2008 International Conference on Rock Magnetism:
Institut d'Études Scientifiques de Cargèse
June 2-7, 2008

Session Overview

Monday, June 2

Evening: Welcome and Tribute to Subir (18:30-19:30)
Talk by B. Moskowitz followed by the conference ice-breaker

Self organized dinner in the village restaurants

Tuesday, June 3

Morning: Mineral Magnetism (09:00 – 12:10)
Convenors/chairs: Josh Feinberg

Lunch at IESC cafeteria

Afternoon: Rock Magnetism (14:00-18:00)
Convenors/chairs: Mike Fuller, Mike Jackson

Self organized dinner in the village restaurants

Wednesday, June 4

Morning: Posters (08:30-9:50)
Convenors/chairs: Mike Jackson

Morning: Extraterrestrial Magnetism (9:50-12:10)
Convenors/chairs: Pierre Rochette

Lunch at IESC cafeteria

Afternoon: Mössbauer Spectroscopy short course (14:00-15:30)
Convenors/chairs: Enver Murad

Late afternoon excursion (16:00-19:00): Boat trip to the Scandola marine natural reserve

Self organized dinner in the village restaurants

Thursday, June 5

Morning: Paleofield Behavior and Records (08:00-12:20)
Convenors/chairs: Rob Coe

Lunch at IESC cafeteria

Afternoon: Magnetic Microscopy short course (14:00-17:00)
Convenors/chairs: Bruce Moskowitz

Evening: Farewell Dinner

Friday, June 6

Morning: Environmental Magnetism (08:30-12:10)
Convenors/chairs: Andrew Roberts, Fabio Florindo

Lunch at IESC cafetaria

Afternoon: Biogeomagnetism and Nanomagnetism (13:50-18:00)
Convenors/chairs: Subir Banerjee, Joshua Feinberg

Self organized dinner in the village restaurants

Saturday, June 7

Field Trip (optional) 9:00-18:00 (lunch on the road)

Departure from IESC, arrival at Ajaccio center with a drop at the airport.

Session Details

Monday, June 2

Evening: Welcome and Tribute to Subir (18:30-19:30)

Convenors/chairs: **Pierre Rochette** (*CEREGE*), **Mike Jackson** (*IRM, University of Minnesota*)
Invited speaker: **Bruce Moskowitz** (*IRM, University of Minnesota*)

Tuesday, June 3

Morning: Mineral Magnetism (09:00 – 12:10)

Convenor/chair: **Josh Feinberg** (*IRM, University of Minnesota*)

9:00 a.m. **France Lagroix** (*Institut de Physique du Globe de Paris (IPGP)*): From Magnetic Order to Magnetic Disorder and the Frustrated World They Embrace (INVITED)
9:30 a.m. **Suzanne McEnroe**, Peter Robinson and Karl Fabian (*Geological Survey of Norway*): Mineral Magnetism: Challenges and Opportunities (INVITED)
10:00 a.m. M. Lübbe, **M. Winklhofer** (*University of Munich*), A.M. Gigler, R.K. Dumas and W. Moritz: Synthesis and characterization of hematite-ilmenite multilayers: preliminary results

10:20 a.m. COFFEE BREAK

10:40 a.m. **A.M. Hirt** (*ETH-Zurich*), B.S.G. Almqvist, and F Martín-Hernández: Magnetic Anisotropy in the Basal Plane of Hematite
11:00 a.m. **Wyn Williams** (*Edinburgh University*), David Krása, Adrian Muxworthy: Assessing the role of magnetostatic interactions using nano-particle arrays (INVITED)
11:30 a.m. **Nathan S. Church** (*University of Cambridge*), Richard J. Harrison, Takeshi Kasama, Joshua M. Feinberg, Rafal E. Dunin-Borkowski: Low temperature magnetic properties of titanomagnetites and magnetic domain wall freezing
11:50 a.m. **Christine Franke** (*LSCE, CEA-CNRS-UVSQ, Gif-sur-Yvette*), Thomas Frederichs, Iuliana Vasiliev, Liao Chang, Andrew Roberts: Distinction between natural iron sulphide components by high-temperature magnetic remanence measurements using a Magnetic Properties Measurement System (MPMS)
12:10 p.m. END OF SESSION - Lunch at IESC cafeteria

Afternoon: Rock Magnetism (14:00-18:00)

Convenors/chairs: **Mike Fuller** (*HIGP-SOEST, U. Hawaii*), **Mike Jackson** (*IRM, University of Minnesota*)

2:00 p.m. **David J. Dunlop** and Özden Özdemir (*University of Toronto*): Rock magnetism: Where do we go from here? (INVITED)

2:30 p.m. C. A. Viddal and **R. M. Roshko**, (*University of Manitoba*): Aging, Memory and Rejuvenation in Collections of Two-Level Subsystems: A Comparison with Spin Glass Dynamic (INVITED)
3:00 p.m. **Karl Fabian** (*Geological Survey of Norway*), Suzanne A. McEnroe, Roman Leonhardt and Daniela I. Hofmann: Which theories of remanence acquisition are necessary to improve paleointensity determinations? (INVITED)
3:30 p.m. **Lisa Tauxe** and R. Mitra (*Scripps Institution of Oceanography*): DRM: Clues from theory and experiment (INVITED)

4:00 p.m. BREAK

4:20 p.m. **Qingsong Liu** (*Institute of Geology and Geophysics, CAS, Beijing*), Andrew P. Roberts, Michael Winklhofer: Quantifying lock-in effects associated with a post-depositional remanent magnetization in paleomagnetic records
4:40 p.m. **Ramon Egli**, (*Ludwig-Maximilian University*): Inversion of magnetic susceptibility measurements: quantitative characterization of ferri- and antiferromagnetic superparamagnetism
5:00 p.m. **Andrew Newell**, (*North Carolina State University*): Fast hysteresis and relaxation calculations
5:20 p.m. **Michael Winklhofer** (*Department of Earth and Environmental Sciences, University of Munich*): An efficient micromagnetic method of calculating FORC diagrams for pseudo-single domain particles
5:40 p.m. **M. H. Darabi** (*Hormozgan University*), John Dearing: Frequency Dependency of magnetic Susceptibility in Dried Ferro Fluid
6:00 p.m. END OF SESSION

Wednesday, June 4

Morning: Posters (08:30-9:50)

Convenors/chairs: **Mike Jackson** (*IRM, University of Minnesota*)

1. **Laurie Brown** (*University of Massachusetts, Amherst, MA*), Suzanne McEnroe and Karl Fabian: Rock magnetic and paleomagnetic properties of oxide-rich samples from the El Laco iron ore deposit, High Andes, Chile
2. **R. Mitra**, L. Tauxe and L. Lanci (*Scripps Institution of Oceanography*): Explanation of saw-tooth behavior in acquisition of IRM
3. **Alva-Valdivia, L. M.**, Rivas-Sanchez, M. L (*Universidad Nacional Autonoma de Mexico*): Natural magnesioferrite-Ti and ilmenite nanoparticles from Jacupiranga Alkaline-Carbonatitic Complex, Brazil: mineralogy and grain size effect
4. **Kazuto Kodama** (*Center for Advanced Marine Core Research, Kochi University*): An AC susceptibility measurement system for detecting the frequency dependence over a wide range of frequencies

5. **Gunther Kletetschka**, Mark Laurenzi, Tomoko Adachi (*Catholic University of America/GSFC-NASA*): Field dependent decrease of magnetic susceptibility in superparamagnetic grains
6. **Norihiro Nakamura** and Yuu Koseki (*Tohoku University*): Fractal Time-Temperature relations in magnetite nanoparticles
7. **Shcherbakov Valera** (*Geophysical Observatory Borok*): On mechanism of formation and fixing of depositional remanent magnetization
8. **Toshitsugu Yamazaki** (*Geological Survey of Japan, AIST*): Magnetostatic interactions in Pacific deep-sea sediments inferred from FORC diagrams: Implications for magnetic grain-size proxy and relative paleointensity normalization
9. **Noriko Kawamura** and Toshitsugu Yamazaki (*Geological Survey of Japan, AIST*): An experimental study of magnetic property and water chemistry changes with temperature in natural marine sediments
10. **B. Housen**, A. Wiser (*Geol Dept, Western Washington University*): Paleomagnetism, Rock Magnetism, and Magnetic Fabrics of Sediment Cores from the Fraser River Delta, Offshore Vancouver, BC (Canada)
11. **Jessica Till**, Mike Jackson, Bruce Moskowitz (*IRM, University of Minnesota*), Insights and Observations on Experimentally Deformed Magnetic Fabrics
12. **E.C. Ferré** (*Southern Illinois University*), Geissman, J.W., Zechmeister, M.S. and Hill, M.J.: Coseismic and postseismic magnetization events recorded in fault pseudotachylytes: thermal, AF and microwave methods
13. **Sonia Rousse** (*IRD - LMTG*), Morgan Ganerød, Mark Smethurst, Trond Torsvik: Multiple Antipodal Remanence Components in the Skye Lava (Uk): Complex Thermal/Chemical History and Self- Reversals
14. **A. Kontny** (*Geologisches Institut, Universität Karlsruhe*), Belén Oliva-Urcia, Frank Dietze, Anja M. Schleicher and C. Vahle: Hot-spot related crustal magnetization and magnetic petrology of basalts from scientific drillings
15. **Belén Oliva-Urcia** (*Universität Karlsruhe*), Agnes Kontny, Carsten Vahle, Anja M. Schleicher: Alteration of the magnetization in basalts due to fluid-rock interactions in high-temperature hydrothermal systems (Krafla, Iceland)
16. **N. Bezaeva** (*CEREGE, Université d'Aix-Marseille 3*), P. Rochette, J. Gattacceca, J. Duprat, G. Rizza, P. Vernazza and V.I. Trukhin: The effects of irradiation on the magnetic properties of rock and synthetic samples: preliminary results
17. **Agnès Elmaleh**, Philippe Sainctavit, Anne-Line Auzende & Bertrand Devouard (*Institut de Minéralogie et de Physique des Milieux Condensés (IMPMC)*): A preliminary study of the relationship between crystal-chemistry and the magnetic properties of cronstedtite, an iron-rich layered silicate found in meteorites
18. **Fatim Hankard** (*CEREGE*), Jérôme Gattacceca, Claude Fermon, Myriam Pannetier, Pierre Rochette, Benoît Langlais: Magnetization distribution in meteorites and terrestrial rocks using a new scanning GMR magnetic microscope
19. Tomoko Adachi, **Gunther Kletetschka** (*Catholic University of America*): Estimate of the magnetic paleofields during the formation of our solar system
20. **Yuhji Yamamoto** (*Center for Advanced Marine Core Research, Kochi University*) and Hiroyuki Hoshi: Paleomagnetic and rock magnetic studies of the Sakurajima 1914 and 1946 andesitic lavas from Japan: a comparison of the LTD-DHT Shaw and Thellier paleointensity methods

21. **Ceri J. Davies**, Mimi J. Hill, John Shaw, Dave Prior (*Geomagnetism Laboratory, Department of Earth & Ocean Sciences, University of Liverpool*): Investigating laboratory induced alteration during palaeointensity determination
22. **Gary Wilson**, Faye Nelson, Christian Zeeden & Shipboard party MD153/Matacore (*University of Otago*): A preliminary paleointensity and geomagnetic excursion record for the Brunhes Normal Chron from New Zealand
23. **Maxwell Brown**, John Shaw and Richard Holme (*University of Liverpool*): Some statistical properties of geomagnetic field reversals recorded in lava flows
24. **Mimi J. Hill** (*University of Liverpool*): Assessing the affect of possible CRM contamination on palaeointensities from a rapidly extruded sequence of lava flows
25. **Patrizia Macrì** and Leonardo Sagnotti (*Istituto Nazionale di Geofisica e Vulcanologia*): Applications of geomagnetic relative paleointensity studies to the dating of late Pleistocene sequences from peri-Antartic margins
26. **Jaume Dinarès-Turell** (*Istituto Nazionale di Geofisica e Vulcanologia*) and Andrew P. Roberts: Mineral-magnetic and relative geomagnetic paleointesity proxy records during the last climatic cycle (0-135 ka) from Mediterranean ODP Hole 963C: suborbital climatic variability and insights for the geomagnetic field
27. **Lucie Ménabréaz** (*CEREGE*), N. Thouveny, G. Camoin and S.P Lund: Geomagnetic field inclination and paleointensity variations recorded by the late pleistocene reef sequence of Tahiti, contribution to the chronology of the deposits
28. **Panaiotu, C.G.** (*University of Bucharest*), Tugui, A., Morozan, A., Hambach, U., Peskay, Z., Seghedi, I., Panaiotu, C.E.: A record of the Cobb Mountain subchron in the Quaternary basalts from the Persani Mountains (Romania)
29. **S. Brachfeld** (*Montclair State University*), E.W. Domack, A. Leventer, S. Ishman, V. Willmott: Holocene History of the Inner Larsen-B Embayment, Antarctic Peninsula
30. A. Venuti, **F. Florindo** (*Istituto Nazionale di Geofisica e Vulcanologia*) and A. Caburlotto: New advancements in the magnetic mineralogy characterization of drift sedimentary sequences from the Antarctic Peninsula, Pacific Margin
31. **Christian Ohneiser** & Gary Wilson (*University of Otago*): An Oceanographic Record From Western-Southland, New Zealand of Eccentricity-Obliquity Paced Glaciations of the Cryosphere During the Middle Miocene
32. **Hirokuni Oda** (*Geological Survey of Japan, AIST*), Yusuke Yokoyama and Satoshi Horiike: An Environmental Magnetic Record of the past 220 kyr from Timor Sea
33. **L. Vigliotti** (*Istituto di Scienze Marine ISMAR-CNR*), K.L. Verosub, A. Piva, A. Asioli, A. Cattaneo, F. Trincardi: Rock-Magnetic Results from Borehole PRAD1-2, a 370 ka Record of Climatic and Environmental Change in the Central Adriatic Sea
34. **Øyvind Paasche** (*Bjerknes Centre of Climate Research*), Reidar Løvlie, Jostein Bakke, Ann Hirt: Reconstructing the response of an arctic glacier to changing climate conditions by means of rock magnetism
35. **Reidar Løvlie** (*University of Bergen*) and Øyvind Paasche: Relating mineral-magnetic properties of glacier-fed lake sediments to catchment and post-depositional processes
36. **Ioan Lascu**, Colin Plank, Subir Banerjee (*IRM - Univ. of Minnesota*): Magnetic properties of recent sediments from Minnesota lakes: Does organic matter control the abundance of biogenic magnetite?
37. **D. Williamson** (*CNRS, CEREGE, Aix-Marseille University*), E. Abdallah, K. Fontijn, M. Jackson, A. Majule, P.-E. Mathé, Y. Garcin, D. Borschnek, S.K. Banerjee, M. Taieb, E.

Mbede: Rock magnetic evidence of a connexion between tephra deposition and monsoon dynamics (Rungwe Volcanic Province, Tanzania)

38. **Hana Fialova** (*Inst. Geophys. Acad. Sci. Czech Rep.*): Magnetic enhancement of soils developed on limestones – case study
39. **Jorge Rivas**, Beatriz Ortega, Elizabeth Solleiro, Sergey Sedov (*National University of Mexico*): Magnetic Susceptibility and Rock Magnetism Properties Analysis: a Record of Genesis and Evolution of Teotihuacan Valley Modern Volcanic Soils Sequence. Preliminary Results
40. **Chenglong Deng** (*Institute of Geology and Geophysics, Chinese Academy of Sciences*): Long-term variation of mineral magnetic properties of Chinese loess/paleosol sequences over the Quaternary
41. **Diana Jordanova** (*Geophysical Institute, Bulg. Acad. Sci.*), Neli Jordanova, Ann Hirt, Dimo Dimov: Mineral magnetic properties of Antarctic soils from Livingston Island (South Schetlands)
42. **E. Petrovsk_** (*Inst. Geophys. Acad. Sci. Czech Rep.*), A. Kapi_ka, B. Kotlík, R. Zbo_il, J. Novák and H. Fialová: Variations in magnetic fraction in atmospheric PM10 at industrial site in dependence of different climatic conditions

Morning: Extraterrestrial Magnetism (9:50-12:10)

Convenors/chairs: **Pierre Rochette** (*CEREGE*)

9:50 a.m.. **Jerome Gattaccec**a, (*CEREGE*): The remanent magnetization of meteorites: Where do we stand now? (INVITED)

10:20 a.m.. **Ben Weiss** (*MIT*): Paleomagnetic records of planetary differentiation and evolution (INVITED)

10:50 a.m.. **Julie Bowles** (*IRM, University of Minnesota*), Julia Hammer, Lisa Tatsumi, Stefanie Brachfeld: Spinel unmixing in synthetic analog Martian crustal rocks: implications for the magnetization of Mars

11:10 a.m.. **Minoru Uehara** (*Tohoku University / CEREGE*):Surface magnetic field distribution of NWA1756 (LL3.10): MI magnetic microscopy

11:30 a.m.. **Pierre Rochette** (*CEREGE*): Magnetic properties of lunar materials: comparison between meteorites and sample return

11:50 a.m. **Stuart A. Gilder** (*Ludwig Maximilians Universität*) and Maxime Le Goff: Systematic Enhancement of Titanomagnetite Magnetization Under Pressure

12:10 p.m. END OF SESSION - Lunch at IESC cafeteria

Afternoon: Mössbauer Spectroscopy short course (14:30-16:00)

Convenors/chairs: **Enver Murad** (*Bayerisches Geologisches Landesamt*)
Invited speakers: **Enver Murad** (*Bayerisches Geologisches Landesamt*)

Late afternoon excursion (16:00-19:00):

Boat trip to the Scandola marine natural reserve

Wednesday, June 4

Thursday, June 5

Morning: Paleofield Behavior and Records (08:00-12:30)

Convenors/chairs: **Rob Coe** (*UC-Santa Cruz*)

8:00 a.m.. **John Tarduno** (*University of Rochester*): The beginning of the dynamo and its relationship to Earth evolution from core to atmosphere (INVITED)
8:30 a.m.. **Catherine Constable** (*UCSD*): Paleomagnetic Field Behavior on Millennial and Million Year Time Scales (INVITED)
9:00 a.m.. Kenneth A. Hoffman and **Brad S. Singer** (*Dept. of Geology & Geophysics, University of Wisconsin-Madison*): Geomagnetic and Paleomagnetic Evidence for Magnetic Source Separation in the Outer Core: Introduction of the Shallow-Core Generated (SCOR) Field
9:20 a.m.. Roman Leonhardt, **Karl Fabian**, Michael Winklhofer, Annika Ferk, Carlo Laj & Catherine Kissel (*Montanuniversity Leoben*): Geomagnetic field evolution during the Laschamp excursion

9:40 a.m. COFFEE BREAK

10:00 a.m. **Mike Fuller** (*HIGP-SOEST, U. Hawaii*): On a possible role for precession as a power source for the geodynamo (INVITED)
10:30 a.m. **Nicolas Thouveny** (*CNRS-Univ Aix-Marseille - CEREGE*): Dipole Lows and Excursions During Interglacials Suggest an Orbital Influence on the Geomagnetic Field (INVITED)
11:00 a.m. **M.J. Dekkers** (*'Fort Hoofddijk', Utrecht University*), H.N Böhnel, E. Herrero-Bervera: Paleointensities from recent lava flows using the multispecimen parallel differential pTRM method
11:20 a.m. **Ron Shaar**(*The Hebrew University of Jerusalem*), Hagai Ron, Amotz Agnon, Lisa Tauxe, Ronit Kessel: Laboratory Test of the Thellier-Type Absolute Paleointensity IZZI Protocol on Synthetic Slag Material
11:40 a.m. **Andrew Biggin** (*Utrecht University*): Why do microwave absolute palaeointensity determinations tend to be lower than their thermal counterparts?
12:00 a.m. **Koji Fukuma** (*Doshisha University*): Surface-interior variation of paleointensity results from submarine pillow basalts
12:20 p.m. END OF SESSION - Lunch at IESC cafeteria

Afternoon: Magnetic Microscopy short course (14:00-17:00)

Convenors/chairs: **Bruce Moskowitz** (*IRM, University of Minnesota*)
Invited speakers:

Richard Harrison (*University of Cambridge*): Imaging magnetic microstructures in the transmission electron microscope
Bruce Moskowitz (*IRM, University of Minnesota*): Scanning-probe magnetic microscopy

Evening: Farewell Dinner

Friday, June 6

Morning: Environmental Magnetism (08:30-12:10)

Convenors/chairs: **Andrew Roberts** (*National Oceanography Centre, University of Southampton*), **Fabio Florindo** (*Istituto Nazionale di Geofisica e Vulcanologia*)

8:30 a.m. **Barbara Maher** (*Lancaster University*): Environmental magnetism: challenges and opportunities (INVITED)
9:00 a.m. **Ted Evans** (*University of Alberta*): Loess Magnetism Revisited (INVITED)
9:30 a.m. **Richard L. Reynolds** (*U.S. Geological Survey*), Jason Neff, Daniel Fernandez, Mark E. Miller, Harland Goldstein, Joseph Rosenbaum, Marith Reheis, Katrina Moser, Michael Ketterer, Frank Urban: Far-traveled magnetite and hematite in deposited atmospheric dust—records of climatic change and human influence on regional landscapes (INVITED)
10:00 a.m. **Leonardo Sagnotti** (*Istituto Nazionale di Geofisica e Vulcanologia*): Environmental magnetism of airborne particulate matter: application to the study and the monitoring of air pollution (INVITED)

10:30 a.m. COFFEE BREAK

10:50 a.m. **R. Egli** (*Ludwig-Maximilian University*): Pedogenic magnetic minerals in soils: some work done with Subir at the IRM
11:10 a.m. **Christine Franke** (*LSCE, CEA-CNRS-UVSQ, Gif-sur-Yvette*), Cindy Priadi, Eric Robin, Catherine Kissel, Phillipe Bonté, Sophie Ayrault, and Pierre Bonville: Characterisation of magnetic particles in the Seine river system: Implications for the determination of natural versus anthropogenic input
11:30 a.m. **Beatriz Ortega** (*Universidad Nacional Autonoma de Mexico*), Alejandro Rodríguez, Socorro Lozano, Margarita Caballero, Isabel Israde, Gabriel Vazquez: Multiproxy records of Holocene environmental change from a tropical lake on western México
11:50 a.m. **Kenneth L. Verosub** (*Univ. of California - Davis*), Luigi Jovane, Gary Acton and Fabio Florindo: Environmental Magnetic Evidence for Milankovitch Forcing of Antarctic Climate in the Ross Sea Sector during the Quaternary
12:10 p.m. END OF SESSION

Afternoon: Biogeomagnetism and Nanomagnetism (13:50-18:00)

Convenors/chairs: **Subir Banerjee** (*IRM, University of Minnesota*), **Josh Feinberg** (*IRM, University of Minnesota*)

1:50 p.m. **C.L. Blanchet** (*University of Bremen*), N. Thouveny and L.Vidal, Formation and significance of greigite in Santa Barbara Basin (USA): Example from the Holocene regime
2:10 p.m. **Andrew P. Roberts**, Christopher J. Rowan, and Thomas Broadbent (*National Oceanography Centre, University of Southampton*): Reductive diagenesis and magnetite dissolution in sediments: A new view

2:30 p.m. **Yohan Guyodo** (*Intitut de Minéralogie et Physique des Milieux Condensés (IMPMC)*): Iron Oxyhydroxides Unusual Magnetic Behaviors (INVITED)
3:00 p.m. **Richard Pattrick** (*The University of Manchester*), V. Coker, R. Harrison, C. Henderson, C. Pearce, N. Telling, G. van der Laan, and D. Vaughan: X-ray magnetic circular dichroism of geomagnetic minerals (INVITED) (40 min)

3:40 p.m. COFFEE BREAK

4:00 p.m. **Richard Frankel** (*California Polytechnic State University*): Magnetosome and Magnetotaxis Mysteries (INVITED)
4:30 p.m. **Michael Winklhofer** (*University of Munich*): What is the physical basis of the magnetic sense in animals? (INVITED)
5:00 p.m. **Claire Carvallo** (*Institut de Minéralogie et de Physique des Milieux Condensés*), Stanislawa Hickey, Damien Faivre, Nicolas Menguy: Formation of magnetite in Magnetospirillum gryphiswaldense studied with FORC diagrams
5:20 p.m. **Amy P Chen** (*IRM, University of Minnesota*), Bruce M. Moskowitz, Ramon Egli, Cooling-treatment dependent remanence and hysteresis properties of SD Fe_3O_4
5:40 p.m. END OF SESSION

Saturday, June 7

Checkout and departure

Field Trip (optional)

(Asco and the Permian volcanics that served to demonstrate the rotation of Corsica with respect to stable Europe)
Leader: **Jerome Gattacceca** (*CEREGE*)

Abstracts in Alphabetical Order by First Author

Estimate of the magnetic paleofields during the formation of our solar system

T. Adachi[1], G. Kletetschka[1,2]

[1]Catholic University of America
[2]Goddard Space Flight Center-NASA

Recent advances in understanding the extraterrestrial processes indicate that magnetization of the extraterrestrial materials may be related to shock history, and other dynamic nebular and astrophysical phenomenon such as: magnetohydrodynamics (MHD), X-ray flare, super novae shock, lightening, magnetic decoupling in giant molecular cloud (GMC). Presence of the remanent magnetization in the chondritic meteorites indicates the existence of 10^{-5} ~10^{-3} T magnetic fields in the early Solar System accretion disk (Wiechen et al., 2005). Such shock history can be found in the terrestrial samples, for example the Vredefort crater has an evidence that impact generated plasma may significantly influenced the resulting magnetization. Therefore we need to view the magnetic data of Bjurbole in terms of the shock history and possible influences due to plasma fields. We employ the efficiency of magnetization as an indicator of the intensity of the process of magnetization. In general the larger the efficiency, the larger the magnetizing field. By studying shocks history of terrestrial materials have an application for search for the parent bodies and the formation of meteorites and other extraterrestrial small bodies. Well educated estimate for the location of the formation may be possible. Also the origin of the magnetization can be inferred. There is no straightforward relation to the location within the solar nebula due to the complex astrophysical processes that originate magnetic fields. Assuming a simple shock magnetization, the efficiency may relate to the magnetic field of the plasma magnetic fields that may have bring the magnetic material close to saturation. Magnetic record of the Bjurbole chondrule may be seen from these above point of view. It may gives information about the distance from the Sun during the formation and/or about the level of plasma field generated during the impact. Bjurbole chondrule may have preserved such record.

