHRSSM can localize magnetocyte or magnetosomes within tissue that otherwise can be challenging to detect. The attached image shows a 2.5 cm diameter scan of pre-compaction Archean sulfide nodules that are variably magnetized by an IRM, with relatively nonmagnetic cores. Matrix, in contrast, is strongly remagnetized by pyrrhotite dating ˜500 myr after deposition of the shale.



キーワード: paleomagnetism, rock magnetism, biomagnetism, magnetic microscopy, biogenic magnetite
Keywords: paleomagnetism, rock magnetism, biomagnetism, magnetic microscopy, biogenic magnetite