Natural magnesioferrite-Ti and ilmenite nanoparticles from Jacupiranga Alkaline-Carbonatitic Complex, Brazil: mineralogy and grain size effect

L. M. Alva-Valdivia, M.L. Rivas-Sanchez

Laboratorio de Paleomagnetismo, Instituto de Geofísica, Universidad Nacional Autónoma de México, Del. Coyoacan 04510 D. F., MEXICO

We report on the finding of magnetic nanoparticles from the mineralized zones of the Cajatí mine, southern Brazil. The ores were formed from magnetite-rich magmas, hydrothermally altered and intruded at crustal depth in excess of 500 m. The mineralogical and textural association between: magnetite and magnesioferrite in carbonatites; and titanomagnetite and magnesioferrite-Ti mineralization in pyroxenites of hedenbergite, seems to be analog mineralizations strongly related to the ionic substitution of Fe^{2+} by Mg. Micrometric scale magnetite was magnetically reduced and divided into distinct range fractions. Magnetic minerals were characterized by transmitted and reflected light optical microscopy, X-ray diffraction, Raman spectroscopy and magnetic properties. Crystallographic identification of nanostructures was done using high-resolution transmission electron microscopy.

Frequency dependent magnetic susceptibility percentage *($\chi_{FD\%}$)* measurements report high values (10%) for he 0.1-6.0 μm range size attributed to dominant fractions of superparamagnetic particles. Coercivity and remanent magnetization of magnetite increase when the particle size decreases, probably due to parallel coupling effects. Hysteresis parameters point out that nearly all values for these ratios are in the PSD grain size region of Day plot. Continuous susceptibility measurements with increasing temperature show that the main magnetic phase seems to be magnetite. Probably maghemite is produced during the cooling process. Relatively high Q ratios (>5) for carbonatite-pyroxenite may indicate a thermo remanent magnetization acquired by the ore during post metamorphic cooling from above the Curie temperature that accounts also for the intense remanence. Vector plots for the pyroxenite samples show reasonably linear and stable magnetic components. The intensity decay curves show that most probably only two components of magnetizations are present.

The effects of irradiation on the magnetic properties of rock and synthetic samples: preliminary results

N. Bezaeva[1,2], P. Rochette[1], J. Gattacceca[1], J. Duprat[3], G. Rizza[4], P. Vernazza[5] and V.I. Trukhin[2]

[1] CEREGE, Aix-Marseille Université, Aix-en-Provence, France
[2] Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia
[3] CSNSM, Orsay, France
[4] Ecole Polytechnique, Laboratoire des Solides Irradiés, CEA-DSM-DRECAM/CNRS, Palaiseau Cedex, France
[5] LESIA, Observatoire de Paris, Meudon Principal Cedex, France

Before coming to Earth through meteorite falls or sample return, all extraterrestrial materials are exposed to different kind of irradiations (Galactic Cosmic Rays, solar wind...), thus arising the question of the influence of irradiation on the magnetic properties of extraterrestrial materials. The original magnetic moment of extraterrestrial rocks studied in the laboratory could already be considerably modified by shocks so it is important to understand if additional modifications are added by the effect of irradiation.

Solar wind and cosmic rays are mostly composed of protons but some ions are also present. We carried out some experiments of irradiation by protons, argon ions (Ar^{18}) and heavy ions (Pb^{82}) to cover a wide range of particles and energies (400 keV for Ar ions, 450 to 800 keV for protons, 1 GeV for Pb ions). Irradiation by protons was realised with the ARAMIS accelerator (Orsay, France), irradiation by heavy ions was realised at GANIL (Caen, France), and irradiation by argon ions was realised at the Observatory of Catania (Italy). In proton experiments we used 3 identical groups of samples but we varied the irradiation dose which is the direct function of the time of exposure to irradiation (from few minutes to few hours). Based on the values of energy of irradiation, the maximum penetration depth of particles into the samples was estimated as 200µm for heavy ions and 10-15µm for protons. According to these estimations we prepared samples with thickness of 300µm (irradiation by heavy ions) and of 20-50µm (irradiation by protons).

In extraterrestrial materials the most common magnetic carriers are Fe-Ni alloys (taenite, tetrataenite and kamacite). Pyrrhotite, magnetite and titanomagnetite also occur. We investigated the effect of irradiation by heavy ions and protons on different types of samples: magnetite-bearing microdiorite, titanomagnetite-bearing basalt, tetrataenite-bearing Bensour LL6 ordinary chondrite, hexagonal pyrrhotite and synthetic samples (epoxy containing powders of monoclinic pyrrhotite, magnetite and iron). The effect of irradiation by argon ions was studied on samples of two achondritic meteorites (the eucrite Bereba, and the diogenite Tatahouine) using a powder of these meteorites incorporated to a non-magnetic matrix.

All magnetic measurements were carried out in CEREGE (Aix-en-Provence). These magnetic measurements, performed before and after irradiation, included measurements of NRM and SIRM, alternating field demagnetization of SIRM, hysteresis properties, susceptibility measurements. We will discuss the effects of irradiation on both the intrinsic magnetic properties and the magnetic remanence of investigated samples.

Why do microwave absolute palaeointensity determinations tend to be lower than their thermal counterparts?

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The application of microwave radiation to absolute palaeointensity studies is a useful innovation since it minimizes the potential for alteration to bias the result and, in its current configuration, allows experiments to be performed quickly on a sample-by-sample basis. It has been demonstrated both theoretically and empirically that the microwave (de)magnetization process is equivalent to its thermal counterpart and numerous studies have produced indistinguishable results using the two methods. However, there have also been several studies published where results produced using microwave systems have been systematically and sometimes very significantly lower than results from the same rocks produced using a conventional thermal Thellier approach. Here we demonstrate that, where these systematic differences exist, they are generally consistent with the predictions of a phenomenological model of multidomain thermoremanence (MD TRM). On this basis, it is argued that the offset is not in large part related to the issue of whether microwave or thermal energy is used to (de)magnetise the samples. Instead, it is the particular measurement protocols that produce the difference. For example, in certain studies where large differences are found, the microwave experiments favour the perpendicular method which can produce slight underestimates and the thermal studies use the Thelliers' classical protocol which can produce significant overestimates. The findings of this study suggest that, while the correct palaeointensity lies between those produced by the two methods, the microwave determination is the more accurate. They also again highlight the fact that modern palaeointensity studies, whether thermal or microwave, must take careful measures to ensure that their results are not biased by MD TRM effects.

Formation and significance of greigite in Santa Barbara Basin (USA): Example from the Holocene regime.

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The sedimentary sequence extracted in Santa Barbara Basin (SBB) during ODP drilling in 1995 has revealed the extraordinary potential of the basin to record climatic and oceanic changes at a very high temporal resolution (130 cm of sediments accumulate in 1000 yrs, Kennett et al., 2000). At present, SBB is filled with water masses characterized by a strong gradient of oxygenation, reaching anoxic conditions at the bottom (<0.1 ml/l, CalCOFI data report, 2007). There, the benthic macrofauna cannot develop, thus allowing the preservation of seasonal deposits of biogenic and terrigenous compounds as millimetric laminations. Despite the existence of a very large dataset and many studies of sediment dynamics, few magnetic studies were performed yet (magnetic susceptibility on ODP 893, Rack et al., 1995 and magnetic properties of superficial sediments, Lund et al., 1992).

The recovery of a giant piston core at the location of the ODP site with the R.V. Marion Dufresne during the coring campaign IMAGESVIII-MONA (2002) then provide the opportunity to investigate the magnetic properties in Holocene and Glacial sediments. Indeed, the core (MD02-2503) was accurately dated using correlation of magnetic susceptibility profiles (with that of ODP 893, Rack et al., 1995) and covers the last 35 ka.

To complement the magnetic properties, measurements of absolute and relative elemental contents were performed (using energy dispersive polarization-XRF and an Aavatech-XRF scanner). Changes in iron, potassium and calcium contents will be presented here. The presence of layers enriched in greigite was first detected using high values of SIRM/K ratio (>10 A/m) and confirmed by strong loss of IRM9T between 300 and 350ºC. Comparison with the lithology and the elemental contents showed that the greigite-rich layers during the Holocene correspond to grey, terrigenous-rich layers, which were related to large flood deposits from the Santa Clara River (Fleischer, 1972). The greigite was formed during suboxic and anoxic periods of the bottom waters and results from the rapid deposition of terrigenous material, acting as an oxidant and preventing the formation of pyrite (FeS_2) from the monosulfide precursors (mackinawite, FeS) (Hunger and Benning, 2007).

A wavelet analyses was performed on the profiles of relative K and Ca contents, that allowed to monitor the changes in flood frequency during the Holocene. The flood frequency appears to be influenced by variation in climatic condition and by modification of the vegetation and soil cover. Indeed, intervals of higher flood frequency (i.e. 2.2-4.6 ka and 9.2-11 ka) correspond to humid conditions resuming after arid conditions, and interval of lower flood frequency (i.e. 0-2.2 ka and 4.6-9.2 ka) correspond to both very humid and very arid conditions. The flood frequencies fall in the range 60 to 2050 yrs and may be attributed i) to the Pacific Decadal Oscillation variability for the highest (60-100 yr) and ii) to the El Nino-Southern Oscillation variability for the lowest (500 and 2000 yrs). The role of the solar forcing on the high frequency range (50-80 yr, 90-140 yr and 170-260 yr) must be acknowledged but remains unclear.

Spinel unmixing in synthetic Martian analog crustal rocks: implications for the magnetization of Mars.

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If the intense magnetization of the Martian crust is of primary igneous origin, a plausible source candidate is single-domain (SD) magnetite; in a slowly-cooled crust, this may be achieved via compositional unmixing (exsolution) of larger, multi-domain (MD) sized oxides. We generate a set of basaltic samples with coarse, MD oxides and then allow these compositionally homogeneous oxides to anneal at temperatures ranging from 590°C to 710°C for 8-10 weeks. We use both an Fe-rich (Fe/Al = 1.5) composition patterned after SNC basaltic meteorites [1], and a composition (Fe/Al = 0.4) more closely resembling a terrestrial basalt [2]. Oxygen fugacity is fixed at the quartz-fayalite-magnetite (QFM) buffer based on data suggesting the oxidation state of the Martian crust is somewhere between iron-wüstite and slightly above QFM [3].

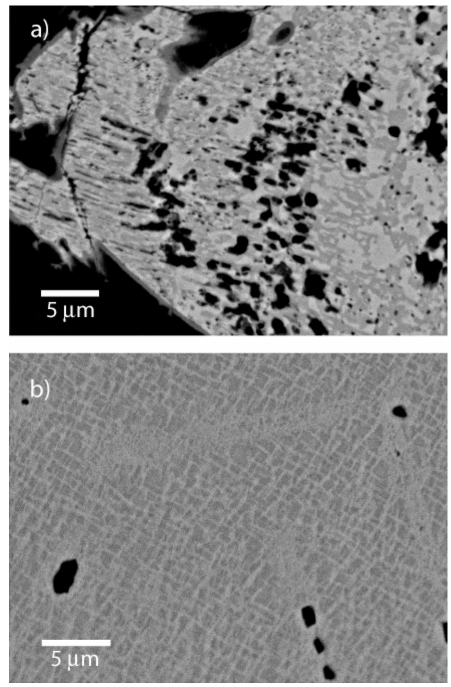

Figure 1. Backscatter images of samples anneled at 710°C. **a)** Meteorite-type (Fe-rich) sample showing both mottled compositional variations and discontinuous, wormy grain dissolution. **b)** Terrestrial-type sample also displays two sets of lamellae at ~90° to each other.

Compared to pre-annealed samples, most annealed samples display dramatic differences in composition, structure and magnetic properties. Most annealed samples display oxide grains with a two-phase, mottled compositional variation (Fig. 1a), one phase enriched in Fe and the other in Ti and Al. Terrestrial-type samples also display some grains with thready, lineated, lamellae (Fig. 1b), in a pattern consistent with spinel (cubic) exsolution structures. Additionally, many annealed oxide grains show evidence for dissolution (Figs. 1a), suggesting disequilibrium with the matrix at anneal temperatures. Magnetically, the annealed samples display a dramatic increase in coercivity and saturation remanence, consistent with a reduction in effective magnetic grain size from MD to SD or pseudo-single-domain size. Samples annealed at higher temperatures display two Curie temperatures, distinct from that of starting material and consistent with unmixing into an Fe-rich and an Fe-poor phase. While the source of the change in domain state is rendered ambiguous by the dissolution textures and precludes firmly linking many of the magnetic effects solely to exsolution at this time, we tentatively suggest that compositional unmixing of spinel oxides in the Martian crust may play a critical role in producing a strong, stable magnetization.

References:. [1] Johnson, M.C., et al. (1991) *Geochim. Cosmochim. Acta*, 55, 349-366. [2] Hamilton, V.E., et al. (2001) *J. Geophys. Res.*, 106, 14,733-14,746. [3] Wadhwa, M. (2008) *Rev. Min. and Geochem.*, 28, 493-510.

Holocene History of the Inner Larsen-B Embayment, Antarctic Peninsula

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The 2002 break-up of the Larsen-B Ice Shelf (LIS-B) enabled access to the termini of glaciers that formerly fed into the ice shelf. Cruises LMG05-02 and NBP06-03 mapped and sampled the seafloor under the former LIS-B. A suite of 18 cores from the LIS-B embayment shows a consistent stratigraphy consisting of < 0.5 m of Holocene silty-clay overlying a diamicton. The Holocene silty clay is barren of diatoms. Together, these observations suggest that the Larsen-B Ice Shelf has been a stable component of the Antarctic Peninsula Ice Cap (APIC) throughout the Holocene. One core from LIS-B shows a different trend. The Hektoria Trough is an 800-m deep glacial trough off Hektoria Glacier, at the northern end of the LIS-B embayment. Sub-bottom profiling reveals the presence at least 20-m of unconsolidated sediment in the trough, which varies in character between acoustically laminated, and packages with weak, discontinuous reflectors. We speculate that the Hektoria Trough was a sub-glacial lake during past glacial intervals when the APIC expanded out onto to the continental shelf. A 2.5-m kasten core (KC5A) was recovered from the Hektoria trough during cruise LMG05-02. The sediment consists of silty-clay with a minor component of very fine sand and is laminated in the uppermost meter. Downcore magnetic and geochemical parameters were used to investigate the terrigenous sediment supplied to the Hektoria Trough. Bulk sediment geochemistry suggests a constant sediment source that is chemically consistent with upper continental crust. Magnetic susceptibility is inversely correlated with the Fe/Ti ratio and inversely correlated with the chemical index of alteration. Intervals characterized by multidomain hysteresis parameters track well with the coarse silt fraction, and may be indicators of fluctuations of the Hektoria glacier grounding line. Our preliminary age model indicates an average sedimentation rate of 21 cm/kyr, which suggests that the basin fill extends back to perhaps 100,000 yr B.P., a rare archive of the late Pleistocene in an ice proximal site. Unlike previous cores collected from the LIS-B embayment, KC5A shows two subsurface peaks in diatom abundance. While the abundance in these peaks is much lower than in the Larsen-A (LIS-A) region, and several orders of magnitude lower than the western Antarctic Peninsula, the presence of these features was unexpected given that all previous cores from the LIS-B region are nearly barren of diatoms, with the exception of the uppermost few centimeters that contain phytoplankton detritus deposited after the 2002 break up event. Based on our preliminary age model, the ages of the diatom peaks occur at 1400 ^{14}C yr BP and 2230 ^{14}C yr BP, respectively. These ages, while not calibrated, are, to first approximation similar to the ages of diatom ooze layers observed in LIS-A sediment cores. KC5A is adjacent to the coast. The presence of diatoms at this site, while sites farther offshore are barren of diatoms, suggests that the ice shelf decoupled from the coast in the past but did not completely collapse. The LIS-B may have remained intact while the LIS-A collapsed due to a combination of colder temperatures or initially thicker ice at this more southerly site.

Rock magnetic and paleomagnetic properties of oxide-rich samples from the El Laco iron ore deposit, High Andes, Chile

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The El Laco iron ore deposit is located on the crest of the Andes of northern Chile (23.8°S, 67.5°W). The deposit is described typically as a Kiruna-type iron ore deposit. Samples of ore contain up to 90% iron oxides, mostly in the form of Ti-free magnetite, with isolated occurrences of hematite and maghemite. Exposures are in an area of 1.8 km^2 around an andesitic volcanic center of Pliocene age. The genesis and origin of the El Laco deposit has been variously interpreted as the result of hydrothermal activity, metasomatic replacement, or original lava flows of iron-rich magma. Oriented samples were collected from five sites within the ore bodies as well as two sites in the adjacent andesitic flows, along with float samples from the extensive mine dumps. Susceptibility values of the ore material fall into two groups, with 75% of the samples having susceptibilities greater than 0.1 SI (mean value of 0.305) and 25% having susceptibilities of less than 0.02 (mean value of 0.011); surrounding andesitic lavas have a mean susceptibility of 0.035 SI. NRM intensities of the ore samples are widely variable, with values as large as 60 A/m, but prove to be difficult to consistently reproduce on both cryogenic or spinner magnetometers. Directions are also highly variable, and show strong viscous components removed at low levels of alternating field demagnetization. Hysteresis properties are also skewed into two distinct groups, with most samples having coercivities less than 30 mT, but with one distinct group with Hc values greater than 400 mT. Low-coercivity (magnetite) samples fall in or close to the pseudo single domain region of the Day plot, while the high coercivity material has both Ms/Mrs and Hcr/Hc ratios very close to 1.0. The high coercivities samples are primarily from one hand sample randomly plucked from the mine dumps, and appear to be intergrowths of hematite and maghemite. Ms-T curves on this hematite-rich high-coercivity material shows a surprisingly high Néel temperature (T_N) of 705^{o}C. Low temperature hysteresis measurements on these samples show a distinct Morin transition.

Some statistical properties of geomagnetic field reversals recorded in lava flows

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Some statistical properties of the transitional field during geomagnetic field reversals have been investigated. This study concentrates on the relationship between directional and intensity variations. Palaeointensities and palaeodirections have been compiled from volcanic sequences that record field reversals of all ages. To compare palaeointensity and palaeodirectional results from multiple global locations they are characterised as virtual dipole moments (VDMs) and virtual geomagnetic poles (VGPs). The assumption that the field is a geocentric dipole during the reversal is certainly flawed due to the observation of various VGP paths for the same reversal (e.g. the Matuyama-Brunhes reversal); however, the use of VDMs and VGPs an effective way to carry out such comparisons. An asymmetry in VDM is not observed between normal and reversed field states. Means of all VDM data that lie between 0° and 60° VGP colatitudes (adjusted for starting polarity), and between 120° and 180° (adjusted VGP colatitudes), are statistically indistinguishable ($6.0 \pm 4.0 \times 10^{22}$ Am^2 compared with $6.8 \pm 3.7 \times 10^{22}$ Am^2). The mean of all transitional VDMs (between 60° and 120° adjusted VGP colatitudes) is $2.3 \pm 1.6 \times 10^{22}$ Am^2, which is approximately 30% of the present day VDM. Using a stricter selection criteria for palaeointensity data and only flow means determined from three or more individual palaeointensity results, the mean transitional VDM remains unchanged at $2.3 \pm 1.0 \times 10^{22}$ Am^2; however, this average is only calculated from 15 flow means. This highlights the need for more high quality transitional palaeointensity data for all reversals as at present it is difficult to justify making robust statements about the nature of transitional reversal behaviour.

Formation of magnetite in *Magnetospirillum gryphiswaldense* studied with FORC diagrams

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Magnetotactic bacteria (MTB) orient and migrate along the Earth magnetic field towards favourable habitats. The synthesize magnetite or sometimes greigite crystals enclosed in magnetosomes. These crystals are characterized by a narrow grain size distribution in the single-domain range, chemical purity and arrangement in linear chains. In order to study the formation of magnetite crystals in MTB, a set of *Magnetospirillum gryphiswaldense* was cultured, following an assay in which the iron uptake is only used for magnetite formation and not for cell growth. A subset of bacteria was then taken out of the growing medium at five different times: t = 30 mn, t = 1h30, t = 3h, t = 5h and t = 8h to study the evolution of magnetite formation as a function of time in the medium. First-order reversal curve (FORC) diagrams were then measured on these five samples. The less mature sample is not magnetic enough to be measurable, however the other four samples show a fairly clear trend in grain size distribution: at t = 1h30, the magnetite crystals are in the superparamagnetic (SP) size range, though the FORC diagram is very noisy (Fig. 1a), and there is a progressive shift towards the stable single-domain size (SSD) range. At t = 8h, most grains are SSD but a small SP contribution remains (Fig. 1d). This trend is confirmed by transmission-electron microscope images, and ARM/SIRM ratio evolution. The interpretation of the FORC distributions along the vertical axis is more difficult, as individual particles behave collectively during hysteresis measurements if they are close to each other, as is the case in the most mature stages of bacteria development. Nevertheless, we find that the full-width at half-maximum of the FORC distributions is about 4 mT, which is in agreement with the interaction field calculated from the dipole field equation. Low-temperature measurements were also carried out on the same samples. Cooling and warming curves of SIRM300K and FC/ZFC curves showed only evidence of a Verwey transition in the most mature sample (TV=115 K). This could be caused by the important SP component present in the less mature sample, or perhaps by partial oxidation.

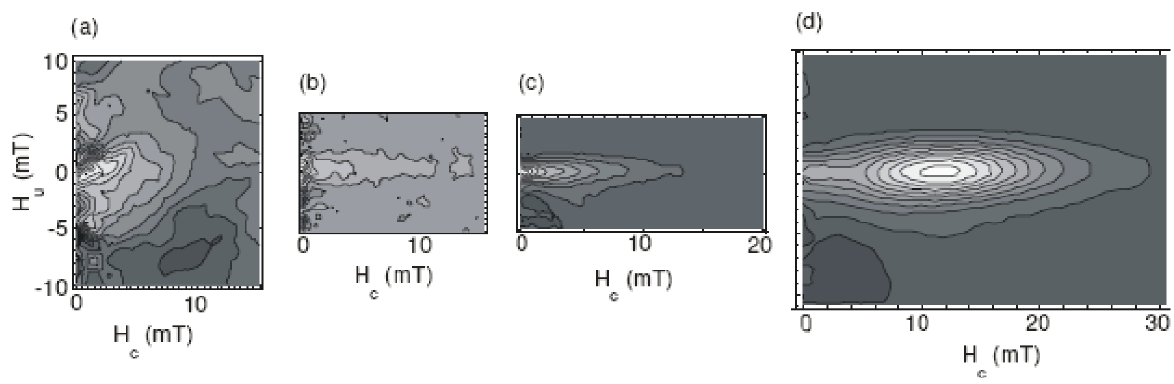

Figure 1: FORC diagrams of the time-course series of *M. gryphiswaldens* after: a: 1h30; b: 3h; c: 5h; d: 8h in the growth medium. SF=4 for all the FORC diagrams.

Cooling-treatment dependent remanence and hysteresis properties of SD Fe_3O_4

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Low-temperature remanence and hysteresis measurements are now used routinely in rock magnetism. The utilities of these measurements include detection of Fe_3O_4 magnetosomes, identification of Fe_3O_4 non-stoichiometry and domain state, and isolation of SD signal by LTD in paleomagnetic studies. While empirical cooling-treatment dependent low-temperature remanence and hysteresis properties have been reported for MD Fe_3O_4 recently, the same has not been forthcoming for SD Fe_3O_4. We will report new results from magnetosomes and synthetic samples with varying non-stoichiometry. Low-temperature isothermal ($5K$) saturation remanence after variable field cooling ($LT\text{-}SIRM\text{-}H_{FC}$, $0 \le H_{FC} \le 2.5T$) through the Verwey transition (T_v) revealed a monotonic increase in $LT\text{-}SIRM(T)$ *vs.* H_{FC} for $0 \le T \le T_v$ up to a critical field (140-384mT, sample dependent) and a monotonic decrease in $LT\text{-}SIRM(T)$ *vs.* H_{FC} for $T_v \le T \le 220K$. The monotonic increase up to the critical field can be understood in the classic view where the applied field poses an increasing control in selecting one of the [100] in the cubic phase to be the new magnetocrystalline easy axis as the sample cool below T_v. The decrease in $LT\text{-}SIRM(T)$ *vs.* H_{FC} when H_{FC} is above the critical field (for $0 \le T \le T_v$), however, is not well understood, but maybe related to a spin-disordered particle surface. The behavior of this spin-disordered phase was probed with another set of cooling-treatment dependent $LT\text{-}SIRM(T)$, where the sample was cooled in $2.5T$ in selected temperature windows ($LT\text{-}SIRM\text{-}T_{pFC}, 5K \le T \le 75K$): FC_{300-x} & ZFC_{x-5}, and ZFC_{300-x} & FC_{x-5}, where $x = 75K$, $55K$, $35K$. The results from these measurements show that the magnitude of $LT\text{-}SIRM(T)$ at $T \le T_v$ depend critically on the presence (or absence) of a cooling field, with the $LT\text{-}SIRM(T)$ being uniformly higher when a field is present between x and $5K$ (i.e. FC_{x-5}) compared to ZFC_{300-5}, and the $LT\text{-}SIRM(T)$ being uniformly lower when a field is absent between x and $5K$ (i.e. ZFC_{x-5}) compared to FC_{300-5}. Furthermore, we observed horizontally shifted hysteresis loop at $10K$ after field cooling in $40mT$, with loop shift $H_{ex} \le 6mT$ (sample dependent), which can also be interpreted to be caused by this spin-disordered phase. Finally, these effects diminishes when the samples are reduced back to near stoichiometry. We will discuss implications of the above mentioned effects on the δ-ratio magnetosome detection method, detection of partially-oxidized Fe_3O_4, and distinct FORC distribution maxima for SD Fe_3O_4 at low-temperature.

Low temperature magnetic properties of titanomagnetites and magnetic domain wall freezing

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Titanomagnetites (the magnetite Fe_3O_4 - ulvöspinel Fe_2TiO_4 solid solution) exhibit dramatic changes in magnetic properties below 150K, including sharp drops in susceptibility and increases in coercivity. The Verwey transition in pure magnetite at 120K is well-documented, but magnetite also shows an additional transition at 50K of uncertain origin; likewise, significant increases in coercivity have been observed in titanomagnetites below 150K, but the cause of these changes has not been fully explained. First order reversal curve (FORC) analyses reveal distinctive changes in coercivity below 150K in multidomain polycrystalline and single crystal samples of compositions TM30-TM50. The FORC distributions indicate a narrow range of coercivities which are significantly higher than those measured at higher temperatures, and which increase further as the sample approaches saturation. A possible explanation for this behavior is provided by a model in the physics literature which predicts a narrowing of magnetic domain walls at low temperatures and hence enhanced pinning. Low temperature AC susceptibility analyses for these samples show frequency dependent relaxation behavior consistent with this model. We also present a method for simulating FORC diagrams which incorporates enhanced pinning fields and gives results very similar to those observed in titanomagnetite.

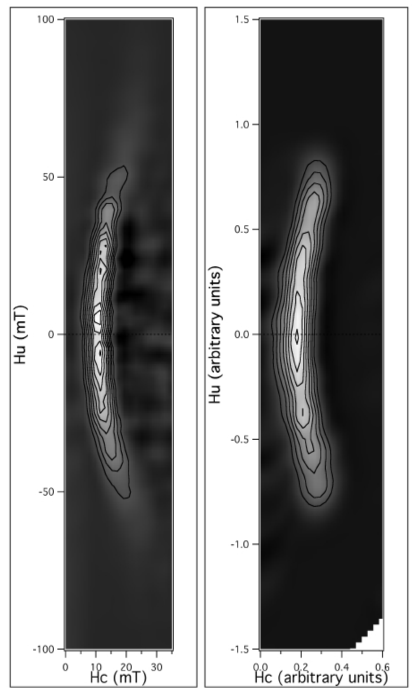

Figure 1. FORC distribution for polycrystalline TM40 at 50K (left) and simulation using enhanced pinning fields (right).

Paleomagnetic Field Behavior on Millennial and Million Year Time Scales

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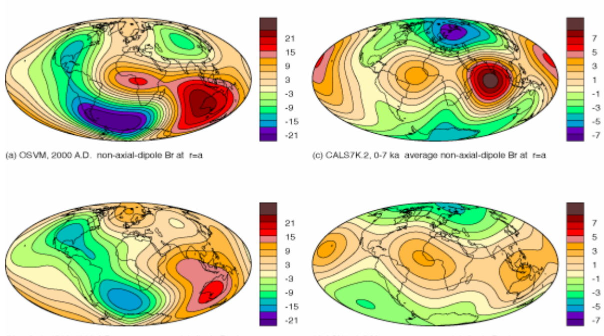
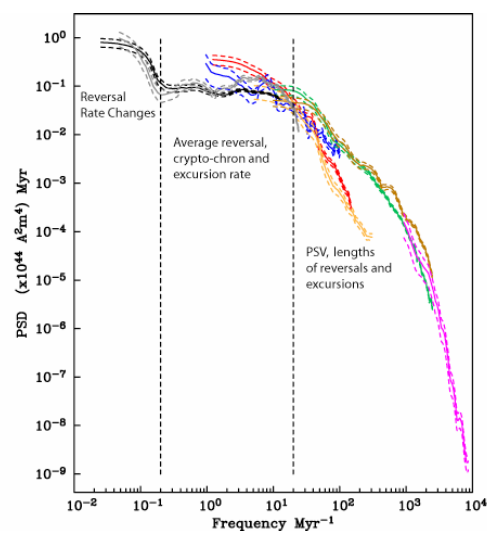
Suitable paleomagnetic data can be used to recover records of temporal change in the geomagnetic field with the goal of determining the primary factors that control its long-term structure and variability. Outstanding questions of interest include the possibility of pinning down long-term hemispheric asymmetries in the secular variation and what causes them, and the conditions that lead to excursions and geomagnetic reversals. The basic tenet that the field averages to that expected of a geocentric axial dipole remains approximately correct on million year time scales, but non-axial-dipole (NAD) contributions to the field do exist and their magnitude varies with the interval over which the field is averaged. As seen in the 2 left-most maps of the figure below, the structure for the 2000 AD and centennial-scale averages of the surface NAD radial component of the magnetic field is quite different from that represented on the right on millennial to million-year time scales. Characterizing the global behavior of the field on the latter time-scales remains a challenge, as is determining the best estimate for the spectrum of dipole moment or other paleointensity variations. In the figure at right the dipole moment power spectrum in the frequency range 1-100 Myr $^{-1}$ is probably best represented by the upper envelope of the disparate curves derived from various sedimentary relative paleointensity records. This talk will provide an overview of efforts to model the long-term variations of the magnetic field incorporating both directional and paleointensity information. Limitations of temporal and spatial sampling, and the influence of data uncertainty are considered in interpreting existing models.





Frequency dependency of magnetic susceptibility in dried ferro fluid

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Frequency dependency of magnetic susceptibility with two Bartington frequencies shows considerable variation with grain size and it seems that the magnetic interaction between the grains has considerable influence on the degree of this dependency. MPMS (Magnetic Property Measurement System) located at the University of Liverpool, Physics Department, has the ability to measure susceptibility from 0 to 1000 Hz and from liquid helium to room temperature. For three different superparamagnetic (SP) grain sizes of magnetite suspended in hydrocarbons, Ferro Fluid (F.F.), the variation of magnetic susceptibility in the whole range of frequencies, at room temperature, were examined to show how the frequency dependency of magnetic susceptibility changes with known grain sizes and also determine whether the magnetic susceptibility of SP grains is influenced by an interactive regime. Our results support the effect of interaction between SP grains (nano particles) on magnetic properties of Dried Ferro Fluid (D.F.F.).

Investigating laboratory induced alteration during palaeointensity determination

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We present palaeointensity data derived from a conventional heating based Thellier investigation in comparison to results obtained from sister samples investigated using the microwave technique. A scanning electron microscope, SEM based study analysing the oxidation characteristics of the samples prior to, during, and post experimental phase accompanies this investigation. Taken from the Shandong region of China, 51 Cretaceous aged basalt samples have initially undergone a suite of rock magnetic experiments in order to determine the remanence carrier, identified as titanomagnetite with an average Curie temperature around 300^{o}C. SEM analysis prior to palaeointensity experiments highlighted a small degree of low temperature oxidation within the crystals. Trellis patterns and ilmenite lamellae typically associated with high temperature oxidation was not apparent. Changes seen will be presented and differences found between microwave and thermal heating discussed.

Paleointensities from recent lava flows using the multispecimen parallel differential pTRM method.

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Obtaining reliable information on the intensity of the Earth's magnetic field in μT, referred to as absolute paleointensity, as function of (geologic) age is a cumbersome task. One requirement is that lavas must have acquired their natural remanent magnetisation by mere cooling after solidification, i.e. a pure thermoremanent magnetization is obtained. For a meaningful paleointensity, the magnetic particles must further be ideally single domain and must not alter during laboratory processing. The latter unfortunately occurs in many cases during the sequential laboratory heatings that constitute the classic Thellier-Thellier style paleointensity determination.

Here, we present new paleointensity data from several locations including Hawaii and Maui (Hawaiian Islands, USA) and the San Quintin volcanic field (Baja California, Mexico) obtained with the multispecimen parallel differential pTRM method (Dekkers and Böhnel, 2006; EPSL, 284, 508-517). This new approach employs analysing the field-dependence for a set of specimens at a single laboratory heating temperature, rather then cycling individual specimens through complex field-temperature cycles for a single laboratory field value. Its outcome is largely domain-state independent and by selecting optimal temperatures the effects of laboratory alteration can be circumvented. Despite the particle size heterogeneity that often occurs, realistic paleointensities are obtained for historic flows for which the paleofield is known rendering credibility to the approach that radically differs from existing absolute paleointensity determination methods.

Mineral-magnetic and relative geomagnetic paleointesity proxy records during the last climatic cycle (0-135 ka) from Mediterranean ODP Hole 963C: suborbital climatic variability and insights for the geomagnetic field

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A continuous high-resolution mineral-magnetic record has been generated from u-channel samples from core ODP-162-963C in the Sicily Channel (37º02.148'N, 13º10.686'E; 480m depth). Low-resolution planktonic $\delta^{18}O$ analysis at this site (Howell et al., 1998; Bottcher et al., 2003) together with high-resolution planktonic $\delta^{18}O$ and planktonic foraminifera and calcareous nannofossil assemblage data for the interval ~33-52 mcd, that includes Marine Isotopic Stage 5 (MIS5), at Hole 963A (Sprovieri et al., 2006), provide the first-order chronological constraints. These indicate that the ~58-m long Hole 963C reaches into MIS6 with high sediment accumulation rates, over 30 cm/ka which renders this core from Site 963 an ideal material to investigate suborbital climatic variability. It can also potentially offer an opportunity to test and enhance geomagnetic field characteristics for this time interval from where several relative paleointensity stacks are available (i.e. NAPIS75, GLOBIS75, SINT800) and different geomagnetic excursions have been described (mostly Mono Lake, ~38 ka; Laschamp, ~42 ka and Blake, ~110-120 ka).

High-resolution alkenone-based and faunal-based sea surface temperature (SST) records were recently published from the westernmost Mediterranean Sea (Martrat et al., 2004, 2007; Pérez-Folgado et al., 2004). These records, resolved at ~400-year spacing, together with the high resolution biostratigraphic study by Sprovieri et al, (2006) in Hole 963A in the Central Mediterranena suggest that the most pronounced North Atlantic cold events were registered even in the Mediterranean Sea. Here we use the mineral-magnetic record from Hole 963C which can be correlated with remarkable consistency with the Dansgaard/Oeschger (D/O) cycles observed in Greenland $\delta^{18}O$ profiles to strengthen this idea. The u-channel data acquired at 1-cm resolution (only independent at about 5 cm) represent a data resolution of about 2-3 years (10-15 years). For relative paleointensity ARM is chosen as normalizer after coherency evaluation between possible normalizers (ARM, IRM and susceptibility) and respective normalized records in order to minimize potential climatic effects. The climatic imprint to the normalized paleointensity proxy is assessed through state-of-the-art spectral analysis techniques. Although the inclination data seems to be blurred the relative paleointensity proxy seems to be consistent with available data and allow further precisions and details to be made regarding the age and nature of relative lows and excursions.

Rock magnetism: Where do we go from here?

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We are in a better position than a decade ago to understand how macroscopic magnetic properties relate to micrometer- and nanometer-scale magnetic particles and their domain structures. Yet some puzzles remain. Magnetic transitions at low temperature are increasingly useful in identifying minerals, cleaning remanences, and determining particle size and morphology but the fundamental nature of the Verwey transition in magnetite and the Morin transition in hematite remain tantalizing. Not only do memories of prior remanences remain in crossing these transitions in zero field but one can produce new remanences by field-heating or field-cooling through the transitions – even in a nominally non-magnetic phase like antiferromagnetic hematite. Can we gain insights into the TRM process by studying analog transition remanences at low temperatures? Thermal demagnetization below the Verwey transition and stepwise low-temperature cleaning above it show broad spectra of remanence melting. Are these direct analogs of blocking/unblocking temperature distributions of TRM? Direct investigation of TRM and partial TRM blocking and unblocking at high temperatures reveal some discrepancies between inferences based on continuous thermal data and more conventional stepwise data as used in Thellier experiments. Partial TRMs sometimes appear to remain constant or even rise during continuous zero-field heating when normalized to allow for the drop in M_S, while heating in steps and recooling to room temperatures always indicates a steadily decreasing remanence. On the other hand, pTRM memory after low-temperature cleaning often does rise in stepwise thermal demagnetization, suggesting an underlying reversed remanence. What combination of wall movements or nucleations/denucleations could be involved? While these may seem esoteric details, the fact that our understanding of TRM – the core of our science – is shaky is unsettling. In the very practical area of granulometry and mixtures of phases, Day plots and FORC diagrams remain ascendant. They provide a wealth of information but how firm is our physical understanding of the details? As the Day plot moves beyond sorting data into boxes towards understanding sample distributions, "PSD" looks remarkably like a simple SD + MD mixture but SD + SP mixtures are more problematic. Although size distributions of many natural mixtures must be continuous across the SP threshold, Day plot modeling of their data only seems to work by invoking an isolated 10 nm population. A powerful but underutilized approach is to trace the trajectory of data measured at different temperatures, high or low, for individual samples. FORC diagrams unquestionably increase our insight into the stability of phases in a sample and how the individual carriers interact. We are, however, a little cavalier in our diagnoses. Self-demagnetizing effects in MD materials are look-alikes of interacting grains in their effects on hysteresis. In interpreting distributions, we rely heavily on the Preisach formalism, which not only reduces particle response to a pair of switching fields but also ignores the fact that those fields themselves evolve with the sample's magnetic state. There is no question that the diagram determined by starting from magnetic saturation is vastly different from one that uses data for an initially demagnetized sample. The latter approach is more likely to yield symmetric distributions and needs to be investigated systematically.

Pedogenic magnetic minerals in soils: some work done with Subir at the IRM

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The iron cycle in soils is controlled by a complex interplay of chemical and biologic processes that are not yet well known. Superparamagnetic iron minerals forming during iron cycling are responsible for part of the magnetic signature of soils, together with magnetic minerals from the parent rock. The susceptibility of soils formed under different climatic conditions over Asia clearly correlates with modern rainfall data. However, this "textbook" picture changes drastically in other places of the World: loessic soils from Alaska and Argentina are characterized by an apparent lack of magnetic enhancement, challenging current theories on pedogenesis.

During my 2-years stay at the IRM, I exchanged ideas on this topic with Subir Banerjee, who drove my attention on the role of antiferromagnetic (af) nanoparticles in the iron cycle of soils. It became immediately clear that the quantitative characterization of natural assemblages of magnetic nanoparticles was a challenging task: First, the parent rock background signal is not necessarily constant, and is difficult to remove it in some cases. Second, pedogenic minerals occur in an extremely wide range of sizes and compositions. The mass normalized susceptibility of af nanoparticles is typically much lower than magnetite; however, pedogenic ferrihydrite, goethite, and hematite occur at much higher concentrations. Therefore, af nanoparticles can contribute significantly to the magnetic signature of some soils or soil horizons. This reality drove the development of new magnetic quantification methods (see "Inversion of magnetic susceptibility measurements: quantitative characterization of ferri- and antiferromagnetic superparamagnetism"). The new techniques have been applied to a series loessic soil profiles from Midwestern United States to (1) obtain information on the pedogenic minerals formation mechanism, and (2) investigate systematic relationships between different pedogenic minerals and the climate. Some of the findings can be summarized as follows: (1) Pedogenic magnetite occurs in a depth range that coincides strictly with the presence of organic matter. The grain size distribution is broad but very consistent in all soils analyzed. Pedogenic magnetite is extremely well dispersed in the soil matrix. The typical distance of the particles is at least 10 times their diameter; contrasting with the compact magnetite nanoparticle clusters obtained in laboratory from biotic or abiotic reduction processes. (2) Af nanoparticles are present at all depths in a soil, and their concentration rises above a relatively constant background just below the horizon where pedogenic magnetite forms. Below a certain depth, the magnetic susceptibility is entirely controlled by af nanoparticles, which share the same magnetic signature with synthetic ferrihydrite and goethite nanoparticles. (3) Magnetite and goethite nanoparticles are strongly correlated in space, suggesting that these two minerals are produced by the same process on a microscopic scale. Together with (1), this supports the concept of "reduction spots" with a radial oxygen gradient, where magnetite grows under the most reducing conditions, while goethite forms after the outward diffusion and subsequent rapid oxidation of FeII. (4) The use of a strictly quantitative estimates of the pedogenic magnetite concentration, instead of the classical susceptiblity enhancement parameter, increases significantly the correlation with mean annual rainfall (MAR). A further improvement is obtained by considering more suitable climatic proxies, such as the potential of water storage (PWS), which is essentially the MAR corrected for evaporation.

Inversion of magnetic susceptibility measurements: quantitative characterization of ferri- and antiferromagnetic superparamagnetism

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A quantitative reconstruction of the magnetic properties of weakly interacting superparamagnetic (SP) particles is obtained from measurements of the low-field magnetic susceptibility as a function of temperature and applied field frequency. The inversion method developed for this purpose is used to obtain (1) the temperature dependence of the magnetic moment and the microcoercivity of the particles, (2) the effective magnetic field produced by magnetostatic (exchange and dipole) interactions between the particles, and (3) the distribution of energy barriers related to the size of the particles. The inversion of susceptibility measurements of samples containing dispersions of well characterized iron oxide nanoparticles shows a clear and systematic difference between ferri- and antiferromagnetic minerals: Magnetite and maghemite nanoparticles are characterized by a weak temperature dependence of the magnetic moment and microcoercivity between 3 and 400 K, as predicted by theoretical models. The reconstructed microcoercivity of both equidimensional and elongated magnetite nanoparticles is characterized by a weak local minimum at temperatures close to the isotropic point, indicating a small crystalline anisotropy contribution. On the other hand, the magnetic moment and microcoercivity of ferrihydrite and goethite nanoparticles depends strongly on the temperature between 3 and 400 K. The magnetic moment increases typically by a factor 5 upon cooling from 400 K to 3 K. The inversion method has also been applied to susceptibility measurements of several samples taken from different soil profiles, allowing following interesting observations: (1) the susceptibility enhancement in soils is produced by both ferri- and antiferromagnetic nanoparticles, (2) the ferrimagnetic component is produced by non-interacting maghemite particles with a very broad distribution of grain sizes, (3) the antiferromagnetic component is extremely similar to synthetic ferrhydrite or goethite nanoparticles, (4) the ferrimagnetic component is sharply confined to the range of depths where organic matter is present, (5) outside of this depth range, 50-100% of the magnetic susceptibility is produced by the antiferromagnetic component, (6) both the ferri- and the antiferromagnetic components are characterized by consistent and well-constrained properties in a variety of soils analyzed. The results obtained with the soil samples show that the susceptibility inversion method is an effective tool for the characterization of complex magnetic mineral mixtures containing SP particles.

A preliminary study of the relationship between crystal-chemistry and the magnetic properties of cronstedtite, an iron-rich layered silicate found in meteorites

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Here we present results obtained by SQUID magnetometry on terrestrial samples of cronstedtite from Kisbanya, Rumania, Przibram, Czech Republic and Salsigne, France. These results give us a preliminary insight into the link between crystal-chemical variations and magnetic properties of this silicate, characterized by low (≤10 K) ordering temperatures and an antiferromagnetic character[1,2,3].

Cronstedtite is one of the major pieces of the hydrated minerals assemblage found in CM2 chondrites, and supposedly formed by *in situ* alteration on the asteroïdal parent body of these primitive meteorites[5]. On Earth, cronstedtite is mostly found in hydrothermal veins[4], where it formed in analogous, low temperature (≤250°C), conditions. Mixed valent, this mineral, formulated $^{O}[Fe^{2+}_{3-x} Fe^{3+}_{x}]$ $^{T}[Si_{2-x} Fe^{3+}_{x}]O_5(OH)_4$ is formed by the stacking of layers containing a plane of octahedra (O), mostly occupied by both Fe^{2+}, and Fe^{3+}, and a plane of tetrahedra (T), more or less equally occupied by Fe^{3+} and silicon. This confers to the structure a strong bi-dimensional character. An influence of the $Fe^{3+}/\Sigma Fe$ ratio –clustering between 40 and 50% in natural cronstedtite- on the magnetic anisotropy is expected, as ferric iron should not give rise to strong anisotropies. The same applies to the T/O iron ratio, because the magnetic coupling between tetrahedral ferric iron and octahedral iron might subdue the bi-dimensional character of the magnetic structure, as suggested earlier[1]. More generally, rearrangements of the pattern of magnetic interactions are expected. The aim of the present study is to investigate the way magnetic properties of cronstedtite are affected by crystal-chemical changes.

Our preliminary results demonstrate the strong magnetic anisotropy of the three samples of cronstedtite. Moreover, because the peak magnetic susceptibility of the single crystals, at 6-7 K, is up to ten times larger when the field is applied parallel rather than perpendicular to the cleavage plane, the easy direction of magnetization in our samples must lie in or close to the plane. The present results, though preliminary, also suggest a decrease of the anisotropy with the ferric iron content[3]. The existence of relaxation processes in the samples studied is suggested by the slight splitting between zero field cooled (ZFC) and field cooled (FC) susceptibility. It is coherent with earlier observations made using Mössbauer spectroscopy. This feature deserves further attention, as it might be indicative of a local ordering of the iron cations, or of ≈10 nanometer scale changes of the composition and stacking sequences of the layers (polytypism), as it has been previously observed in this mineral[6]. This study opens interesting perspectives as to the link between bulk or local variations of the $Fe^{3+}/\Sigma Fe$ ratio and the stacking sequence and the magnetic properties. It will be further developed by a fine scale characterization of the samples by transmission electron microscopy.

References: [1]Coey, J.M.D, Bakas, T., McDonagh, C.M., & Litterst, F.J., Phys. Chem. Minerals 16, 394 (1989); [2]Coey, J.M.D, Moukarika, A. & Ballet, O. J. Appl. Phys. 53, 8320 (1981); [3]Coey, J.M.D, Ballet, O., Moukarika, A. & Soubeyroux, J.L. Phys. Chem. Minerals 7, 141 (1981); [4]e.g. Browning, L.B., McSween, H.Y. Jr. & Zolensky, M.E., Geochim. Cosmochim. Acta 60, 2621 (1996); [5]Frondel, C. American Mineralogist, 47, 781 (1962); [6]Kogure, T., Hybler, J.& Yoshida, H. Clays Clay Minerals, 50, 504 (2002)

Loess magnetism revisited

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The globally widespread aeolian silt known as *loess* has been studied scientifically for almost two centuries, but the significance of its magnetism was not recognized until about 25 years ago. A literature search indicates that hundreds of papers have been forthcoming—and there's no sign of any slowing down. Two main themes have emerged: *magnetostratigraphy* and *magnetoclimatology*. The identification of geomagnetic reversals matching the global polarity time scale firmly established the chronology of loess deposition, and the magnetic encoding of ice-age glaciations permitted firm teleconnections to be made between continental and oceanic climatic records. Both of these aspects are particularly well illustrated by the classic sections in the Chinese Loess Plateau (CLP), where the neoformation of magnetic minerals during interglacial periods leads to an increase in magnetic susceptibility. This *pedological model* is by no means restricted to the CLP, but it is not universal. At several important sites, the complete opposite is found, with magnetic peaks in glacial intervals. This alternative pattern has been attributed to stronger average winds during glacial periods leading to increased entrainment of dense iron-oxide particles. For example, in the Ob River drainage, southern Siberia, this *wind vigour* model tracks the last glacial-interglacial cycle and also captures the signatures of the abrupt cold pulses responsible for the Heinrich layers in North Atlantic marine sediments.

Despite the many successes, several problems remain. Can the two magnetoclimatological models to be reconciled? Can the magnetic signals be converted into quantitative measures of palaeoclimatic parameters, such as rainfall? Some authors have proposed specific climofunctions, but there is no general agreement on the resulting values. Progress in these areas will require a better understanding of the complex mineral pathways involved. To this end, two promising lines of enquiry are currently being pursued: direct experimental synthesis of relevant mineral nanophases to calibrate field data, and development of advanced unmixing protocols.

In addition to these palaeoclimate applications, it is now clear that the fidelity of loess as a geomagnetic recorder has serious shortcomings. The first-order pattern of the main polarity reversals is not in doubt, but clear stratigraphic discrepancies exist between different continental locations and between oceanic and continental records. These have usually been attributed to some form of slow "lock-in" process that smooths—and delays—remanence acquisition. However, in zones where even subtle lithological variations occur, it is found that multiple apparent polarity flips are artificially generated. Thus on the one hand, smoothing eliminates high frequencies, but on the other, lithologically-controlled variable lock-in generates them! Without an adequate model of the remanence acquisition process(es) it is unwise to interpret many reported results in terms of genuine geomagnetic field behaviour.

In all of these endeavours, it is essential to keep in mind that the magnetic properties of loess should not be considered in isolation. Crucial information from loess is also provided by a wide variety of topics ranging from grain-size analyses to snails—and a host of studies on lacustrine and marine deposits permit the loess data to be integrated into the overall history of global change.

Which theories of remanence acquisition are necessary to improve paleointensity determinations

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Subir Banerjee has contributed many key insights into the rock magnetic methods used to determine the history of Earth's magnetic field intensity. An attempt will be made to narrow down what is still left for us to do today. Starting from the systematic analyses of Thellier, a main focus has been to utilize the extremely stable thermoremanence (TRM) of rocks to infer the field strength in which TRM was acquired. Understanding the physics of TRM became a major research field in rock magnetism. While single-domain theory is generally accepted, the TRM of pseudo-single-domain and multidomain particles require a more complex approach. Yet, already the assumption of a pure natural TRM acquisition can be questioned, and chemical or mineralogical remanence-acquisition (CRM) processes have to be considered. This is of special importance in rocks where magnetite is NOT the predominant remanence carrier. Constructing a comprehensive theory of thermo-chemical remanence acquisition is an important task to be addressed in the coming years, and an example of lamellar remanence acquisition will be presented. Another important advance in paleointensity determination was the systematic use of sedimentary remanence (SRM) to obtain dense relative paleointensity (RPI) records with extremely good time control. Yet, remanence acquisition in sediments is much more difficult to understand than TRM. It is an open question whether our physical understanding of SRM is sufficient to establish a reliable theory of RPI. An extensive example from a stratigraphic network shows, that compositional variations in marine sediments considerably influence the inferred RPI signal. In the last years, several new methods for paleointensity determination have been proposed, however most still lack a thorough theoretical basis. Here, a promising approach of multiple-specimen paleointensity determination will be theoretically discussed. Physical rock magnetism was created as an independent research field around 1940. It is not astonishing that after less than 70 years there is still much space for new developments.

Coseismic and postseismic magnetization events recorded in fault pseudotachylytes: thermal, AF and microwave methods

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During seismic rupture, motion along a fault plane may generate sufficient frictional heat, during a relatively short period of time, to cause local melting and formation of a pseudotachylyte vein. Estimates from corrosion microstructures around quartz grains suggest that temperatures as high as 1700-2000ºC are common, especially in quartzo-feldspathic gneisses and granitic rocks. Under these conditions, hydrous silicates, such as biotite, muscovite or phengite, break down and liberate their iron into the melt. Depending on local oxygen fugacity conditions, new Fe-Ti oxides form upon quenching of the melt.

An extensive mineralogical study of pseudotachylytes from over 20 localities shows that magnetite is by far the most common Fe-Ti oxide formed during coseismic quenching of the melt, although maghemite has been reported in at least one occurrence. In the cases where the host rock did not originally contain magnetite this newly formed magnetite can be interpreted to have crystallized within a few seconds to tens of seconds after seismic slip. The magnetic grain size is typically a mix of SD and PSD grains.

The NRM acquisition process may involve up to three successive magnetization events: i) a thermoremanent magnetization (TRM) acquired as grains cool below their blocking temperature; ii) a seismic lightning isothermal remanent magnetization (*s*LIRM), acquired as coseismic electric currents strike along the highly conductive pseudotachylyte vein; and, possibly, iii) a chemical remanent magnetization (CRM) acquired after cooling by hydrothermal alteration of preseismic and coseismic mineral assemblages. Hydrothermal alteration, attested by transformation of magnetite into hematite, is restricted along pseudotachylyte vein margins and along brittle fractures that cut across the vein. The very edge of the vein may locally host grey specular hematite. Selective microsampling allows separation of altered parts (red/maroon) of veins from the apparently less altered parts (black/blue).

Demagnetization experiments have been performed using thermal, alternating field (AF) and microwave methods. Thermal treatment is the most logical approach for separating the contributions of hematite or maghemite due to postseismic alteration. In fresh samples, AF demagnetization allows definition of the direction of the *s*LIRM component (oblique to the geomagnetic field and at a high angle to the vein plane) and may allow estimates of the intensity of the magnetizing field (up to 40 times larger than the Earth field). The microwave approach offers a valuable compromise between thermal and AF methods with the significant advantage of avoiding heating induced mineralogic changes.

Magnetic enhancement of soils developed on limestones – case study

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Characterization of iron-bearing minerals, which are responsible for magnetic enhancement, is essential in environmental studies based on the application of magnetic methods. Discrimination between different magnetic contributions plays major role. In the case of polluted soils developed on non-magnetic background, magnetic susceptibility is usually strongly enhanced in the topsoil layer (down to 10 cm) and rapidly decreases with depth. Contrary to that, in unpolluted areas with strong natural magnetic background (mostly on basaltic bedrock), magnetic signal is increasing with depth. In our study we will present and discuss our observations of soils with high magnetic susceptibility and high frequency-dependence, located in relatively unpolluted area and developed on non-magnetic basement rocks (limestones). Set of magnetic analysis of soil and rock samples were carried out (VSM, MPMS and thermomagnetic measurements). Furthermore, non-magnetic measurements, such as Mössbauer spectroscopy, SEM observations and CBD extractions, were accomplished. Based on these results, a high content of ultra-fine superparamagnetic particles, probably magnetite, seems to be responsible for the magnetic enhancement of soil samples. We suppose that magnetic parameters are influenced by soil forming processes, which, during weathering, transform initially paramagnetic iron minerals present in the limestones. Study of possible oxidation and reduction mechanisms will be a major task for the future investigation.
This work is supported by Czech Academy of Sciences through a grant No. KJB300120604.

Characterisation of magnetic particles in the Seine river system : Implications for the determination of natural versus anthropogenic input

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The presented study seeks new proxy parameters and techniques to trace geological and anthropogenic processes in the Seine river system in France already largely investigated within the framework of the PIREN-SEINE program. We develop finger prints for mechanical and chemical weathering processes, the regionalisation of the suspended material, the influence of fluvial transport mechanisms, and the comparison of natural input versus anthropogenic pollution.

Therefore we apply a combination of straightforward rock magnetic and advanced electron microscopic techniques. This interdisciplinary approach allows for the rapid analysis of a relatively high number of sediment trap samples with standard methods such as magnetic hysteresis measurements on the bulk material.

Clear trends can be identified from those results, concerning the magnetomineralogy, magnetic grain size and concentration of magnetic material in the samples. Each river (stretch) shows its specific trend line depending on the regional input and weathering conditions, its catchment area, potential pollution, and its seasonal changes and geochemical environment. Two major downstream profiles (the Seine and the Marne) are chosen to demonstrate this.

Detailed analyses are performed on magnetic concentrates for representative sample locations, which were recovered using heavy liquid separation. Absolute quantification of the various types identified in the magnetic microparticle assemblage are achieved by automatic visualisation and particle classification in scanning electron miroscopy. Mössbauer spectroscopy is applied to quantify the delicately countable nanoparticle fraction, for example fine grained hematite, goethite, and ferrihydrite. Low-temperature thermomagnetic remanence measurements give additional information on the presence or absence of specific mineral phases and their crystallinity. The rock magnetic and electron microscopic studies are further completed by geochemical ICP analyses performed on bulk samples and magnetic extracts.

Distinction between natural iron sulphide components by high-temperature magnetic remanence measurements using a Magnetic Properties Measurement System (MPMS)

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The ferrimagnetic sulphide mineral greigite (Fe_3S_4) has been subject of geomagnetic studies in the past, but only recently clear evidence has shown the presence of differing greigite phases in geological records. We present a new thermomagnetic technique applying magnetic remanence measurements in an oxygen-free environment in the range from room tempetature to 530°C using a highly sensitive *Quantum Design MPMS* (at the University of Bremen). These measurements are suitable to detect the exact starting temperature of the thermomagnetic decay of greigite-containing natural samples. Heating is performed in an ideal helium/near vacuum atmosphere. Therefore oxidation effects of sulphides can be neglected. These new experiments are compared with more classical methods by linking their thermomagnetic results to those of standard Curie balance measurements.

Dekkers et al. (2000) performed Curie balance heating experiments on synthetic greigite in air and in argon flushed atmosphere. Their results show lower decay temperatures for heating in air compared to heating in argon. This temperature shift is associated with oxidation effects during heating which can be minimized using the argon gas flushing technique. Nevertheless, only if actually no free oxygen is present during the heating experiment, oxidation effects can be distinghuished from true magnetic decay behaviour. This is provided by the completely closed and oxygen free sample chamber of the MPMS.

The temperature dependence of magnetic remanence and magnetization of natural greigite-rich samples of a recent (Gulf of Mexico; Fu et al. subm.) as well as several paleo high-sedimentation regimes (Caparthian Fordeep; Vasiliev et al. 2007; Valle Ricca section, Rome, Florindo and Sagnotti 1995, van Dongen et al. 2007) were examined to test the sensitivity of our method. It is shown that in these specific samples, two distinct temperature ranges for the magnetic decay of greigite can be discriminated. We attribute those features to the presence of two different greigite populations: a very fine biogenic SD and a (slightly) coarser chemogenic SD phase, for which Vasiliev et al. (in rev.) provided clear evidence in their samples using transmission electron microscopy. The presented high-temperature MPMS method constitutes a well-defined and highly sensitive magnetic tool to unambigously detect and distinghish between those two magnetically similar SD greigite components of different origin.

References:

Dekkers, M.J., Passier, H.F. and Schoonen, M.A.A, 2000. Magnetic properties of hydrothermally synthesized greigite (Fe_3S_4) — II. High- and low-temperature characteristics, Geophys. J. Int., 141, 809–819.

Florindo, F. and Sagnotti, L., 1995, Palaeomagnetism and rock magnetism in the upper Pliocene Valle Ricca (Rome, Italy) section, Geophys. J; Int., 123, 340-354.

Fu, Y., von Dobeneck, T., Franke, C., Heslop, D., Kasten, S. Rock magnetic identification and geochemical process models of greigite formation in Quaternary marine sediments from the Gulf of Mexico (IODP Hole U1319A), Earth Planet. Sci: Lett., subm.

van Dongen, B.E., Roberts, A.P., Schouten, S., Jiang, W.T., Florindo, F., and Pancost, R.D., 2007. Formation of iron sulfide nodules during anaerobic oxidation of methane, Geochim. Cosmochim. Acta, 71, 5155-5167.
Vasiliev, I., Dekkers, M.J., Krijgsman, W., Franke, C., Langereis, C.G. and Mullender, T.A.T., 2007. Early diagenetic greigite as a recorder of the palaeomagnetic signal in Miocene–Pliocene sedimentary rocks of the Carpathian foredeep (Romania), Geophys. J. Int., 171, 613-629.
Vasiliev, I., Franke, C., Meeldijk, J.D., Dekkers, M.J., Langereis, C.G. and Krijgsman, W. Fossil greigite magnetosomes carrying a primary remanent magnetisation, Science, in rev.

Magnetosome and magnetotaxis mysteries

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Magnetotactic bacteria make single-magnetic-domain crystals of magnetite and greigite in intracellular structures called magnetosomes. The magnetosome crystals are arranged in linear chains that make the cells into self-propelled, permanent, biomagnets that migrate along geomagnetic field lines. Although much has been learned about these bacteria, only in the last few years has it been possible to address the question of how they control formation and arrangement of the magnetosomes in the cell. I will review some of the recent results and highlight questions about magnetosomes and magnetotaxis that remain unresolved.

Surface-interior variation of paleointensity results from submarine pillow basalts

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Submarine pillow basalts are supposed to be one of principal contributors to marine magnetic anomalies and the magnetic properties have been thoroughly studied. Recently the glassy rinds are routinely utilized as ideal materials for Thellier paleointensity experiments. From the glassy surface to the crystalline interior magnetic properties rapidly change, and the variations have been explained by grain-size dependent alteration or variable iron/titanium content of titanomagnetite.

A pillow basalt block that was collected by a submersible SHINKAI 6500 near the Southwest Indian Ridge was examined for the surface-interior variation of magnetic properties and Thellier paleointensity results. The erupted age is estimated less than a few tens of thousand years. An about 10 cm long column was extracted and sliced into 2 or 2.5 mm thick sections parallel to the surface. Thermomagnetic analyses indicated that the glassy rind is virtually barren of magnetic materials but the inside crystalline portion contains titanomaghemite. Hysteresis properties, obtained by applying a maximum field of 5 T, showed that the saturation magnetization steadily increases from the surface to the interior, Mr/Ms have the high peak values near the glass and crystalline boundary but still lower than 0.5, and coercivity values reach almost 100 mT near the boundary. Natural remanent magnetization (NRM) intensity rapidly increases around the boundary by several orders of magnitude.

Thellier double-heating paleointensity experiments with partial thermoremanent magnetization (pTRM) checks were done by heating and cooling 2 or 2.5 mm thick sections in Ar atmosphere. The glassy rind sample showed ill behaviors during the Thellier experiment primarily due to the low NRM intensity. Only two sections of 2 to 6 mm from the surface showed linear trends on the Arai diagrams and pass the pTRM tests, giving expected paleointensity values from the IGRF. Deeper than 6 mm from the surface, all the sections exhibit downward convex curves on the Arai diagrams suggesting that multidomain effects predominate the behaviors. However, if connected the room and highest temperature points on the Arai diagrams, these sections give similar paleointensity values as the near-surface sections.

Submarine pillow basalts can provide reliable Thellier paleointensity values not only from the glass rind but also from the cryptocrystalline portion near the surface. However, the thickness is only a few millimeters because the magnetic properties quite rapidly change with increasing distance from the surface. Such a thin cryptocrystalline portion should be generally missed or mixed up when using a standard sized specimen, but NRM intensities are higher by several orders of magnitude than the glass rind. Although the inside crystalline portion of pillow basalts is not suitable for Thellier paleointensity experiments, it gives rise to marine magnetic anomalies reflecting paleointensity variations in some degree.

On a possible role for precession as a power source for the geodynamo.

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The possibility that precession might play a role in driving the geodynamo was proposed by Malkus (1968). However, papers by Rochester et al. (1975) and Loper (1975) argued strongly against any role for precession. Since that time Vanyo (1991) has been among the few advocates for precession as a spower source for the dynamo. Several authors have suggested that there is expression of obliquity period in the paleomagnetic record, implying a role for precession in driving the dynamo. However, even that observation remains controversial. The power at 41,000 years is only weak. Yet, it does appear, as will be discussed, that (1) excursions and major intensity lows are associated with minima in the obliquity signal during the last 800 kyrs (2) the distribution of the length of events less than 100,000 years peaks at 30 – 40,000 years. i.e. a little shorter than the obliquity cycle (3) reversals preferentially occur when the amplitude of the obliquity signal is low in the past 5 Myrs. (4) reversals occur preferentially within the obliquity cycle close to the point of inflection in the decrease from the maximum value (Fuller, 2006). Since that time some confirmation has emerged for observations 1 and 4. These observations have been rexamined with special emphasis upon the most recent and best dated reversals and excursions. The results are consistent with the earlier suggestion that there is expression of the 41,000yr obliquity cycle in the paleomagnetic record. Thus precession may play a role in driving the dynamo. However, possible relative motion between core and mantle due to changes in surface mass distribution, which are caused by climatic changes, may also occur, as has been suggested earlier.

The remanent magnetization of meteorites: Where do we stand now?

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The study of the remanent magnetization and magnetic properties of extraterrestrial materials aims to a better understanding of solar system evolution (characterization of primordial magnetic fields in the protoplanetary nebula) and of planetary evolution (knowledge of past magnetic fields and of the formation and evolution mechanisms of solid bodies in the Solar system). Despite decades of research in this field, today there is no clear answer to questions as simple as:

- why are chondrites magnetized?
- what is the origin of the heterogeneous orientation of the magnetization in most meteorites, down to at least the mm scale?

After a short review of the current knowledge, we will focus on the numerous phenomena that complicate the interpretation of the remanent magnetization of chondrites: metamorphism, hypervelocity impacts, terrestrial weathering, peculiar magnetic minerals, relaxation of ~4.5 Ga year old magnetizations... Can the original magnetization of chondrites (if it ever existed) survive until today? Can it be interpreted safely?

We will try and show that the answer is yes, at least for a limited number of meteorites. Thanks to the recent reflux of interest in extraterrestrial magnetism, and in particular the use of magnetic microscopy, significant progresses in this field are expected in a near future.

Systematic enhancement of titanomagnetite magnetization under pressure

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A poorly understood facet of magnetism concerns its response to the imposition of very high pressures. Here we show that pressure systematically enhances the magnetic properties of titaniferous oxides (titanomagnetite), which are the principal carriers of magnetic remanence in nature. For example, at 4 GPa, saturation remanent magnetization intensities increase by a factor of 2, 3, 13 and 21 for titanomagnetite with 0, 20, 40 and 60% titanium in the structure, respectively. Magnetic coercivity also dramatically rises with pressure for high Ti species. The magnetization intensities and coercivities remain permanently elevated after pressure release. Pressure thus makes multi-domain titanomagnetite more single domain-like, which can explain deeply rooted magnetic anomalies on Earth and other planets.

Iron oxyhydroxides unusual magnetic behaviors

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Iron oxyhydroxides such as goethite (alpha-FeOOH), ferrihydrite ($Fe_5HO_8 \cdot 4H_2O$), or lepidocrocite (gamma-FeOOH) constitute a group of minerals playing an important role in the bio-geo-chemical cylce of iron. The formation, growth, and alteration of these minerals impact diverse fields of research including paleoclimate, paleomagnetism, and heavy-metals mobility in the environment. Understanding the environmental controls on iron oxyhydroxides growth and alteration is thus critical. The high-sensitivity of magnetic measurements to iron oxides and oxyhydroxides make them a powerful analytical tool, which can be further enhanced when combined with other techniques such as x-ray diffraction, Mössbauer spectroscopy, high-resolution transmission electron microscopy and synchrotron radiation based techniques such as EXAFS (extended x-ray absorption fine structure) or XMCD (x-ray magnetic circular dichroism).

Recent studies have shown that essential information can be obtained through the investigation of synthetic nanoparticles made under controlled chemical and thermodynamic conditions. Such nanoparticles may subsequently form larger particles through oriented-aggregation, or be reduced to more magnetic phases. In particular, chemical interactions between iron oxyhydroxides and micro-organisms are of great interest in environmental magnetism and paleomagnetism, as they have implications for an accurate data interpretation.

Iron oxyhydroxides can be described as antiferromagnets with a small ferromagnetic-like moment. For example, goethite is characterized by sublattice magnetizations lying along the crystallographic c-axis, which should yield zero remanence. Its unexpected weak ferromagnetism may thus result from an unbalanced number of atomic moments. This anomalous behavior is significantly enhanced at low temperature (2-300 K) in superparamagnetic nanogoethite particles, which may result from a finite size effect (odd number of atomic planes), a larger surface to volume ratio (surface defects), or a slight change in the atomic structure. A similar particle-size dependent magnetic behavior also exists in ferrihydrite.

At the Cargèse meeting, recent data obtained on iron oxyhydroxides will be presented, with a special focus on small particles and nanoparticles of goethite, ferrihydrite and lepidocrocite. Puzzling magnetic results obtained at low temperature and in high magnetic induction (up to 14T) point to complex magnetic behaviors in goethite and lepidocrocite. In particular, the possible presence of nanoclusters of highly-magnetic material either within lepidocrocite crystals or as interacting co-precipitates will be evocated. Such nanoclusters may (or may not) serve as seeds for the growth of more magnetic iron oxides during lepidocrocite bio-reduction.

Magnetization distribution in meteorites and terrestrial rocks using a new scanning GMR magnetic microscope

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We have recently developed a new scanning magnetic microscope to image surface magnetic fields of room temperature polished samples. This microscope uses an array of Giant Magneto Resistance (GMR) sensors that are sensitive to one horizontal component of the magnetic field. The size of each sensing element is 5µmx50µm. The field equivalent noise of the sensors is about $1\,nT/\sqrt{Hz}$ with a sensing current of 1mA. The spatial resolution of the system is related to the sample-to-sensor distance that can be as low as 50 µm. This room-temperature small-sized magnetic microscope allow us to detect and quantify small-scale and weak magnetic field patterns. We retrieve the magnetization distribution in both synthetic materials and natural extraterrestrial and terrestrial rocks by inverting the magnetic field data provided by the scanning GMR magnetic microscope.

Imaging magnetic microstructures in the transmission electron microscope

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In this mini course I will provide an overview of the techniques available for studying magnetic materials in the transmission electron microscope (TEM), including both Lorentz microscopy and electron holography. The talk will discuss some of the practical aspects of magnetic imaging in the TEM, from sample preparation to a step-by-step introduction to processing electron holograms, as well as a discussion of methods one can use to simulate and understand what is being observed, and the advantages and limitations of the techniques in comparison to other methods. The talk will be illustrated with examples including the interaction between magnetic domain walls and ferroelastic twin walls below the Verwey transition in magnetite, the interaction between magnetic domain walls and antiphase boundaries in ilmenite-hematite, the magnetic properties of natural and genetically modified magnetotactic bacteria, the effect of exsolution microstructures on the magnetite properties of titanomagnetite, and the single-domain to vortex state transition size in Fe spheres.

Assessing the affect of possible CRM contamination on palaeointensities from a rapidly extruded sequence of lava flows

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The premise behind absolute palaeointensity determinations is that the natural remanent magnetisation (NRM) is a thermal remanent magnetisation (TRM) acquired on cooling. If however, the NRM is contaminated by some form of chemical or thermochemical remanence (CRM and TCRM) then the palaeointensity estimate may not be reliable. 89 samples (kindly supplied by Prof. Zhu Palaeomagnetism and Geochronology Laboratory (SKL-LE), Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China) which came from 27 rapidly extruded lavas underwent microwave palaeointensity analysis with 77 samples giving seemingly reliable results. Comprehensive rock magnetic and SEM investigations were also carried out and there is evidence to suggest that the samples have experienced alteration and that maghaemite is present to varying degrees. Attempts to correlate the palaeointensity results with numerous rock magnetic parameters failed to find any significant relationship. It is therefore suggested that the rock magnetic parameters are not characteristic of the remanence carriers or that the palaeointensity results are reflecting real variations in the geomagnetic field. There is correlation (though not perfect) between demagnetisation and Curie temperature leading to the conclusion that real geomagnetic variations are seen even if the absolute palaeointensity estimate may be biased.

Magnetic anisotropy in the basal plane of hematite

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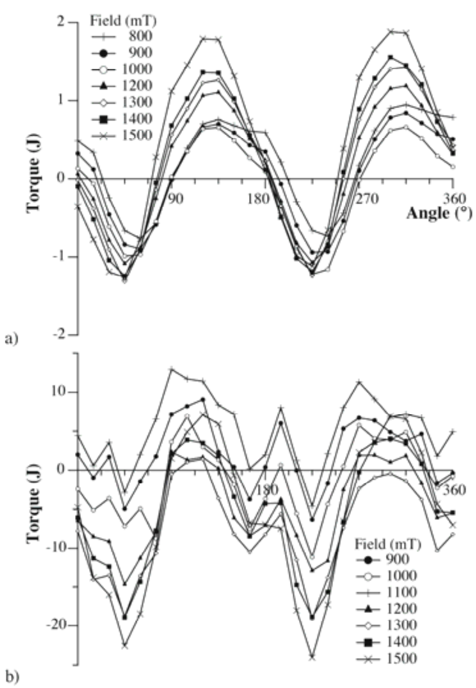
Forty-five years ago a paper by S.K. Banerjee [1] appeared with the title "An attempt to observe basal plane anisotropy of hematite". He measured four crystals from Elba, using a high-field torque magnetometer, and found that the torque signal was dominated by a uniaxial anisotropy with a weaker biaxial and triaxial component. He reasoned that this uniaxial signal arose from crystalline defects. In the following years there were a series of studies examining the anisotropy in the basal plane of hematite [2-5]. The general conclusion from these studies was that the triaxial anisotropy in the basal plane arises from twinning and lattice stress.

We have investigated the magnetic anisotropy for a series of hematite single crystals from Elba and other locations on a high-field torsion magnetometer. For all of the crystals the anisotropy within the basal plane is approximately two orders of magnitude smaller than normal to this plane. Most of the crystals are dominated by a uniaxial anisotropy within the basal plane (Fig. 1a, b). The torque signal in the basal plane increases when measured at 77 K, and higher-order coefficients become significant (Fig. 1c). These preliminary results suggest that cooling through the Morin transition leads to an additional stress within the lattice.



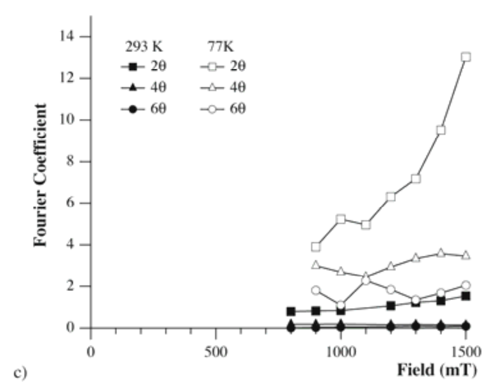


Figure 1. Example of the torque signal in the basal plane of a single crystal of hematite; a) toque curves at 293K; b) toque curves at 77K; and c) Fourier coefficients at 293 and 77 K.

References: [1] S. K. Banerjee, Phil. Mag. **8,** 2119–2120 (1963). [2] P. J. Flanders and J. P. Remeika, Phil. Mag. **10,** 1271-1288 (1965). [3] P. Flanders and W. J. Schuele, Phil. Mag. **9,** 485-490 (1964). [4] H. Porath and C. B. Raleigh, J. Appl. Phys. **38,** 2401-2402 (1967). [5] H. Porath and F. H. Chamalaun, Pure Appl. Geophys. **64,** 81-88 (1966).

Geomagnetic and Paleomagnetic Evidence for Magnetic Source Separation in the Outer Core: Introduction of the Shallow-Core Generated *(SCOR)* Field

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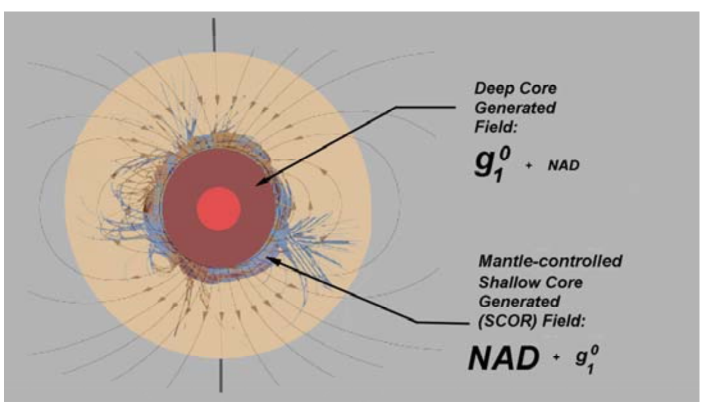
It has long been known that the dipole component of the geomagnetic field is unique, being anomalously strong both at Earth's surface as well as at the core-mantle boundary (CMB). It has also been proposed that the dipole is generated at greater depths within the core fluid than are observed higher order, non-dipole field components, being more capable of reaching and emerging from the CMB. However, since the power associated with the equatorial dipole is consistent with the white-to-pink spectra found for the non-dipole field terms, the axial dipole term stands alone having unique characteristics.

We contend further that the axial dipole component is quasi-independent of the remainder of the field (the so-called non-axial dipole field, or NAD-field), an assertion deduced from (1) observations of NAD-field structure over the past 400 years, and (2) a correspondence with paleomagnetic data associated with recordings of transitional fields when the axial dipole term may have been virtually absent. Specifically, clusters of transitional virtual geomagnetic poles (VGPs) dating back to the mid-Cenozoic are often observed to be tied to NAD-field structure, indicating a near-invariant control for on order of 10^7 yr by the lowermost mantle over the pattern of magnetic flux emerging from the core.

These findings suggest a need to consider the spatial aspects of field structure and generation in a new way, requiring the replacement of mathematically-based formulations (e.g. dipole—non-dipole and axial dipole—NAD) with one having a more physical basis. We argue that the geomagnetic field may be spatially separated with depth within the core and propose the term *SCOR*-field to denote that part of the field developed in the shallow core, controlled by the lower mantle, and observable when the deep-core-generated axial dipole is virtually destroyed. However, the SCOR-field likely contributes a small fraction of g_1^0 to any spherical harmonic analysis while there is good reason to assume the deeper core-generated field contains a small fraction of certain NAD-field components. The question we now pose is: At what point during a polarity transition does the SCOR-field reverse?



Paleomagnetism, rock magnetism, and magnetic fabrics of sediment cores from the Fraser River Delta, offshore Vancouver, BC (Canada)

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We will present the results of a comprehensive study of several 10m long sediment cores, collected as part of the VENUS project, from the Fraser River Delta, offshore Vancouver, BC (Canada). The Fraser Delta is an active Holocene feature prograding in to the Straight of Georgia,B.C. The delta is characterized as a deep water (locally >200m), mixed tidal-fluvial deltaic system that is subject to a 5 m spring tidal range and modest wave intensity conditions (Hart et al., 1998). The delta is the main depositional feature of the $2.5x10^5$ km^2 Fraser Basin, which is the dominated by mountainous terrain of the British Columbia Coast Range (Hart et al., 1998). Modern sedimentation rates, calculated by detection of atmospheric fallout of ^{137}Cesium have been shown to vary widely along the Fraser river foreslope as a result of oceanographic circulation and human influence. Near the mouth of the main channel rates were found to be in excess of 13 cm yr^{-1}. At distance greater than 4 km distal to the channel mouth rates drop to less than 3 cm yr^{-1}. South of the channel, in the region where cores for this study were collected rates exceed 10 cm yr^{-1} along the delta front and decrease to less than 3 cm yr^{-1} at the base of the delta slope (Hart et al., 1998). These rapid deposition rates, and the nature of this prograding delta, combine to elevate the potential for significant local hazards due to slope failure events of this delta system.

Our study included three lines of investigation. First, magnetic fabrics (AMS and ARM) were determined in order to assess possible slope creep or crypto-slump features. Second, detailed paleomagnetic measurements were made, to determine if these data could be used to better date the sediments using PSV comparisons, and to re-orient the cores if possible. Third, detailed rock-magnetic and chemistry work in order to better understand the magnetic mineralogy and carriers of the magnetic fabric and paleomagnetic signals.

The AMS results were complicated by the presence of either inverse, or “mixed” fabrics, which was verified by the ARM anisotropy studies, and the rock-magnetic studies. Interpretation of these results in terms of slope-related processes is underway.

The paleomagnetic results indicate that the sediments record a well-defined magnetization. The inclinations are uniformly steep, as expected for the site location. Utilization of relative paleointensity techniques (with normalization made by either partial ARM, or by the Tauxe et al 1995 pseudo-Thellier technique) indicate that relative paleointensity increases in a regular fashion down-core. We have tentatively correlated both Inclination and relative paleointensities in these cores with records of magnetic field from the nearby Victoria, BC geomagnetic observatory. If these tentative correlations are correct, these sediments are providing a nice record of both direction and relative intensity of the geomagnetic field over the past ~50 years.

Mineral magnetic properties of Antarctic soils from Livingston Island (South Schetlands)

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Processes and mechanisms of soil formation in an extreme environment are of primary importance for better understanding the role of different factors in determining the mineralogy of weathering products in the presence of organic matter. The aim of the present study is to obtain comprehensive information about the main magnetic phases and their origin in the soils from Livingston Island. Twenty three soil samples were gathered along the coast line near the Bulgarian and Spanish Antarctic Bases. Soils are developed on the sediments from Myers Bluff formation and the main vegetation is represented by mosses. Magnetic measurements including low field susceptibility, frequency dependent susceptibility, laboratory imparted anhysteretic and isothermal remanences, hysteresis measurements, thermomagnetic analysis of susceptibility indicate the presence of two magnetic phases with contrasting coercivities and unblocking temperatures of 260^{o}C and 570^{o}C. The "in situ" formation of superparamagnetic grains is evidenced by the percent frequency dependent susceptibilities of up to 6%. Elemental composition of soil samples and rocks from parent material are characterized by XRF analysis. The presence of amorphous short range ordered compounds is estimated through oxalate extraction procedure. The ratio Feo/Fetotal varies between 0.06 and 0.11. pH measurements indicate mostly acid soil reaction.

This research is carried out in the frames of SCOPES project IB7320-110723 "Environmental Applications of Soil Magnetism for Sustainable Land Use" and the Bulgarian National Antarctic Program.

An experimental study of magnetic property and water chemistry changes with temperature in natural marine sediments

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Magnetic minerals in marine sediments are dissolved and/or formed during early diagenesis, thereby masking the original magnetic information on paleomagnetism and paleoenvironment. It is thus essential to clarify early diagenetic effects on magnetic properties of marine sediments. Early diagenesis is controlled by various chemical factors during sedimentation and postdepositional processes. For example, flux of organic matter, temperature, and diffusion of oxygen from oxic bottom water into sediments. Previous studies reported that the oxygen diffusion and organic matter affect magnetic properties of surface sediments (Kawamura et al., 2007; 2008). Temperature of sediments increases with burial depth, but its effect on magnetic properties is not fully understood. In order to clarify the effect of temperature on magnetic mineral alteration, experiments with controlled temperature were performed in this study. For the experiments, the sediment cores up to 28.5 cm in length were collected using a multiple corer at 51 16.00 N, 149 12.50 E, water depth 1250 m, in the central Okhotsk Sea during the R/V YOKOSUKA YK07-12 cruise in 2007. The sediments are composed of diatom ooze with silty clay. The color of the topmost sediments (0-3 cm) is brownish black, and the color changes downward from olive brown (3-15 cm) to dark olive (15-28.5 cm). The data of pH, Eh, and dissolved oxygen (DO) in bottom and pore water were obtained from one core onboard within a few hours after the core recovery. The value of pH gradually increases, and Eh decreases with depth. DO values rapidly decrease and reach the minimum at 12 cm. These results suggest that the sediments are under an anoxic condition with increasing burial depth. Other cores were immediately sealed up onboard. One core was frozen under -20°C for six months, and was then thawed out at 5°C. Other cores from the same location were put at 8°C and 18-22°C, respectively. In order to investigate water just above the sediments, pH and Eh were measured. Results show that the value of pH decreases, and Eh increases with temperature. To investigate magnetic mineral alteration with chemical changes of water, low-temperature magnetometry, the measurements of remanent coercivity (Hcr), coercivity (Hc), remanent magnetization (Ms), and saturation magnetization (Mr) were performed on the topmost sediments. Results of the low-temperature magnetometry show the occurrence of the Veywey transition at 110 K. However, the transition is not clear on the samples taken from the cores kept at 8°C and 18-22°C. The Hcr/Hc and Mr/Ms ratios of the sediments at 5°C and 8°C are not significantly different. However, the Mr/Ms ratio of the sediments at 18-22°C is higher than those of the sediments at 5°C and 8°C, suggesting that magnetic grain size becomes finer. This suggests that magnetic grain size is affected by changes in the chemistry of water.

Field dependent decrease of magnetic susceptibility in superparamagnetic grains

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Magnetic susceptibility of a given material characterizes how the magnetic material reacts to the change in its magnetic environment. When magnetic grains get small enough so they become superparamagnetic, the magnetic susceptibility becomes strong function of both the frequency and amplitude of the applied magnetic field. In order to study this effect magnetic material must be available that contains well distributed non interacting grains with narrow grain size distribution. Such material has been discovered in Yucca mountain area (Nevada). A unit in the Tiva Canyon Tuff that was quickly quenched and reheated, allowing formation of multiple grains with uniform grain size distribution.

Interestingly we observed that this material's susceptibility decreases with increasing amplitude of the field. Such observation was only detectable for larger frequencies (>2 kHz).

Synthesized nano-magnetic particles were made such that samples of basaltic composition were made by first quick quenching (generation of multiple nucleation sites) followed by reheating (precipitation of actual magnetic carriers). This material showed similar susceptibility decrease with alternating field amplitude.

We interpret these measurements as following. Due to large frequency the individual small grains induce electrical currents along their surfaces whose magnetic field opposes the applied field and therefore with larger ambient field amplitude the grains do not experience the applied field in its full extent. This behavior can be utilized by relating the susceptibility decrease to the conductivity of the silicate material in which the oxide grain is residing.

An AC susceptibility measurement system for detecting the frequency dependence over a wide range of frequencies

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The aim of this study is to devise an unique equipment that enables susceptibility measurements over a broad frequency spectrum ranging from 10 to 10^5 kHz, which could provide new experimental data for better understanding rock magnetic characteristics, including grain size distribution near the SP-SD boundary, the effect of grain interactions and any other rock magnetic information applicable to environmental magnetism. The new measurement system consists of a primary coil for applying an excitation field to a small, millimeter-size, sample, and a set of pickup coils linked in series and wound oppositely for compensation. The number of turns for the primary coil is 5,000 and that for the respective pickup coil is 2,000. All of them are made of a copper wire, 800 micrometer in diameter, and wound around a quartz-glass tube of 8 mm in diameter. The excitation field is produced by a commercial function generator with two independent outputs, capable of generating sinusoidal current with frequencies of 0 to 10 MHz. To achieve null compensation of the pickup coil output, a mutual inductor coil is linked in series with the pickup coil system, to which the function generator supplies, through the second output, a small current that can be adjusted in phase and magnitude to compensate an unbalanced output prior to loading a sample. The resulting signal output voltage is fed, through a differential amplifier, to a digital rock-in amplifier that is connected to the primary coil as a reference signal input. The AC frequency spans from 10 to 200 kHz depending on the limitation of the lock-in amplifier, but can be changed continuously over the entire range. The outputs from the lock-in amplifier, in both magnitude and phase, are fed to a PC to draw frequency dependence spectrum of both real and imaginary parts of AC susceptibility. System calibration has been made using a synthetic, paramagnetic Gd_2O_3 powder, and several natural paramagnetic samples as Yucca Mountain tuff that has ever been used for inter-laboratory calibrations.

Hot-spot related crustal magnetization and magnetic petrology of basalts from scientific drillings

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The rock magnetic behavior and Fe-Ti oxide petrology of subaerial and submarine basalts have been extensively studied over the last decades because of their importance in understanding Earth's magnetic anomalies. Combined rock magnetic and magneto-mineralogic investigations on different basalt lithologies from scientific drillings at Hawaii and Iceland have shown that multiple processes related to the geodynamic setting, the emplacement and cooling history and the alteration history affect the texture and composition of the originally homogeneous titanomagnetite. Along with these modifications significant variation in rock magnetic properties like magnetic susceptibility, Curie temperature, coercivity force or natural remanent magnetization (NRM) occurs. Hawaiian basalts from the scientific drillings HSDP-2, SOH-1 and SOH-4 have e.g. NRM intensities between <1 and 13 A/m, which is distinctly lower than those measured on several localities on Iceland (Fig. 1). Surface samples from fissure eruptions of the Reykjanes peninsula show 4 – 32 A/m and drill cores from the Stardalur central volcano (subaerial basaltic lava flows and dykes) even show very high values up to 120 A/m. Although the main controlling factors for these high NRM values seem to be the primary magma composition and cooling history, secondary processes like high-temperature decomposition reactions and hydrothermal alteration likely contribute. On the other side, magnetization in fissure-related subaerial lavas from drill cores in active geothermal fields (Krafla) is distinctly reduced (below 5 A/m) while the magnetic susceptibility increases (up to 140 x 10^{-3} SI). Both of these two effects respond to the alteration of titanomagnetite to cation-deficient magnetite and furthermore to titanomaghemite. In addition, secondary magnetite can be precipitated from hydrothermal fluids increasing NRM or the Fe-Ti oxides can be transformed to dia- and paramagnetic minerals and the NRM is destroyed. Modifications of rock magnetic properties related to magnetic mineralogy changes will be discussed for the basalts with different strong magnetization using data from TEM and low-temperature magnetic measurements.

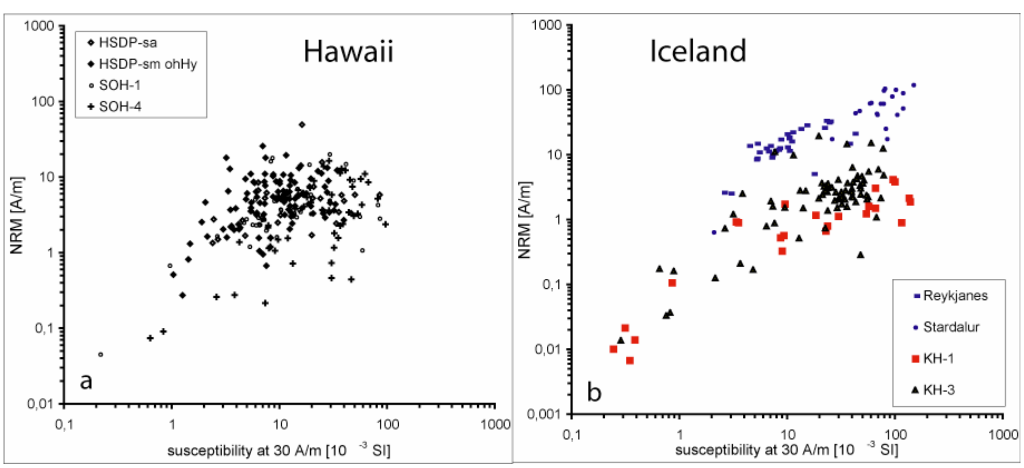

Figure. 1: NRM versus magnetic susceptibility for basalts of different drill cores and localities from Hawaii (a) and Iceland (b).

From magnetic order to magnetic disorder and the frustrated world they embrace

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Low temperature magnetic measurements (below 300 K) are increasingly being sought in geophysical studies to characterize the magnetic mineral assemblages because they present numerous advantages such as the elimination of experimentally induced chemical alteration. For the hematite-ilmenite solid solution series ($y FeTiO_3 \cdot (1-y) \cdot Fe_2O_3$), where one end-member magetically disorders at ~950 K (hematite) and the other at ~60 K (ilmenite), access to low temperatures is a neccessity for investigating the magnetic behaviour of compositions with *y* values greater than ~0.75.

Across the solid solution series the crystal structure has a rhombohedral symmetry. However, ilmenite's space group has a lower symmetry than that of hematite, owing to the presence of two different ions (Fe^{2+} and Ti^{4+}) on the cationic sites. As titanium enters hematite's crystal structure two Fe^{3+} atoms are replaced by one Fe^{2+} and one Ti^{4+} cation. Ferrous iron and titanium atoms either order on alternate sublattices or enter randomly if quenched from a temperature above the cation order–disorder phase transition (T_{OD}). The distribution of ferrous iron and titanium atoms coupled to the concentration of ferric iron atoms dictate the strength and sign of the superexchange interactions which in turn fundamentally controls the magnetic behaviour.

For titanium rich compositions of the hematite-ilmenite solid solution series, the cation distribution generates varied magnetically ordered states with antiferromagnetism, ferrimagnetism, superamagnetism and spin glass states being observed over a fairly small compositional range. For example, the long range magnetic order in ilmenite ($y = 1$) is antiferromagnetic while for $y = 0.7$ long range magnetic order can be ferrimagnetic generating a saturation magnetization one third that of magnetite at room temperature. Moreover, across the temperature range of magnetic order a given composition displays at a minimum two different magnetic states and the coexistence of magnetic states is not excluded.

Certain magnetic properties such as large and narrow frequency dependent peaks in the out-of-phase component of AC magnetic susceptibility are observed in single phase ferrian ilmenite as well as other mineral systems. Most commonly this feature results from a distribution of blocking temperatures as particles go from a thermally unstable yet magnetically ordered state (superparamagnetism) to a thermally stable state at lower temperatures. Similar behaviour is also characteristic of spin glass phase transition and recently it has been suggested that a similar feature in titanomagnetite may be coincident with the cessation of electron hopping between ferrous and ferric iron atoms as temperature decreases.

Through static and dynamics magnetic measurements the equilibrium and non-equilibrium magnetic properties of ferrian ilmenites with *y*-values > 0.65 are being investigated. Here, the volume ratio of ordered versus disordered cation clusters and the size of the clusters play a key role, if not decisive, over what magnetic state(s) will be observed at a given temperature.

Magnetic properties of recent sediments from Minnesota lakes: Does organic matter control the abundance of biogenic magnetite?

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The magnetic properties of surface sediments from a dozen Minnesota lakes have been analyzed in order to determine trends in composition and grain size of the magnetic sedimentary fraction across lake basins. The lakes, chosen along an east-west moisture gradient and a north-south temperature gradient, were sampled along perpendicular transects at every meter of bathymetric change. Magnetic susceptibility (MS), IRM, ARM, and percent organic matter (OM) were measured on all samples (~450). Representative samples were chosen from shoreline, littoral, and profundal settings and subjected to more detailed magnetic analyses. We measured hysteresis loops, dependence of MS on frequency and temperature, low temperature remanence thermal demagnetization, room temperature remanence behavior in cooling-warming cycles, and coercivity spectra from ARM demagnetization curves. Spatial trends in magnetic particle concentration and grain size are consistent for all lakes. The shoreline samples have low magnetic concentrations and large grain size (ARM/IRM<0.03). The littoral zone is characterized by the highest ARM/IRM ratios (0.15-0.28) indicating fine grain size, while profundal samples have slightly lower ARM/IRM values, depending on the magnitude of summer water-column stratification, and highest concentration values. Shoreline samples contain almost exclusively multi-domain (MD) magnetite grains, while littoral and profundal samples have a mix of MD and single-domain (SD) grains. We observe a linear relationship between OM and ARM/IRM, showing a dependence of magnetic grain size on organic carbon concentration. The deconvolution of bulk coercivity of high organic samples obtained from the ARM demagnetization curves yields three magnetic components. The individual coercitvities of these components are 10-20 mT, 25-35 mT, and 60-75 mT respectively. The two components with higher coercivities are identified as biogenic and carry 50-75% of the total magnetization of the sample. The positive correlation between biogenic magnetite and organic carbon points out the role the latter has in the process of production and preservation of magnetosomes. Organic matter decomposition depletes the dissolved oxygen and leads to the establishment of temporary or permanent anoxic conditions in the sediment. If the consumption of oxygen is incomplete or if oxygen diffuses from the overlying water column (e.g. in the littoral zone, above the oxycline), magnetite has a better chance of being preserved. If anoxia is severe dissolution of magnetic grains will occur, with smaller particles being preferentially dissolved.

Geomagnetic field evolution during the Laschamp excursion

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Since the last geomagnetic reversal, 780,000 years ago, the Earth's magnetic field repeatedly dropped dramatically in intensity, often associated with large variations in local field direction, but without a global polarity flip. Structure and dynamics of these geomagnetic excursions, and especially the difference between excursions and polarity reversals, have remained elusive so far. For the best documented excursion, the Laschamp event at 41,000 years BP, we here have reconstructed the evolution of the global field morphology by Bayesian inversion of several high-resolution palaeomagnetic records. We obtain an excursion scenario in which inverse magnetic flux patches at the core-mantle boundary emerge near the equator, and then move poleward. Contrary to the situation during the last reversal, these flux patches do not cross the hydrodynamic boundary of the inner-core tangent cylinder. While the last geomagnetic reversal was heralded by a substantial increase of non-dipolar field components, prior to the Laschamp excursion both, dipolar and non-dipolar field decay at the same rate. This result suggests that the nature of an upcoming geomagnetic field instability can be predicted several hundred years in advance. Even though during the Laschamp excursion the dipolar field at the Earth's surface prevailed, the reconstructed dynamic non-dipolar components lead to considerable deviations among predicted records at different locations. The inverse model even explains why at some locations no directional change during the Laschamp excursion can be observed.

Quantifying lock-in effects associated with a post-depositional remanent magnetization in paleomagnetic records

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Paleomagnetic signals recorded by sediments have been altered to variable extents by remanence lock-in processes, which serve as a low-pass band filter. Lock-in processes cause: 1) filtering of high-frequency signals, and 2) downward displacement of sedimentary paleomagnetic records. Various lock-in density functions have been proposed to simulate and quantify the lock-in effects on paleomagnetic records. Input signals can be represented by a linear summation of different sine functions through Fourier series analysis. For general purposes, a sine function can be used as the general input signal. Therefore, analytical solutions can be obtained by directly integrating the convolution between the input and lock-in density functions (in this study, we used sine, linear and exponential lock-in density functions). Our analytical solutions show that a sine lock-in density function simply downward displace the input signal with different wavelength by a fixed value (*L*) of one quarter of the wavelength of the filter function. In contrast, *L* for the case of exponential and linear lock-in density functions systematically increases with increasing the wavelengths of both the input signal and the filter functions. This will cause a spatial distribution of *L* for the input signals and yield an asymmetrical pattern for the output. With these new understandings, the lock-in depth and *L* were further analyzed for the paleomagnetic inclinations crossing the Matuyama-Brunhes geomagnetic reversal recorded at Ocean Drilling Program sites 982 and 983. The lock-in zone and the corresponding *L* for these two sites are estimated to be about 15 cm and 5 cm, respectively, which indicates that the downward displacement of paleomagnetic records solely due to lock-in processes is rather small for these two sites. Our results provide a practical way to quantify effects of the lock-in processes, and therefore to significantly improve our understanding of the fidelity of paleomagnetic signals recorded by natural sediments.

Relating mineral-magnetic properties of glacier-fed lake sediments to catchment and post-depositional processes.

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Past climate variations may be reconstructed using sediment-records from pro-glacial lakes. Magnetic properties of sediments from such lakes are controlled by climate modulated glacial processes, bed-rock composition, catchment deposition/erosion and post-depositional alteration of magnetic minerals. We report on results from a glacierized catchment located in Arctic Norway (69°N), where a small temperate glacier have fed an adjacent lake for the last ~ 4000 years. Additional sedimentary input is derived from non-glaciated parts of the catchment including a delta, several talus cones and moraines. Today, seasonal discharge runs through both colluvial and glacigenic deposits before entering the lake. Samples were retrieved from downstream bedrock exposures, boulders, surface sediments dispersed throughout the glacierized catchment above and below the lake, as well as several cores raised from the lake. We have obtained physical grain size distributions (from 2mm to <38μ) and a range of bulk magnetic parameters assessing concentration, composition and 'grain size' of magnetic minerals.

Catchment material upstream of the lake consists of coarse sand while medium sand dominates the downstream surface material. The lake sediments are entirely composed of material smaller than 63 μm. Thermomagnetic analysis (Curie-curves) suggests that the bedrock is characterized by magnetite (T_c=580°C) often 'overprinted' with a dominant paramagnetic component. Some 50% of the bedrock samples contain pyrrhotite, but this mineral has neither been identified in any samples from the adjacent surface material nor in the lake-sediments. This either implies that catchment material has not been derived from the present-day bedrock-surface, or that pyrrhotite is rapidly weathered and decomposed into non-magnetic mineral phases when released from the bed-rock. Concentrations of magnetic minerals are significantly higher above the lake than below the lake, implying that the lake serves as a sink for the heavier magnetic minerals. Thermomagnetic analysis of the smallest grain size fractions (<38μ) from above and below the lake show more or less developed maghemite ⇒hematite inversions between 300-400°C. This maghemite inversion feature is even more developed in the top 10 cm and below 110 cm of the lake sediments. The absence of highly maghematized magnetite in the present surface material from above and below the lake suggests post-depositional oxidation within the lake, probably related to climate-driven processes (temperature, over-turning).

Synthesis and characterization of hematite-ilmenite multilayers: preliminary results

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The experimental investigation of "lamellar" magnetism in the hematite-ilmenite system so far has been limited to natural nanoscale exsolutions. To study systematically the effect of lamella thickness on the magnetic properties of the system, we have grown thin films of hematite with and without intercalated Ti-oxide monolayers on various substrates. The films were characterized in situ (X-ray diffraction, Auger spectroscopy) and ex situ (Raman spectroscopy, atomic- and magnetic force microscopy, magnetic bulk measurement techniques using MPMS and VSM).

It turns out that already a Ti-oxide monolayer in a hematite film dramatically changes the magnetic properties of hematite. Such a hematite - Ti-oxide - hematite sandwich is ten-times more magnetic compared to a pure hematite thin film, which cannot be explained by the properties of the individual phases and clearly shows that a new magnetic phase emerges in the contact layer. Importantly, the coercive field rises from 15 mT at room temperature to 88 mT at 10 K after field cooling. This coercivity enhancement, in combination with a small exchange bias of 3 mT, points to exchange coupling between ferrimagnetic and antiferromagnetic layer.

Applications of geomagnetic relative paleointensity studies to the dating of late Pleistocene sequences from peri-Antartic margins

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Records of relative paleointensity (RPI) of the earth magnetic field provide an original stratigraphic tool to solve chronological uncertainties in deep sea sedimentary records, which particularly valuable when they lack other bio- and chronostratigraphic constraints. In this context, we present the results of paleomagnetic investigations carried out on 12 gravity cores recovered in late Pleistocene sedimentary sequences from two different locations of the peri-Antarctic margins (western continental rise of the Antarctic Peninsula and the Wilkes Land basin offshore the East Antarctic craton). The aim was to obtain a high-resolution RPI chronology, to which refer the occurrence of geological and climatic events recorded in these sequences, and to provide the first records of the geomagnetic field variations during the late Pleistocene from the southern high latitudes. The RPI records obtained for each core were used to date and correlate the sedimentary sequences by comparison with the global reference RPI stack SINT-800. As the individual normalized RPI records were in mutual close agreement, they were merged in two regional RPI stacking curves, spanning the last 300 kyr and showing a low standard deviation. We discuss the problems and the achievements in addressing chronostratigraphic problems in the studied sequences and the procedure of stacking of the individual RPI records. The comparison of the regional RPI stacks with the global SINT-800 indicated that, whereas only some small scale features are uncorrelated, the long-term geomagnetic RPI features are very consistent in age and amplitude and can be globally correlated. This corroborates the valuable potential of RPI studies in fine-grained sequences as a long-range correlation tool. At the same time, the analysis of the ChRM inclination stacks shows that the paleomagnetic inclinations fluctuate around the expected value for such high latitude sites and maintain always a normal polarity, moreover several swings to shallow paleomagnetic inclinations occur and may be correlated to known global geomagnetic excursions, providing an additional support to the establishment of paleomagnetic high-resolution age models.

Environmental magnetism: Challenges and opportunities

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Centre for Environmental Magnetism & Palaeomagnetism
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Environmental magnetism has made rapid strides in the last 25 years, with significant progress achieved in our understanding of natural magnetic materials and the environmental information they encode. This enhanced understanding has been assisted by a host of new measurement and/or data analysis techniques, including, for example, magnetic extractions and electron microscopy, statistical unmixing of individual magnetic components in natural magnetic assemblages, off-axis electron holography, SQUID microscopy, and first-order reversal curves. Yet funding for many of our magnetic laboratories can be difficult to find and/or maintain, and competition with other types of environmentally-related research intense. How can we address and resolve the paradox of significant progress within the field but sometimes limited or even reduced levels of funding? Can we demonstrate increasingly valuable contributions to key climate and/or environmental questions, of such impact that other disciplines both recognize and seek out (and fund) research input from the magnetic community?

Mineral magnetism: Challenges and opportunities

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Subir Banerjee's contributions to mineral magnetism arise from both theoretical and experimental work. In addition, one of his great achievements in furthering our understanding of rock and mineral magnetism was the establishment of the IRM. After a visit to the IRM, one is well armed with detailed magnetic measurements, which can be used to entice collaborators in the wider world of science. Study of magnetic behavior of minerals is in a renaissance, partly due to technological advances allowing us to determine, image and map structures down to the nanometer and even atomic scale. Combining magnetic measurements with independent techniques, such as Mössbauer, neutron scattering, chemical mapping by electron microprobe and TEM, secondary electron mapping, and X-ray diffraction with synchrotron radiation, opens new opportunities to answer questions about magnetism. These have arisen partly because of programs giving access to specialized laboratories like the IRM, and because of the decrease in costs associated with computation time, needed to analyze and model data. For Monte Carlo simulations, micromagnetic modeling and density functional theory calculations, advances in computers in the last decade allow much desktop research previously limited to large computer facilities. Recent examples are shown of cross-disciplinary projects and how they contributed to understanding of mineral magnetism.

Current interest in mineral magnetism is not limited to academic pursuits. Rapid developments in nanotechnology present challenges in the study and application of fine-particle magnetism. Interest is also fuelled by exploration for natural resources, especially in areas where infrastructure is limited. Large mapping programs involving satellites, and worldwide cooperations, resulting in the recent release of the World Digital Magnetic Anomaly Map, have also rekindled interest in crustal magnetization on Earth, and other bodies. These programs offer new opportunities to study the magnetic behavior of crustal rocks, including studies addressing the effects pressure, temperature and fabric on magnetism.

Geomagnetic field inclination and paleointensity variations recorded by the late pleistocene reef sequence of Tahiti, contribution to the chronology of the deposits

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The scientific objectives of the IODP 310 Expedition were to reconstruct sea-level and paleoclimatic changes and the evolution of the Tahiti fossil reef system during the late Pleistocene and Holocene through a multidisciplinary approach. Rock magnetic and paleomagnetic approaches can contribute to achieve those objectives both by providing proxies of the terrigeneous fluxes to the reef and by establishing a magnetostratigraphic sequence based on the nature, direction and intensity of the magnetization. Completing radiometric dating (^{14}C or U series), series of magnetostratigraphic markers such as geomagnetic paleointensity lows and geomagnetic excursions -known to have occurred during the end of the Brunhes normal polarity epoch (780 ka BP) - provide robust chronological constraints. Along the 79m-thick pleistocene reef sequence collected in the Maraa area (S-W of the Tahiti-Nui Island), paleomagnetic specimens were drilled in all consolidated facies. Magnetic susceptibility, Natural Remanent Magnetization, Anhysteretic and Isothermal remanent magnetization measurements reveal that a mixture of single-domain, pseudo-single domain and multidomain grains of titano-magnetite is the main magnetic carrier. NRM inclination values compatible with the dipole field direction demonstrate that this material reliably recorded the geomagnetic paleosecular variation. Series of reversed inclinations and low relative paleointensities are however recorded in few stratigraphical subunits. These have been correlated with known geomagnetic excursions based on the availability of a few radiometric ages: part of the Blake event (115-120 kyr BP) is therefore identified between 103 and 119 m b.p.s.l, otherwise constrained by an age of ~134 ka BP at ~117 m. With subsidence rates ranging from 0.25 to 0.5 mm/yr, these reef deposits can be attributed to the marine isotope stage (MIS) transition 5/6 and to the MIS 5. Between 140 and 156 m b.p.s.l, the thick sequence including reef frameworks also records low relative paleointensities and directional instabilities including another geomagnetic excursion. This reef unit could have been deposited during a sea level highstand, possibly during stage 9, or earlier depending on different scenarios of subsidence rates. The relative paleointensity record also enables the identification of two other lowstand reef units, in agreement with sedimentologic data.

Explanation of saw-tooth behavior in acquisition of IRM

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Isothermal remanance acquisition in hematite has been observed to have a sawtooth pattern when a given IRM level is repeated in the opposite sense (e.g., Tauxe et al., 1990; see example in Figure). They attributed the behavior to meta-stable multidomain walls. We propose that the anisotropy can be explained by taking into account the magnetocrystalline anisotropy of single domain hematite. Hematite has a 6-fold anisotropy in the basal plane, the free energy per unit volume E being: $E=E_0 + K\sin^2(n/2\ \theta) - M_sB \sin \Psi \cos(\theta - \phi)$, where E_0 is an energy independent of the angle, K the anisotropy constant, n the number of easy directions, M_s the spontaneous magnetization, B the applied field, Ψ the angle between **B** and the c-axis, and θ and ϕ the angles between a reference easy axis and M_s and the in-plane component of **B** respectively (Dunlop 1971). Energy extrema are found by setting $dE/d\theta = 0$. At a critical value of the applied field magnetic moments of some grains will jump from one energy minimum direction to another which is nearer to the applied field. With increasing field the number of grains making such a transition will increase, which increases the acquired remanence. After the initial application of a field in one direction, the moments are not random and have preferred directions. If the field direction is then reversed without a change in the intensity then the assemblage has a higher coercivity because of the preferred alignment of the moments in the opposite direction. This explains the decrease in the net remanence (see point labeled "a" in the Figure). If the applied field is subsequently increased in the opposite direction then the moments will be realigned again (increasing the field values align successively more moments), and we see a net increase in remanance (see "b" in the Figure). Although the numerical modeling deals exclusively with minerals having anisotropy restricted to a single plane (e.g., magnetocrystalline in hematite), it can be extended to identify non-uniaxial or non-single domain behaviour in magnetite. For instance changing the model parameter n, ie number of easy direction in a mineral to 2 (uniaxial) we find that the sawtooth disappears. This could thus be a useful test for single domain magnetites which are mostly dominated with a uniaxial shape anisotropy. Our experiments have so far not yielded any sample which is devoid of the sawtooth. This can either suggest the rarity of such an assemblage or other complicating factors like magnetic interactions.

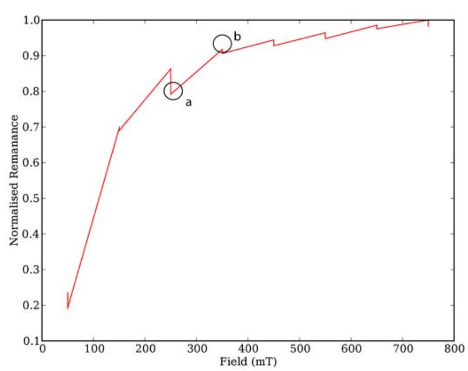

Figure 1: Sample carrying detrital single domain hematite subjected to increasing field strengths ranging from 150 mT to 750 mT. The field direction was reversed for each field strength.

References:

Dunlop D. J. (1971), Magnetic properties of fine-particle hematite, *Ann. Geophys.*, *27*, 269–293.

Tauxe L., Constable C., Stokking L. (1990) Origin of characteristic remanence in Siwalik red beds. J. Geophys. Res. 95, 4391-4404,1990.

Fractal Time-Temperature relations in magnetite nanoparticles

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Neel's thermal activation theory of magnetic relaxation is a fundamental basis of rock and paleomagnetism. Following Pullaiah et al. (1975), we can derive a time-temperature nomogram for single domain nanoparticle ensembles describing that a remanence acquired during a time at a temperature can unblock during shorter heating step at higher temperature. This nomogram does not fit natural rock examples, which show anomalously higher unblocking temperatures than predicted by Pullaiah's nomogram. Although this departure from Neel theory is often attributed to multidomain particles, it is also well known that there are counter-examples indicating higher unblocking temperatures in Kent (1985)'s Appalachian carbonates and Jackson and Worm (2001)'s Trenton limestone even with stable single domain particles. Better agreement has been found for the nomogram based on Walton (1980)'s calculation invoking volume distributions. However, Walton's formula fails to deduce Pullaiah's nomogram because his power-index is not proportional to unity. To overcome this problem, we propose a fractal model to fit natural data with fractal grain volume distribution ($N(v) \sim v^{1-D}$) by varying power indices (D) from unique (D=1: Neel's theory) through log-normal (D=2: Walton's theory) to fractal distribution (1/D/2, D>2: new model) (Fig. 1). This model assumes that the volume is proportional to the natural logarithm of relaxation time. Fig. 1 shows that our model continuously deduced previous theories and also predicts the much higher anomalous unblocking temperatures results of Kent (1985) with D=3.4 for single-domain magnetite ensembles including slightly larger volumes.

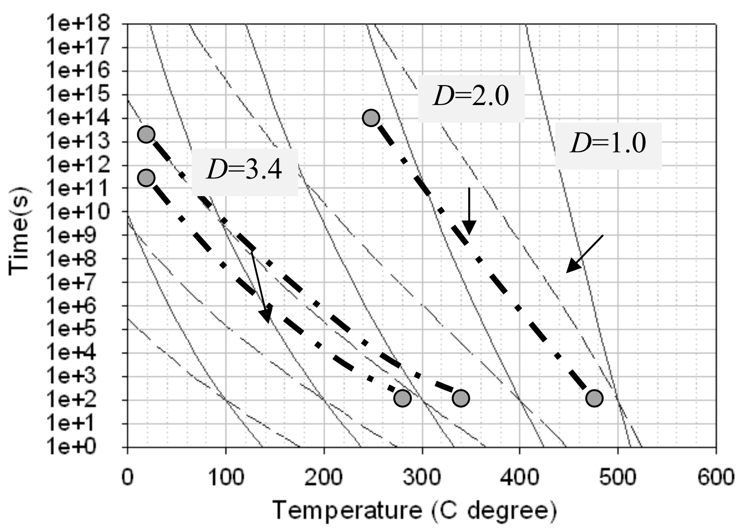

Figure 1: A new fractal time-temperature nomo gram for stable single domain magnetite. D=1: Pullaiah et al. (1975), D=2: Walton (1980) and D=3.4: Kent (1985)

Fast hysteresis and relaxation calculations

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Models of hysteresis for aggregates of minerals require fast, accurate calculations of magnetization curves - particularly important if one is modeling first order reversal curves (FORCs). A new algorithm is presented that greatly increases the speed and accuracy of such calculations. It involves a predictor that accurately estimates the next point on a magnetization curve, a corrector that refines the guess, and an algorithm that determines the length of the next step. This algorithm can calculate magnetization curves five to ten times faster and is far more reliable near jumps than previous methods. It can also calculate energy barriers orders of magnitude faster than any previous method. A few uses of this algorithm are presented.

An environmental magnetic record of the past 200 kyr from the Timor Sea

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Environmental magnetic study was conducted on long piston core MD05-2970 from Timor Sea off northwest of Australia during IMAGES cruise. The site is located at Lat. 9°25’ 00S and Lon. 130°60’00E with a water depth of 437 m and the total length of the core is 29.82 m. Sediment consists of calcarious silt to clay with abundant foraminifera. ^{14}C and oxygen isotope measurements revealed that the core preserved 220 kyr long record and that the sedimentation rates range from 18 cm/kyr at the top to 10 cm/kyr at the bottom. Intensity of natural remanent magnetization is reduced two orders of magnitude by diagenetic dissolution of magnetic minerals below 0.3 mbsf, which resulted in a poor paleomagnetic record. There are some horizons which show reversed or intermediate polarity directions with higher magnetization intensity and higher coercivity compared with the adjacent samples. This can be interpreted as CRM acquired in the direction different from the Earth’s magnetic field. Low temperature magnetometry and thermal demagnetization of composite IRM revealed that dominant magnetic mineral is magnetite with trace amount of hematite. Zone of dissolution is characterized by downward decrease in Sratio to 0.7 mbsf and subsequent increase to 2 mbsf. This can be interpreted as an initial dissolution of fine grained (possibly biogenic) magnetite and subsequent dissolution of hematite below 0.7 mbsf. Median destructive field of ARM is lower (~15 mT) during marine oxygen isotope stage (MIS) 7 compared with the values above. Grain size parameters also show relatively higher values (finer grained) and paleomagnetic directions are defined better (smaller MAD values) for MIS 7. These indicate that finer grained magnetic minerals deposited or remained during MIS 7, which might have been resulted from environmental change between MIS 7 and later stages.

An oceanographic record from Western-Southland, New Zealand of eccentricity-obliquity paced glaciations of the cryosphere during the Middle Miocene

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We present a unique magnetic susceptibility and paleocurrent record of the middle Miocene expansion of the cryosphere from the South-West Pacific. A high resolution, astronomically tuned, magneto-biostratigraphic age model provides age control of the magnetic susceptibility and Anisotropy of Magnetic Susceptibility (AMS) record from a mudstone succession in Western Southland, New Zealand. The magnetic susceptibility record gives a measure of the carbonate content of the sediment and therefore serves as a proxy for ice volume linked ocean productivity. Spectral and wavelet analysis of the magnetic susceptibility record reveals alternating periods of eccentricity and obliquity dominated cycling. The transitions between these periods seem to be controlled by the long period (ca. 1.2Ma) variation in amplitude of obliquity. A proxy for the middle Miocene ocean current strength is provided by the AMS data, which suggest a dynamic ocean system around New Zealand with phases of increasing and decreasing current strengths at ~13.7 Ma, ~15 Ma and ~15.8 Ma, respectively. In each case, times of maximum inflow and hence ice expansion were paced with eccentricity and deglaciations were paced with obliquity. The data support the suggestions of Imbrie *et al* (1993), that large ice sheets amplify eccentricity pacing of climate. The data also indicate that eccentricity paced glaciations dominated the middle Miocene climate.

References:

Imbrie, J.; Berger, A.; Boyle, E. A.; Clemens, S. C.; Duffy, A.; Howard, W. R.; Kukla, G.; Kutzbach, J.; Martinson, D. G.; McIntyre, A.; Mix, A. C.; Molfino, B.; Morley, J. J.; Peterson, L. C.; Pisias, N. G.; Prell, W. L.; Raymo, M. E.; Shackleton, N. J.; Toggweiler, J. R. 1993: On the structure and origin of major glaciation cycles 2. The 100000-year cycle. Paleoceanography 8: 699-736.

Alteration of the magnetization in basalts due to fluid-rock interactions in high-temperature hydrothermal systems (Krafla, Iceland)

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The magnetic properties of the basalts at Krafla show a direct influence of hydrothermal alteration. The samples come from two drill cores situated at the rim of the 8 km diameter caldera. The samples were taken from KH1 (200 m depth) and KH3 (400 m depth) drill cores. The sampled basalts are affected by the high-temperature (> 150°C) geothermal active area, which is situated at the bottom of the caldera. The geothermal area is responsible for the surveyed aeromagnetic low. The last fissure eruptions occurred between 1974 and 1985 with the subsequent effects on the hydrothermal system (higher temperature and concentration of magmatic volatiles in the hot fluids).

The study of the magnetic properties of volcanic rocks affected by hydrothermal alteration is significant to understand magnetic anomalies related to MORB and its tectonic implications. In our study we aim to characterize the magnetic phases at Krafla basalts in order to constrain the effects of the hydrothermal alteration on the magnetic properties of basalts with low NRM.

The secondary minerals characterize the samples in the chlorite-smectite zone with no differentiation between the cores. The observed loss of NRM (< 5 A/m) in the standard samples is due to fluid-rock interactions with low-temperature oxidation (< 350 °C) together with the alteration and dissolution of cation deficient titanomagnetites (titanomaghemites) and production of sulphides, sphene and rutile, whereas the high susceptibility detected (0.8–140 x 10^{-3} SI) is related to a primary factor of the basalts (higher quantity of ferromagnetic minerals in MD sizes). The χ-T curves and textural observations indicate 3 main types of ferromagnetic grains. 1) High cation deficient titanomagnetite (for most samples in KH1 and 4 in KH3). 2) Low cation deficient titanomagnetite (16 samples in KH3) and 3) Ghost textures, where only paramagnetic minerals are left (6 samples in KH-1 and only 1 in KH-3). Only one sample in KH-1 shows stoichiometric magnetite. The magnetic phases strongly alter depending on the porosity of the rocks, but the alteration profile seems not to be dependent with depth. A higher degree of dissolved textures of Ti-magnetite is seen in KH1, which seems to be stronger affected by the recent activity in the geothermal field.

Multiproxy records of Holocene environmental change from a tropical lake on western México

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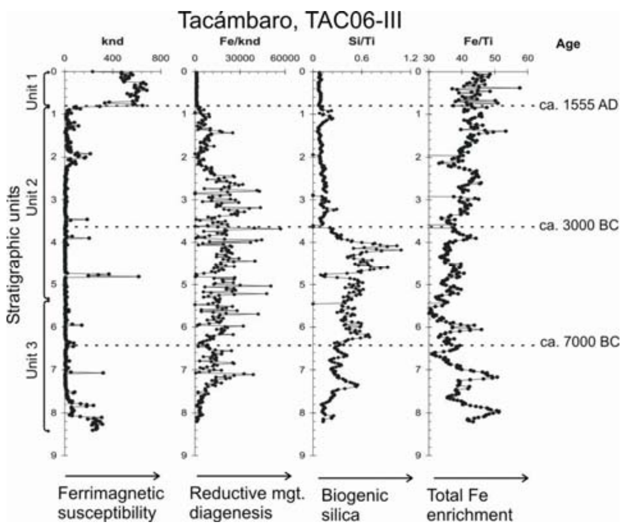

A 9 m core from Tacambaro (Michoacan State, Mexico), a maar lake in western-central Mexico, was collected using a Usinger piston corer. The recovered sequence is mostly laminated and presents several tephra layers, the most conspicuous of them a >30 cm lapilli in the bottom of the core. The lake has a small closed basin located at 19° 12.7' N, 101° 27.5' W, 1500 m asl. The lake itself is 0.3 km in diameter and has a maximum depth of 30 m. The climate is tropical sub-humid, with summer rainy season (annual pp 1,120 mm/yr, mean annual temperature 18 ºC). According to AMS 14C dating, the sequence spans the last ca. 9000 cal yr BP. This sequence is of particular interest for the region, as it would provide a high resolution record which will complement the previously proposed climatic trends, as the early and mid-Holocene dry conditions recorded in several sedimentary sequences from central Mexico, the timing of the dry episode of the archeological Classic period, and the moisture characteristics and time span of the Little Ice Age. Also, it would provide new data for the tephrochronology in the region, and the history of pre-Hispanic settlement. Combined analysis on rock magnetism parameters, geochemical data logged by X-ray fluorescence ITRAX core scanner, and diatom, pollen and carbon content provide the basis to create high resolution records of terrigenous input, redoximorphic iron mineral diagenesis, biogenic productivity and vegetation history in response to climatic and environmental variability. Main fluctuations are recorded at ca. 1555 cal AD, 3000 cal BC and 7000 cal BC.

Reconstructing the response of an arctic glacier to changing climate conditions by means of rock magnetism

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Glaciers are among the most trusted indicators of climate change, but observational records rarely cover more than the last 100 years. For this reason alone alternative sources of information must be invoked in order to produce longer time series. Analyzing suspended sediments deposited in downstream lakes are probably the most common archive currently used to reconstruct past glacier activity. There are several advantages using lacustrine sediments for such a purpose, the foremost being that one can get continuous high-resolution time series that spans thousands of years. The precision of glacial reconstructions are, however, often difficult to assess and usually depend on several critical assumptions. A recurring challenge lies in identifying and isolating a ‘clean signal’ from a bulk minerogenic sample, as extracted from the lake sediments, that truly represents glacial activity rather than other sediment sources.

Here we will present data from an ongoing research project (MAGNET) that seeks to reconstruct an arctic glacier by analyzing the rock magnetic properties of lake sediments; other complementing methods such as XRF- and physical grain size analyzes are also applied. Ten sediment cores have been retrieved from a first order glacier-fed basin and selected cores have been analyzed in detail. In addition a series of samples from the surrounding catchment have been collected and studied. Preliminary results suggest the sediment yields a relatively strong, but stable magnetization with magnetite as the main ferromagnetic constituent. The magnetic granulometry, based on hysteresis and FORC measurements, indicate the presence of pseudo-single domain (PSD) grains. The inferred size of the glacier appears to have little or no bearing on magnetic grain size. From (χ)ARM, (s)IRM and χBulk measurements we interpret the glacier to have been present during most of the record, although it was probably absent or very small during the earliest part of the record. Significant oscillations characterise a larger part of the record, which may indicate that the glacier responds in a ‘systematic’ way to changes in the climate forcing. A persistent weakening of the signal is nevertheless observed towards present day conditions. Much of this variability can be explained by the relative influence of summer temperature (ablation) and winter precipitation (accumulation).

A record of the Cobb Mountain subchron in the Quaternary basalts from the Persani Mountains (Romania)

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The alkali basaltic volcanism in the Persani Mountains (46°N, 25.2°E), although of modest extensions (ca. 22x8 km), represents an important Quaternary alkali basaltic provided inside the Carphatians and south-eastern Europe. Volcanological investigations revealed several stages, each one starting with phreatic or phreatomagmatic eruptions followed by less energetic strombolian or effusive activity. K-Ar ages have show that there are two phases of volcanism. The first one took place between 1.5 ma and 1.2 Ma. The second one was 600 ka later, around 0.6 Ma.

We present results from 19 sites sampled in the first volcanic phase. Rockmagnetic properties (field and temperature dependence of the magnetic susceptibility, hysteresis properties) shows that magnetic mineralogy is dominate by a mixture of magnetite and titanomagnetite. The content in titan is relative low in the lavas erupted at the beginning of the first phase of eruptions. The lavas from the main phase of eruptions contain high Ti-magnetite with Curie temperature as low as 200°C and a strong filed variation of the magnetic susceptibility. The structure of the natural remanent magnetization was analyzed using both thermal and AF demagnetizations. Normal polarity (7 sites, probably from 4-5 independent flows) and transitional directions (8 sites from 5 flows) was dominant between the sites from this phase of eruptions. Only 4 sites (from 2-3 lava flows) have reversed polarity. The majority of transitional directions were recorded in one of the best developed and exposed volcanic structure: the Racos volcanic complex. Transitional directions recorded in this complex are characterized by a shallow inclination and an arc-like distribution of the declinations. K-Ar ages from two laboratories gave a mean age for these transitional directions of (1.24±0.09) Ma. Since this age is close to the accepted age for the Cobb Mountain subchron, we interpret the results from the Racos volcanic complex as a record of this event. The rest of the sites with normal polarity have K-Ar ages with relative large errors. Their distribution places these sites inside a relative long period with reversed polarity in the middle part of the Matuyama chron. The most probable correlation of these sites with normal polarity is with the full normal polarity of the Cobb Mountain subcron. A new research project, founded by CNCSIS, was started in 2008 to obtain more details about the directional and paleointensity changes recorded by the Quaternary volcanism from the Persani Mountains.

X-ray magnetic circular dichroism of geomagnetic minerals

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X-ray magnetic circular dichroism (XMCD) is an element-specific spectroscopic technique that can provide quantitative information on site occupancies and oxidation states in natural ferri- and ferromagnetic minerals. XMCD is the difference between the X-ray absorption spectra (XAS) for left- and right-circularly polarized X-rays; the spectra are collected with the magnetic field set parallel and antiparallel, respectively, to the helicity vector of the X-rays, which is along the direction of the synchrotron radiation beam. In addition, the XAS analysis of transition metal *L* edges, from which the XMCD spectra are derived, provides complementary information on the electronic structure and oxidation state of the specific elements. Magnetites and other ferrimagnetic iron-bearing spinels provide a good example of the capabilities of the technique. In the example below (Fig. 1), the XAS Fe $L_{2,3}$ spectrum of a natural magnetite powder was collected on a soft X-ray beamline using a 'flipper' magnet switching the direction of the 0.6T magnetic field at each data point. The difference signal (XMCD) between these spectra is shown below and the three main peaks, from left to right, correspond primarily to the tetrahedral (d^5 T_d) and Fe^{3+} octahedral (d^5 O_h) sites, respectively. Changes in the ratio between these three components reflect either different degrees of oxidation of the magnetite or substitution of other elements into the iron sites (typically Co, Ni, Mn) − XAS and XMCD spectra can also be collected from these other elements. Quantitative evaluation of the site occupancies can be obtained by comparison with calculated spectra of elements in specific sites and oxidations states (see Fig. 2) [4]. In substitutional series, such as magnetite (Fe_3O_4)–spinel ($MgAl_2O_4$) and magnetite–ulvospinel (Fe_2TiO_4), the progressive substitution of the components can be tracked. Ferrite spinel nanoparticles produced by naturally occurring metal reducing bacteria have also been examined by XMCD to compare their properties and potential technological performance to their inorganic counterparts. Other magnetic geomaterials examined are pyrrhotites ($Fe_{1-x}S$) and greigite (Fe_3S_4).

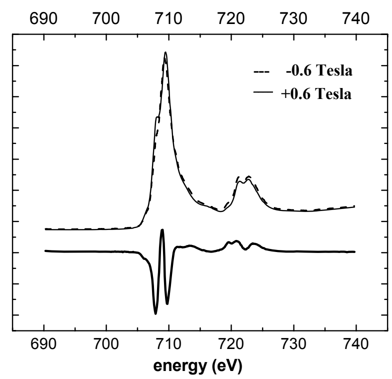

Figure 1: XAS and MCD of magnetite

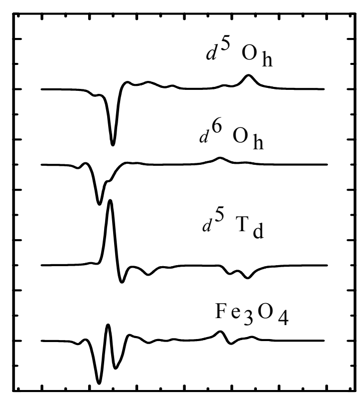

Figure 2: Calculated XMCD of the specific sites together with summed signal in magnetite

References: [1] Coker, V.S., Pearce, C.I., Lang, C., van der Laan, G., Pattrick, R.A.D., Telling, N.D., Schüler, D., Arenholz, E. and Lloyd, J.R. (2007) *Eur. J. Mineral*. 19, 707-716. [2] Coker, V.S., Bell, A.M.T., Pearce, C.I., Pattrick, R.A.D., van der Laan, G. and Lloyd, J.R. (2008) *Am Mineral*, 93, 540-7.[3] Pattrick, R.A.D., van der Laan, G., Henderson, C.M.B., Kuiper, P., Dudzik, E., Vaughan, D.J. (2002). *Eur. J. Mineral.* 14, 1095-1102. [4] van der Laan, G., and Kirkman, I.W. (1992) *J. Phys. Condens. Matter.*, 4, 4189-4204. [5] Pearce, C.I., Pattrick, R.A.D., Henderson, C.M.B, van der Laan, G. and Vaughan, D.J. (2006) *Am. Mineral*. 91, 880-893.

Variations in magnetic fraction in atmospheric PM10 at industrial site in dependence of different climatic conditions

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Several studies showed that atmospheric dust contains significant portion of magnetic particles, typically spherules of anthropogenic origin, composed mainly of (metal-substituted) magnetite and/or maghemite. These particles can be detected and characterized with very high sensitivity. Furthermore, depending on the pollution sources and sampling site, concentration of these particles may show significant correlation with the total PM10 (particulate matter – a major air pollutant consisting of tiny solid or liquid particles of soot, dust, smoke, fumes, and aerosols - with a diameter less than or equal to 10 microns) concentration and several heavy metals. In our contribution, we will show variations in PM10 concentration and concentration of magnetic particles in daily samples collected during one week at an industrial site, where the air pollution is controlled by close large steel works. While variations in daily PM10 concentration are only about ±20% of the weekly average, concentration of magnetic particles varies significantly, the maximum value being 1 order higher than the minimum one (Fig. 1). This scatter can be attributed to variations in the prevailing wind direction. In case of prevailing west to south-west winds (Monday, August 20), PM10 is very rich in magnetic particles emitted from the close steel works (700 m from the sampling station), while magnetic fraction is significantly diluted during August 17-18, when mainly north-east wind direction. In this direction, no major source of magnetic particles, comparable to the steel plant, is located within some few kilometers. This work is supported by the Grant Agency of the Acad. Sci. of the Czech Republic under grant A300120606.

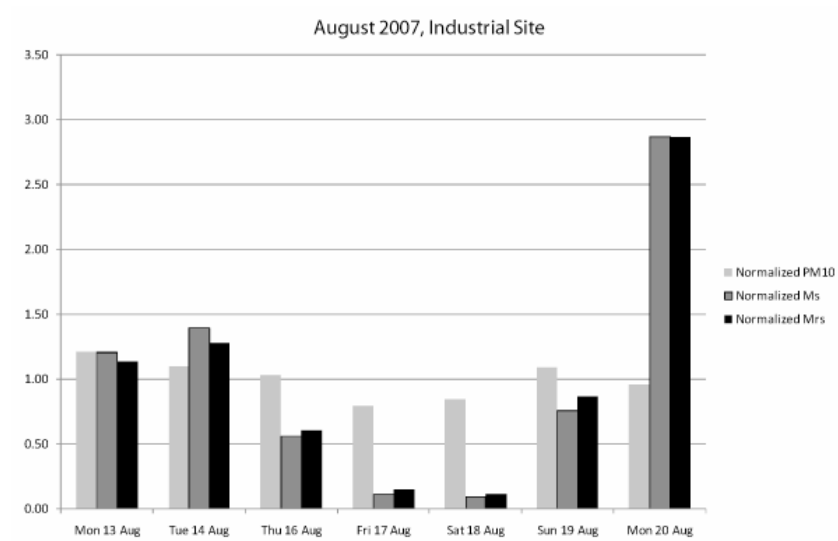

Figure 1. Daily variations in concentration of PM10 and magnetic particles at industrial site with air quality determined by nearby steel plant, normalized to weekly average.

Far-traveled magnetite and hematite in deposited atmospheric dust—records of climatic change and human influence on regional landscapes

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Wind erosion, dust emission, and dust deposition depend on conditions and factors that link climate, weather, vegetation dynamics and phenology, geomorphology, hydrology, and human activities. Uncertainties about future wind erosion and dust emission, related to both natural and human forces, complicate forecasting of eolian effects on climate forcing, land management, water management, air quality, ecosystem dynamics (losses and gains of nutrients), and human health and conditions in developed and developing countries.

Environmental magnetism plays an important role in understanding past records of dust fallout that improve our ability to assess future causes and effects of dust emission and deposition. Characterization of magnetite and hematite in surficial deposits, in conjunction with physical, chemical, and isotopic methods, helps to assess the sources of these minerals, whether local or distant, and anthropogenic or natural.

Records of dust composition and flux may be found in certain lake sediments and soils that can be dated by radionuclide and luminescence methods. Recent results from isolated, high-elevation lakes in the western U.S. indicate that human activity over the past 150 years has greatly altered regional dust composition and dust flux, compared with dust deposited during multi-decadal droughts within the past millennium. At settings in which watershed bedrock lacks magnetite, silt-sized, detrital titanium-bearing magnetite controls magnetization in lake sediments and records eolian magnetite deposition. Eolian magnetite content increases abruptly by as much as 6x from about the 1930s to 1980s, corresponding with increases in many mining and industrial metals and likely resulting from increased intensity of human activity and landscape disturbance. Similar associations are found for dust-bearing sediments in isolated, subaerial pockets on high-elevation bedrock surfaces, along a 700-km-long transect across southwestern U.S.

Nutrients delivered as atmospheric dust and incorporated into soils commonly enrich ecosystems. In some settings, the resulting enhanced soil fertility closely corresponds with the abundance of eolian titanium-bearing magnetite. Subsequent disturbance of such landscapes may result in wind erosion. Comparisons of magnetic and chemical attributes in a variety of field settings, along with ongoing monitoring of wind erosion at sites with known disturbance histories (e.g., livestock grazing), demonstrate the loss of original eolian magnetite and nutrients as a result of wind erosion. Declines in titanium-bearing magnetite, a proxy for nutrient loads in these settings, can even be measured as decreases in magnetic susceptibility in the field, relative to nearby undisturbed areas. In other landscape settings, measures of magnetic susceptibility indicate that the redistribution of eolian dust along hill-slope gradients influences landscape-level patterns in the distribution of invasive exotic species.

Magnetic susceptibility and rock magnetism properties analysis: A record of genesis and evolution of TeotihuacanValley modern volcanic soils sequence. Preliminary results.

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We are using rock magnetism properties analysis for the purpose of identifying a pattern magnetic-pedogenic on volcanic soils that can be correlated with the processes occurring in the soil, which are stronger influenced by environmental conditions presents during the formation and evolution of the soil. To obtain it, we seek to follow up on the mobility of minerals within the horizons, which are preserved evidence of the various processes that regulate the transformation the mineralogical composition of soil. So we are studying five modern soil sections (CGBE, CGN, MAS, SNP and OTUM) which are spread along a catena inside Teotihuacan Valley. Major of C^{14} dating were took on upper horizons of first paleosol inside sequences, which reflex edges between 2890 ± 60 (OTUM) and 22670 ±290 (CGN) yrs B.P.

Despite profiles presents similar conditions of precipitation and temperature profiles have a different pedogenic evolution stages, and according with World Reference Base criteria, soils were classified like Cambisol (CGBE), Calcisol (MAS), Feozem (SNP) and Fluvisol (SNP and OTUM) like elementary pedogenic units respectively. Magnetic profiles are consistent among them, with a close relationship between the parameters analyzed. Magnetic properties from each profile reflex magnetic signal, which print a characteristic magnetic sign. However, like a main feature, major profiles show clearly a little enhancement at upper horizons. Probably like a respond of human activity, because upper horizons correspond with Ap horizons (cultivations horizon), which remove and mix material from middle and bottom horizons. Nevertheless other possibility it is contribution of material from other sites and/or a relative rapid transformation of mineralogy like a respond to a little changes intensity of environment conditions, because the magnetic mineralogy has shown to be highly sensitive to changes in rates the environment in which it develops soil.

Reductive diagenesis and magnetite dissolution in sediments: A new view

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It has been conclusively demonstrated over the last 25 years that magnetite dissolution and pyrite formation are ubiquitous in anoxic, sulphate-reducing sedimentary environments. In such environments, a pristine detrital magnetic mineral assemblage only survives in the uppermost part of a sedimentary sequence. A precipitous decline in magnetite concentration coincides with the onset of sulphate-reduction, which causes pyritization of the detrital iron-bearing minerals. The usefulness of the surviving paleomagnetic record is usually argued to depend on how much of the primary detrital magnetic assemblage survives diagenetic dissolution. Ratios of hysteresis parameters are often observed to undergo a looping trend on a “Day” plot, starting from typical pseudo-single domain-like values. Down-core increases of B_{cr}/B_c and decreases of M_r/M_s with the onset of diagenetic dissolution is argued to be a response to the progressive dissolution of single domain (SD) grains. The loop back to higher M_r/M_s and lower B_{cr}/B_c values is then often taken to indicate fragmentation of initially multi-domain (MD) grains that survive as smaller SD grains. We have made detailed magnetic and scanning electron miscroscope observations of two sediment cores from the Oman and northern California margins. We document a loss of detrital magnetic iron oxides at shallow depths, and progressive down-core growth of greigite that survives along with increasing concentrations of paramagnetic pyrite. Progressive growth of greigite will start with a large concentration of superparamagnetic (SP) nanoparticles before the particles grow through the SD blocking volume. This can explain the apparently paradoxical suggestion that diagenetically reduced sediments contain enhanced concentrations of particles with SP behaviour. Our observations also provide a more likely alternative explanation for the looping of hysteresis parameters on a Day plot. The initial decrease in M_r/M_s and increase in B_{cr}/B_c values can be attributed to a combination of dissolution of SD magnetite and an increase in SP behaviour with initial growth of ultra-fine greigite. The return of the loop to higher M_r/M_s and lower B_{cr}/B_c values is explained by progressive growth of greigite through the SD blocking volume, with increasing concentrations of stable SD greigite grains resulting in higher M_r/M_s values. We have observed this looping trend in data from several published records in addition to our two new records (Oregon margin, Korea Strait, Japan Sea, Niger Fan, Argentine margin, and the Ontong-Java Plateau). These processes therefore appear to be widespread in reducing environments. Our observations have profound implications for paleomagnetic records from sulphate-reducing environments. The ongoing growth of greigite at depth in the studied cores indicates two things. First, the recorded paleomagnetic signal is offset from the age of the surrounding sediments by 10’s of kyr. Second, the recorded paleomagnetic signal is an integrated magnetization acquired over the entire interval in which greigite grows. In the studied cases, smoothing occurs over intervals of 10’s to 100’s of kyr. Much more attention needs to be paid to the possibility of compromised paleomagnetic records carried by greigite.

Magnetic properties of lunar materials: comparison between meteorites and sample return

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Our natural satellite is the only body in the solar system from which samples are available through two completely different processes: sampling by man made spacecrafts, i.e. « sample return », and natural sampling by impact and transport to the Earth, i.e. meteorites. While the samples returned by the Apollo 11 to 17 missions from 1969 to 1972 (380 kg of soils and rocks) and by the Luna 16, 20 and 24 missions from 1970 to 1976 (320 g of soils and minute rock fragments) has been the subject of considerable work in the years following missions, only two lunar meteorites have studied previously: Yamato 791197 and ALH81005. We will present a comprehensive study of lunar meteorites (about 100 meteorites from 50 different falls), and compare it to published data on the Apollo and Luna missions, as well as new data from the Luna 16 and 20 surface soil samples, and from the Luna 24 two meters long core. We concentrate on magnetic susceptibility (χin nm^3/kg) and saturation remanence (M_{rs} in mAm^2/kg) that reflects the amount and grain size of metallic iron. In Luna soils χ decreases with increasing depth and grain size, due to the predominance of metal nanoparticles due to regolithization processes (amount of metal up to a few %). Meteorites, Luna and Appolo samples share the same wide range of susceptibility ($1.9<\log\chi<4.6$) and remanence ($-1< M_{rs} <2.5$), although meteorites have on average lower metal content due to a lower regolithic component. Most mare basalts appear nearly paramagnetic (metal content <<0.1%) and more magnetic rock are found within the highland or impact reprocessed materials. Meteorites provide a better sampling of the anorthosite highland lithology, very rare in sample return collection. This lithology provides the least magnetic material ever sampled in the solar system ($\log\chi<2.5$).

Multiple antipodal remanence components in the Skye Lava (UK): Complex thermal/chemical history and self- reversals

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Large Igneous Provinces, overwhelmingly of basaltic affinity are the surface expressions of catastrophically rapid dissipation of large quantities of internal heat. With an estimated volume of ca 10^7 km^3, the North Atlantic Igneous Province (NAIP) represents the third largest magmatic event on Earth for the last 150 Ma. The formation of the NAIP has been linked to the proto-Icelandic plume through paleogeographic reconstructions and geochemical observations. However, despite active research focus since the late 1980's, the temporal and physico-chemical ties between NAIP rocks, hotspot motion and continental break-up have not been demonstrated to fit a single regionally applicable and consistent geodynamic model. Therefore, in the framework of reinvestigating the paleomagnetic directions of the British Tertiary Igneous Province (BTIP), a sampling of ~200 cores (19 sites) in the lava pile of the Isle of Skye (Scotland) has been undertaken. Although 80% of the samples showed 'expected' behaviour with one or two components, three sites (20%) exhibits complex magnetization with up to five well constrained mostly antipodal components. This peculiar behaviour is only triggered trough careful stepwise thermal demagnetisation up to 590°C. Alternative field demagnetisation on companion core usually exhibits only two components. We are able to rule out acquisition of stray fields in laboratory equipment as an explanation and are left with an open question as to the origin of these multiple directionally opposed components. Variation in remanence stability under thermal and alternating field demagnetisation may reflect the combined action of two alteration processes, namely deuteric oxidation and regional alteration, which could have created secondary minerals that have the ability to self-reverse under specific conditions. It has been demonstrated for the Skye lava that regional hydrothermal activity widely occurs and that it can alter the magnetic properties of titanomagnetite in low deuteric oxidation states to such an extent that thermally stable magnetic phases with a single Tc above 500˚ may appear. It is also a common feature in basaltic rocks that primary titanium-rich titanomagnetite, after crystallizing at high temperature, subsequently undergoes some oxyexsolution during magma cooling leading to the formation of additional magnetic carriers and potential high interaction fields. In order to identify the different magnetic phases occurring in these samples and better define their origin, rock magnetic measurements, SEM, Electron microprobe and Magnetic Force microscopy analyses have been undertaken. The history of alteration of these lavas will be explored as well as alternative explanations for multiple self-reversals resulting from complex chemical or thermal remagnetisation.

Environmental magnetism of airborne particulate matter: application to the study and the monitoring of air pollution

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Concentration of airborne particulate matter (PM) is presently of particular concern in urban and industrial environments, due to the public awareness that the fine PM fraction (i.e., that with aerodynamic dimensions less than 10 μm, known as PM_{10}) poses severe hazards and risks for the health of citizens. The scientific interest in the understanding the origin and the dispersal patterns of airborne particulate matter is driven by the social interest in the effects of atmospheric pollution, with a demand to develop innovative techniques to better characterize the sources, the spreading mechanisms and the dispersal in to the environment of PM_{10} due to pollution and/or various natural processes. Classical rock magnetic techniques may be applied to characterize the magnetic fraction of airborne particulate matter and provide an original tool to trace the concentration and diffusion of the PM magnetic fraction in metropolitan and industrial areas. In recent years, a variety of environmental magnetic studies on PM have been carried out, using either tree leaves as natural and widespread collectors of PM, or paper filters specifically designed to collect PM_{10} (or $PM_{2.5}$) and employed in automated stations for the monitoring of air quality. These studies demonstrated that the environmental biomagnetic monitoring is a powerful tool to delineate the capillary distribution of magnetic (anthropogenic) PM in urban environments and may support the planning and the search for a proper and representative allocation of the air quality monitoring stations. The detailed magnetic characterization of PM proved to be also useful to define proxies for the identification and the tracing of the time and space changes in variable mixtures of PM populations originated from distinct natural and anthropogenic sources.

In this talk, I will present an updated review of the achievements reached on these subjects and I will try to point out the open problems and the possible future developments.
I will also discuss the laboratory treatments and analytical tools that are presently recommended in order to establish a sound and shared protocol for the use of rock magnetic techniques to provide reliable and sensitive proxies for the monitoring of airborne PM anthropogenic pollution.

Laboratory test of the Thellier-type absolute paleointensity IZZI protocol on synthetic slag material

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The Thellier-Thellier method is the most accepted and widely used technique for paleointesity determination. Yet, the accuracy and efficiency of the method are under dispute. Furthermore, there is little agreement on the proper application of the method. For example, there is no standard set of data-selection criteria and no standard way to interpret non-ideal behavior. Here we present an innovative experimental design that aims to provide a rigorous test of the Thellier method. In addition to a reliability test, our experiments will provide guiding principles for interpreting non-ideal data-sets. The technique includes a silicate melt solidifying under controlled laboratory conditions (controlled magnetic field, cooling rate, and fugacity), producing synthetic slag sample. Our ability to control various parameters enables us to produce a large set of samples with magnetic properties ranging from single-domain to multi-domain with TRM acquired under magnetic field intensity ranging from zero to 100 μT. We use slag material, which was recently shown to be applicable for archeointensity, and in some cases even preferable to the traditionally used baked-clay artifacts. SEM images of the synthetic material and the archeological material confirm that our experimental design successfully reproduces ancient slag properties. A first set of three samples with pseudo-single-domain expected behavior was produced under field intensities of 30, 60, and 90 μT. A second set of eight samples with expected multi-domain behavior was produced under field intensities of 20, 40, 60, and 80 μT. Four to five specimens were cut from each sample for Thellier-type experiments using the IZZI protocol. Moreover, we apply additional measurement in order to calculate TRM anisotropy tensor, cooling rate correction, and non-linear TRM acquisition. Here we present preliminary data from IZZI experiments on a total of fifty specimens. This data-set consists of ideal linear Arai plots with little or zero presence of MD as well as non-ideal Arai plots demonstrating different levels of zigzag and concave behaviors.

On mechanism of formation and fixing of depositional remanent magnetization.

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Numerical analysis of flocculation of depositing particles accounting for their Brownian motion, Stokes' and magnetostatic forces is developed. The aggregates, generated as the results of collisions, have an irregular shape and average fractal dimension d = 1.83. The sedimentation velocity of a cluster is proportional to R^{d-1}, i.e. $R^{0.83}$, where R is the size of the cluster, what is very close to the empiric relationship reported by Gibbs. Noteworthy, that already at the earliest stages of the sedimentation, fine particles enter into association with more coarse grains.

A certain coupling of magnetic grains is observed only at their high enough concentrations exceeding 5 % from the concentration of all particles. At smaller concentrations the magnetic particles are randomly distributed among the non-magnetic ones. As such the situation practically never met in natural conditions, this result gives additional argument that chains of magnetic particles found in deposits, have the biogenic origin.

Analysis of coagulation process based on Smoluchovsky equation have shown that the process of deposition obeys the scaling law: the distribution function $N(n)$ of the number N of clusters (in unit volume) with given number n of particles composing a cluster is invariant when the product Hu = const. Here H is a depth and u is the rate of sedimentation. Thus, for the case of lake sediments with of the depth of the basin $H \sim 100$ m and $u \sim 0.3$ mm/year, the redeposition into settling tube with the depth $H \sim 0.1$ m should be performed with $u \sim 1$ mm/day. Besides, in order to keep the similarity of $N(n)$, the redeposition procedure must be quasi-continuous, i.e done by frequent small portions. Otherwise $N(n)$ will be considerably distorted as the coarse grains first reach the bottom, while the fine ones cover the top of the sediment layer. The redeposition of deep sea sediments, due to their much more slow accumulation, should take months. The coagulation and collisions are important factors forming the intensity of depositional magnetization M_{sed} in lakes and shallow seas, provided that the depositing material is fine, with sizes < 3 μm, where they may dramatically decrease M_{sed}. Then For oceanic sediments the coagulation is negligible. Of course, for laboratory redeposition experiments the coagulation and collisions are always crucial factors.

The beginning of the dynamo and its relationship to Earth evolution from core to atmosphere

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The strength of the early geomagnetic field is of importance for understanding the evolution of the core, surface environment and atmosphere. Palaeomagnetic and palaeointensity data from rocks formed near the boundary of the Proterozoic and Archaean eons (~2.5 Ga), show many hallmarks of the more recent geomagnetic field: reversals are recorded and available palaeointensity values are similar to those from younger rocks. Interestingly, palaeosecular variation data indicate a dipole-dominated morphology, possibly more dipolar than that seen in the 0-5 Ma geomagnetic field (Smirnov and Tarduno, 2004). This is consistent with some numerical geodynamo simulations with a smaller inner core (e.g. Coe and Glatzmaier, 2006). Here I discuss efforts to see through the ubiquitous low grade metamorphism that affects Archean rocks to obtain even older records of the magnetic field. Specifically, we use a CO_2 laser heating approach and direct-current SQUID magnetometer measurements to obtain palaeodirections and intensities from single silicate crystals that host magnetite inclusions. We have found 3.2 Ga field strengths that are within 50% of the present-day value (Tarduno et al., 2007). This contrasts with some prior assertions that the mid-Archean field was some 10 times weaker than present-day (the prior studies were derived from rocks with secondary thermochemical remanent magnetizations rather than primary thermoremanent magnetizations). The pre-3.2 Ga field strength is unknown. Two scenarios have been offered: (1) The dynamo started shortly after core formation, and the subsequent field strength has been within a factor of 2-3 of the modern value since its initiation; (2) the field was at null values at 3.9-3.8 Ga and commenced between 3.8 and 3.2 Ga. The latter scenario relies on a hypothesis to explain the amount and isotopic composition of nitrogen found in lunar soils. These may have been derived from Earth's atmosphere via the solar wind (Ozima et al., 2005) in the absence of geomagnetic field that would otherwise shield atmospheric erosion. The possibility and implications of a delayed dynamo onset on Earth (Labrosse et al., 2007) and on Mars will be discussed, as will our efforts to address the presence/absence of the geomagnetic field between 3.2 and 3.9 billion years ago using the terrestrial rock record. The available constraints on ancient magnetic shielding will also be reviewed in light of the increased radiation and particle flux associated with the active young Sun.

References:

Coe and Glatzmaier, Symmetry and stability of the geomagnetic field, *GRL*, L21311, 2006. Labrosse et al., A crystallizing dense magma ocean at the base of the Earth's mantle, *Nature*, 450, 866-868, 2007.

Ozima et al., Terrestrial nitrogen and noble gases in lunar soils, *Nature*, 436, 655-659, 2005.

Smirnov and Tarduno, Secular variation of the Late Archean-Early Proterozoic geodynamo, *GRL,* 31, L16607, 2004.

Tarduno et al., Geomagnetic field strength 3.2 billion years ago recorded by single silicate crystals, *Nature*, 446, 657-660, 2007.

DRM: Clues from theory and experiment

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Sedimentary paleointensity studies rest upon the basic assumption that detrital remanent magnetization (DRM) is linearly related to the ambient field in which sediments acquired magnetization and many paleomagnetic applications assume that the magnetization is parallel to the geomagnetic field. Yet, paleomagnetic data from sediments show that DRM is complicated. Factors other than the magnetic field such as particle size, shape, nature of sediments, hydrodynamic forces etc all affect how sediments get magnetized.

Sedimentary studies of DRM have shown almost from the beginning (e.g., Ising, 1942) that sediments can display inclination error, yet the mechanisms that control it are poorly understood and there are probably several different mechanisms at play (depositional inclination error as envisioned by, e.g., King (1955) or from compaction (e.g., Anson and Kodama, 1987). Moreover, Tauxe et al. (2006) suggested that even the linear dependence of DRM on the magnetic field may not always hold true.

One of the most important controls on DRM is flocculation (Shcherbakov and Shcherbakova, 1983; Lu et al., 1990). Its role in controlling DRM magnitude has been explored but its influence on the directional properties of DRM is virtually unexplored. In a series of laboratory experiments in different field and flocculation states we have confirmed the strong non-linearity of certain sedimentary systems. In addition, we have documented a marked dependence of inclination error with the field strength and flocculation state. Our findings have serious implications for paleosecular variation studies using sediments, in particular from low salinity environments, such as lakes.

Dipole lows and excursions during interglacials suggest an orbital influence on the geomagnetic field

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The contribution of astronomical precession to the geodynamo energy budget recently re-gained some credibility on theoretical and experimental grounds. Paleomagnetic tests of such an hypothesis remain highly controversial mostly because the geomagnetic moment variations reconstructed at the 10^4 – 10^6 y scale are suspected to be biased by paleoenvironmental signals. However, altogether, the available indicators [i) depositional remanent magnetization of sediment (paleodirections and paleointensity), ii) magnetization of the deep sea floor basalts, iii) geochemical records of cosmogenic isotopes production] produce well-constrained series of geomagnetic dipole lows, most often directely recorded with the related excursions, along the last million years. This series analysed in terms of periodicity and compared with contemporaneous $\delta^{18}O$ records provides several clues converging on a presumption of orbital or paleoclimatic influence on the geodynamo regime: i) periodicities slide from ~30 to 120 ka, in the range of orbital periods (axis precession, obliquity and eccentricity); ii) deep and abrupt dipole lows (ensuring the maximum variance of all proxy data series) present a striking tendency to occur during or at the termination of interglacials; iii) often coinciding with low obliquity periods, dipole lows lag by ~20 ka (half the Obliquity period) the deglaciation (initiated by high obliquity); iv) two third of the time elapsed since the last reversal was characterized by growing (resp decaying) dipole moment during glaciations (resp. deglaciations).

Such observations definitely discard the idea that low dipole field and excursions could be related to glacial episodes. The present data sets however are not precise and complete enough to affirm that the dipole "lows – interglacials" relationship is more than a misleading coincidence. Yet, an orbital influence, implying an indirect paleoclimate-paleofield relationship, would have crucial implications for the understanding and prediction of the future Climate – Field connections: a next dipole low and excursion before the end of the present interglacial?

Insights and observations on experimentally deformed magnetic fabrics

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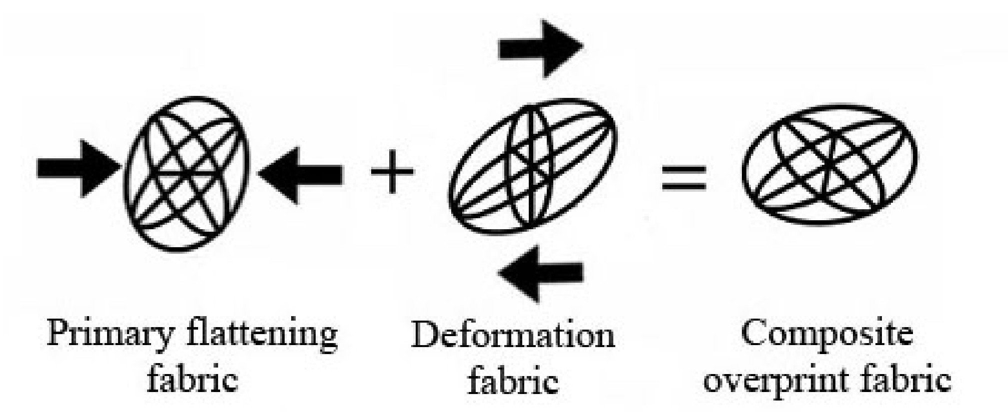
Deformation experiments on magnetite-bearing carbonate aggregates deformed in simple shear were performed under metamorphic conditions to examine the effects of grain rotation and stress on magnetic fabric character and remanence stability. Samples containing high-blocking temperature, pseudo-single domain magnetite in a calcite matrix were given weak-field thermal magnetizations and deformed at 500˚C. Remanence measurements revealed that a primary remanent magnetization can withstand differential stress on the order of one-half GPa. Anisotropy measurements show systematic increases in magnetic fabric intensity with increasing strain. Samples with isotropic or weak initial fabrics were created and deformed with the intention that these would serve as a control against samples with strong initial fabrics. However, it was found that deformation of "isotropic" samples involves complex grain rotation dynamics, resulting in fabrics with unexpected orientations. Ultimately, these experiments have underscored the important role that initial fabrics play in determining the character of deformation fabrics. A conceptual model has been created to help understand certain aspects of the data.



Surface magnetic field distribution of NWA1756 (LL3.10): MI magnetic microscopy

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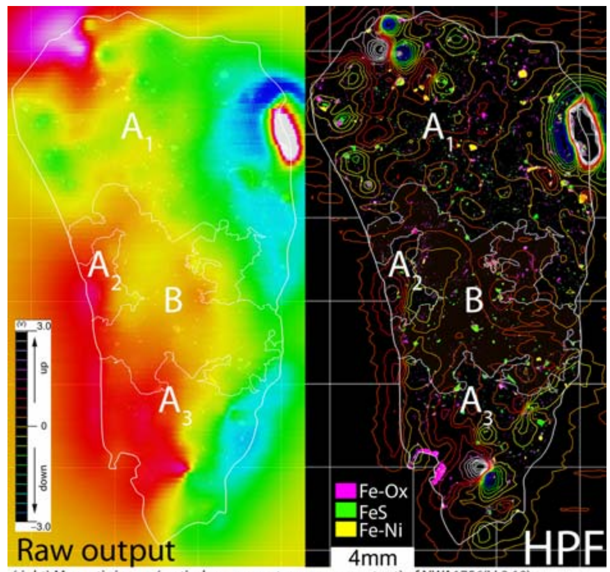
A 2 mm slab of NWA 1756 (LL3.10) primitive type-3 ordinary chondrite was observed by a scanning magneto-impedance (MI) magnetic microscope. The MI magnetic microscope does not use feedback- and bias-field coils, and achieves spatial and magnetic resolutions of 300 μm and ~20 nT, respectively. Scanning electron microscopic (SEM) observations confirmed that this sample consists of two cm-scaled lithologies: a fragmented type-3 chondritic lithology (lithology A) and a completely shock-melted lithology (lithology B). Magnetic minerals are fine-grained iron-nickel metals, polycrystalline iron-nickel metal aggregates, and iron-(hydro)oxides that usually replace a part of the polycrystalline metals. Magnetic anomalies shown in the magnetic image are: (a) mm-scaled anomalies clearly corresponding to the magnetic minerals and chondrules found in the backscattered electron image, (b) mm-scaled anomalies whose carriers have not been identified, and (c) mm- to cm-scaled anomalies corresponding to the magnetization of the clasts and the whole sample. The directions of the most anomalies are westward or downward, which are probably magnetized by terrestrial weathering and/or metamorphism. The anomalies (b) are probably carried by the magnetic minerals hidden under the surface. On the other hand, anomalies (c) may be explained by assemblages of homogeneously magnetized fine-grained magnetic minerals. This suggests that assemblages of fine-grained magnetic grains, such as SD grains, are observable when their magnetic moments are ordered into the same direction, even if their grain sizes are much smaller than the spatial resolution of the MI magnetic microscope (300 μm). For example, the anomaly on the clast A_2 appears to be explained by this hypothesis rather than a single hidden magnetic mineral. Although further demagnetization experiments must be conducted, such assemblage can correspond to an ensemble of grains recognized in a demagnetization spectrum.



(right) Magnetic image (vertical component, raw sensor output) of NWA1756(LL3.10).
(left) Contour plot of high-pass filtered data superimposed on a sketch of the opaque phases.

New advancements in the magnetic mineralogy characterization of drift sedimentary sequences from the Antarctic Peninsula, Pacific Margin

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This work aims to characterize the magnetic mineralogy of two sediment cores taken in the framework of the SEdiment Drift of the ANtarctic Offshore project (SEDANO) along the Pacific Continental Margin of the Antarctic Peninsula. High resolution measurements were performed on u-channels and about forty-three discrete samples. ARM/κ magnetic parameter resulted to be a good indicator of grain-size variability and reflects changes in the sedimentation on the rise when the ice sheet fluctuated on the continental shelf. An integrated age model is provided for cores SED-12 and -13, which are both characterized by high sedimentation rates. Previous paleomagnetic studies on sequences from the same drift suggest iron sulfides along magnetite are the main magnetic carriers in the glacial intervals. We present results from observations on magnetic extracts from glacial/interglacial intervals undertaken using FESEM (Field Emission scanning electron microscope) and elemental analyses on individual mineral grains using energy dispersive spectrometer (EDS). Only a few isolate grains of iron sulfides were observed in the extracts from SED-07 core. It is likely that these grains are too fine for EDS analysis and the lack of >1 micron sulfide made difficult its identification of this phase. However, not even aggregates which are more easy to be identify were observed. We found only a case of the presence of sulfide on detrital Fe-oxides that would suggest an authigenic origin in this case. These findings could have implications on the nature of sulfides (greigite/pyrrhotite phases) and allowed new assumptions on sedimentary history of drift sequences in this area.

Environmental magnetic evidence for Milankovitch forcing of Antarctic climate in the Ross Sea Sector during the Quaternary

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Antarctica is a primary driver of global climate, but to date, there has been no clear evidence that the climate of the Ross Sea exhibits Milankovitch cyclicity. We have been studying the paleomagnetic and environmental magnetic properties of Eltanin 27-21, an 18-meter long piston core collected in the Ross Sea near Cape Adare in 1968 by the USNS Eltanin as part of Operation Deep Freeze. The magnetic polarity of 680 discrete samples from the core was used to develop an age model extending from the top of the Brunhes Chron to the Reunion Subchron. When converted to the time scale, the downcore variations of several environmental magnetic parameters exhibit features consistent with 40-ky cyclicity prior to the mid-Pleistocene transition and 100-ky cyclicity afterward. In order to better understand the nature of these features, we determined whether the environmental magnetic parameters had high or low values at each magnetic polarity boundary and compared that result with the marine oxygen isotope stage associated with the boundary. In general, high magnetic concentrations occurred in interglacials while low concentrations occurred in glacials. On the other hand, downcore variations in environmental magnetic ratios, hysteresis parameters and FORC diagrams indicated that the magnetic grain size had remained constant through glacial/interglacial variations. We surmise that the magnetic grains were derived primarily from magnetite-bearing volcanic rocks in the vicinity of the Ross Sea and that changes in magnetic concentration in the Eltanin 27-21 core were caused by mixing with material with much lower magnetic concentration brought into the Ross Sea in greater and lesser amounts during glacial and interglacial times. Our results demonstrate for the first time that during the Quaternary, the climate of the Ross Sea sector was subject to Milankovitch forcing. They also provide a distal record of environmental magnetic paleoclimate proxies in the Ross Sea that can be compared with the proximal records being obtained from the ANDRILL project.

Aging, memory and rejuvenation in collections of two-level subsystems: A comparison with spin glass dynamics

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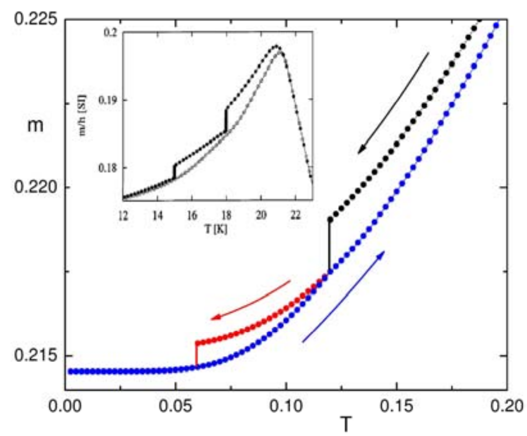
A spin glass is a collection of magnetic moments which undergo an apparently cooperative phase transition, below a well-defined critical temperature T_G , into a magnetically frozen state in which the moments are locked into an orientationally random configuration which lacks the long-rang uniform or periodic order typical of conventional frozen magnetic states. The three defining characteristics of the nonequilibrium relaxation dynamics of spin glasses are aging, memory, and rejuvenation. **Aging** refers to the observation that the magnetic response depends on the time t_a for which the system is held at constant temperature following cooling from above to below T_G . **Memory** refers to the observation that if cooling in a field (zero or nonzero) below T_G is temporarily halted and the system is aged at a constant temperature T for a time t_a before cooling is resumed, then the magnetic response exhibits a "step" (in the field cooled case) or a "dip" (in the zero field cooled case) at the ageing temperature T when the system is subsequently warmed from low temperatures in a field. **Rejuvenation** refers to the observation that if aging at temperature T is followed by a temperature shift from T to $T \pm \Delta T$ then, for sufficiently large shifts ΔT, the system relaxes as if it was unaffected by the previous aging at T and had been cooled directly to $T \pm \Delta T$. This paper presents detailed numerical simulations of magnetic relaxation isotherms for a Preisach collection of two-level subsystems in response to all of the standard field and temperature histories which are typically employed experimentally to probe the relaxation dynamics of spin glasses. Each subsystem is characterized by a moment μ, a dissipation barrier W_d, and a level splitting W_s, and the ensemble is described by a distribution of characteristic energies $p(W_d,W_s)$. The purpose of the investigation was to search for evidence of nonequilibrium aging phenomena in Preisach assemblies of bistable subsystems, and to explore their relationship and possible relevance to spin glass dynamics. These simulations show that Preisach systems do indeed exhibit aging, memory and, potentially, rejuvenation effects, analogous to those observed in real nanoparticulate assemblies and other spin glasses, including certain properties which have traditionally been assumed to be a unique signature of collectively ordered, frustrated spin glasses and nanoparticulate superspin glasses, such as the "flatness" of the field-cooled magnetization below the critical temperature, and memory effects in the zero field cooled magnetization. The insert in the figure on the right shows two-step memory in the measured field cooled moment of an $FeMnTiO_3$ spin glass, and the main body of the figure shows a numerical simulation for a Preisach collection of two-level subsystems.



Rock-magnetic results from Borehole PRAD1-2, a 370 ka record of climatic and environmental change in the Central Adriatic Sea

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In the framework of Promess-1 project we present paleomagnetic and rock-magnetic results (U-channel measurements) from a long borehole (Prad1-2) drilled in the Central Adriatic Basin. The 71.2 meters of sediment represent a continuous record deposited during the last four glacial-interglacial cycles (late MIS11-MIS1; about 370 ka).

A multiproxy integrated chronological framework was established by using oxygen and carbon stable isotopes, magnetostratigraphy and the main microfaunistic bioevents. The paleomagnetic record indicates an interval of reverse polarity identified, on the basis of its stratigraphic position near the MIS6/MIS5 boundary, as the Iceland Basin excursion (IBE).

The magnetic mineralogy is dominated by magnetite, and variations in both concentration (ARM, SIRM) and grain-size related magnetic parameters (SIRM/ARM) reflect changes in sediment supply during the glacial-interglacial stages as well as changes in environmental conditions including the formation of sapropel layers. Fine-grained material is predominant during interglacial periods whereas larger grain sizes characterize glacial stages. The latter also exhibit an increasing coercivity, particularly evident during MIS2 and MIS8. Peak values in anhysteretic remanence could be related to the presence of bacterial magnetite during interglacials. Selective dissolution of magnetic grains (low ARM and SIRM values coupled with high SIRM/ARM ratio) clearly identify anoxic layers representative of sapropel layers, and their presence is quite surprising at the shallow water depth of only 185.5 meters. This study shows that magnetic parameters can be a powerful tool for reconstructing oceanographic and climatic changes occurring in the Adriatic Basin, and these variations appear to be in phase with the Mediterranean and North Atlantic systems.

Paleomagnetic records of planetary differentiation and evolution

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Remanent magnetization in terrestrial rocks records the time behavior of the Earth's geomagnetic field and the thermal history of the interior. The internal evolution of other differentiated bodies in the solar system should similarly be recorded in meteorite and returned samples from these bodies. In fact, the ancient ages and relatively superior state of preservation of extraterrestrial planetary surfaces should permit us to understand the evolution of planetary objects during very early epochs from which we have essentially no terrestrial rock record. But extraterrestrial materials also present special challenges, including lack of geologic context, unfamiliar minerals, and shock processing. Against the backdrop of nearly five decades of previous research, we review the state of our understanding of planetary paleomagnetism, focusing in particular on the magnetic records of differentiated objects including Mars, the Moon, and other achondrite parent bodies. We argue that despite considerable limitations imposed by this unfamiliar sample suite, we have learned fundamental things about the histories of these parent bodies, which in turn have broad implications for our general understanding of planetary evolution and field generation.

Assessing the role of magnetostatic interactions using nano-particle arrays

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Although it has long been recognised that inter-grain magnetostatic interactions can play a dominant role in controlling their palaeomagnetic recording fidelity, it has only been relatively recently that the experimental and computation tools have become available for us to fully investigate the problem.

Experimental investigations of magnetostatic interactions formally relied upon using powdered samples of minerals, such as magnetite, dispersed in a non-magnetic matrix. Such samples have yielded useful information, but it has always been difficult to avoid both a spread in grain sizes, and particle clumping - making it almost impossible to determine the effective inter-grain separation. These experimental observations also lacked theoretical verification since the complex non-linear interactions were not amenable to easy computation.

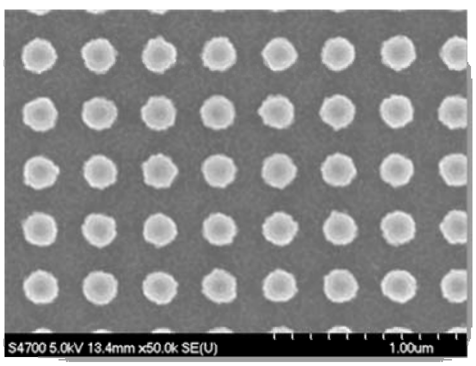

Figure 1. Part of an array of magnetite particles formed by electron-beam lithography of a thin film of iron

We have taken a radically different approach to producing laboratory samples, whereby we pattern thin films of iron using electron beam lithography. The patterns are first made on a silicon nitrate (SiN) hard layer by etching in SF_6/N_2 gas mixture, and subsequently into the Fe layer by dry etching in CO/NH_3. The patterned Fe is then oxidised to Fe_3O_4 (Fig 1). This method is capable of producing mono-dispersions of magnetite, having a precisely defined grain size and shape covering the single domain to pseudo-single-domain grain sizes, and with inter-particle separations from near touching to 3 times the width of a grain (essentially non-interacting). The magnetic characterisation of these samples is then achieved using hysteresis measurements and FORC analysis.

The results are compared against numerical modeling using a finite-element (FE) micromagnetic model. Although FE models require much more CPU time than finite-difference models is used so that a much better account of the grain shape and inert-grain separation is achieved. A new, highly-parallel micromagnetic algorithm will be discussed, along with the modeling of the particle arrays.

Rock magnetic evidence of a connexion between *tephra* deposition and monsoon dynamics (Rungwe Volcanic Province, Tanzania)

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Most outcropping, unconsolidated and pedogenized rocks from the Rungwe Volcanic Province (RVP) in southern Tanzania consist in weathered pyroclastic materials of basaltic and trachytic composition. To document the original characteristics of such materials as emitted during the last 45 ka, the magnetic properties (magnetic susceptibility, remanence, hysteresis, low- and high-T measurements) of numerous well dated and preserved *tephra* layers as deposited in the Lake Masoko sedimentary sequence (south of the RVP) have been analyzed. Complementary analysis were performed on outcropping ash deposits from the Rungwe toposequence and volcanic glass shard concentrates. Two main groups of *tephra* are identified according to their respectively high and low (Ti-) magnetite phenocryst content and associated magnetic signatures. Only a few events correspond to the first group and locate during the late glacial period. Their high mafic content is consistent with the activity of the Kiejo and local, low-altitude activity along the Mbaka fault and Masoko area. These events likely include the hydromagmatic explosions which resulted in the formation of recent maar structures such as Kambanganguru, Kungururu or Itamba (a few km South and East of Masoko).

In contrast, the second group (more than 50 events during the last 45 ky) has a relatively low iron content. The glass exhibits an SP to SD dominant signature. Ti- magnetite and -hematite inclusions are suggested from low-T behaviours. The impoverishment in phenocrysts and MD-like ferromagnetic grains together with the fine and well sorted glass shard assemblages are consistent with the surtseyan activity of the Rungwe or Ngozi volcanoes, which emitted more differenciated lavas (trachy-phonolites) during the Pleistocene. Due to the increased probability of *tephra* deposition near climatic precession extremes, i.e. during northern hemisphere insolation maxima (11 and 35 ka BP) *and* southern hemisphere insolation maxima (1 and 23 ka BP), our results suggest a relationship between the regional hydrology (driven here by monsoon) and explosive activity in the RVP. Further site studies are needed north of the RVP to better reconstruct the control of wind direction on *tephra* fallout.

Contribution of the French CLEHA-ECLIPSE and RESON-CORUS programs.

A preliminary paleointensity and geomagnetic excursion record for the Brunhes Normal Chron from New Zealand.

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The recent Matacore MD152 voyage of the RV Marion DuFresne collected long piston cores from the west coast of the South Island and the east coast of the North Island, New Zealand. Sedimentation rates in the West Coast cores are ~2-3 cm/k.y. and they extend back to the B/M boundary, whereas sedimentation rates in the East Coast cores are >10 cm/k.y. and they only extend back to ~250 Ka. U-channels from the cores have been subjected to step-wise AF demagnetization and imparted with an ARM at 1.0 Gauss. All moment measurements were made on the pass through 2G cryogenic magnetometer housed in the field free room at the University of Otago. Coercivity and IRM data indicate that magnetite is the predominant carrier. Grain-size does vary between cores and between sedimentary units within cores. However, within sedimentary units grains size appears to be uniform. At this stage our record extends back to the Brunhes / Matuyama Boundary with paleointesnisty minima and inclination flattening events correlated with the Mono Lake, Laschamp, Blake, Albuquerque, Iceland Basin, Pringle Falls and Mamaku excursions. Other younger excursions are also recognized. It is possible to match aspects of our paleointensity record with that reported by Macri et al. (2004) and also Valet & Meynadier so we are reasonably confident that we can use paleointensity as a correlation and dating tool, at least for the Late Pleistocene, in the New Zealand region. Independent correlation is also available from tephra horizons recovered in the same Marion DuFresne cores.

References:

Macri, P., Sagnotti, L., Dinares-Turrell, J., Caburlotto, A., 2004. A composite record of Late Pleistocene relative geomagnetic paleointensity from the Wilkes Land Basin (Antarctica). Physics of the Earth and Planetary Interiors, v. 151, 223-242.

Valet, J.-P., Meynadier, L., 1993. Geomagentic field Intensity and reversals during the past four million years. Nature, v. 366, 234-238.

What is the physical basis of the magnetic sense in animals?

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Various animals across all major groups are known to be capable of using the geomagnetic field as an orientation cue. The underlying physical mechanisms of the magnetic sense are not satisfactorily understood yet, despite some recent progress. This talk gives an overview of the two most prominent hypotheses about the physical basis, the so-called *radical pair* and *magnetite* hypothesis, respectively. Both are physically plausible and their predictions are in agreement with behavioural experiments. The hypotheses are complimentary in that the corresponding mechanisms seem to be realized in two kinds of sensory cells that serve two different purposes – the radical-pair mechanism for the basic task of detecting the local field direction, and a magnetite-based mechanism for the advanced task of determining small variations in field intensity, which are believed to provide more specific information about the position as part of the navigational map.

The *radical pair* hypothesis is based on the fact that weak (Earth-strength) magnetic fields influence chemical reactions that involve an intermediate step with two unpaired electrons. The relative alignment of the unpaired electron spins on each radical controls the reaction rates and yields, and in turn is controlled by the hyperfine field from the magnetic nuclei and modulated by an external magnetic field. Hyperfine interactions typically are anisotropic, hence the effects of an external field on the reactions depend on its orientation relative to the molecular frame of reference. A $\cos(2\,\phi)$ dependence is predicted here, which is in agreement with the fact that the compass sense of migratory birds detects the axial orientation of magnetic field lines, but not their polarity. Behavioural experiments using radiofrequency magnetic fields to specifically perturb that mechanism also suggest its involvement in the compass sense of birds. However, the candidate molecules and structures are missing.

The *magnetite* hypothesis, on the other hand, is more straightforward in so far as magnetite-containing cells have already been identified in nerve tissue of trout and homing pigeons. In trout, single-domain crystals of magnetite, presumably arranged in chains, could work as simple torque receptors, conceptually similar to the case of magnetic bacteria. In homing pigeons, the situation is more complex, where specific nerve endings contain numerous micron-sized clusters of superparamagnetic magnetite (grain size < 8 nm) besides chains of micron-sized amorphous platelets made up mainly of ferric iron and phosphorous. The superparamagnetic clusters may well act as magneto-elastic transformers, converting field changes into shape changes, on the basis of which a field-intensity meter of moderate sensitivity can be realized. The role of the amorphous substance is not clear yet. Provided that it is similar to biological ferrihydrite (a hydrous ferric-oxide-phosphate), its susceptibility at body temperature would be two orders of magnitude smaller than that of the magnetite clusters, which makes a magnetic field amplification through this substance unlikely. It therefore remains somewhat enigmatic by what mechanisms homing pigeons and trout may achieve the high magnetic field discrimination (100 nT) on the receptor level, as deduced from electrophysiological experiments and behavioural studies.

An efficient micromagnetic method of calculating FORC diagrams for pseudo-single domain particles

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First-order reversal curve (FORC) diagrams are a useful statistical tool for studying distributions of magnetic properties in sample, from which the prevailing domain state and switching mechanisms can be inferred. When it comes to micromagnetic simulations of FORCs, it is clear that distributions of magnetic properties need to be modelled in order to mimic the statistical character of real FORC diagrams. This has been done successfully for non-interacting and interacting single-domain particles (Newell, G3 2005; Muxworthy & Williams, JAP 2005; Egli, JGR 2006), but remains a computational challenge for assemblages of incoherently switching particles. Here it is shown how FORC diagrams can be computed efficiently for an assemblage of pseudo-single domain particles in the limit of negligible inter-particle interactions. A rigorous micromagnetic computation is only needed to compute a full branch of the hysteresis loop in the first place for each particle of the assemblage. By rearranging the data, the FORC diagram for the assemblage can then be constructed solely on the basis of each major branch, without having to explicitly compute FORCs. Besides being computation-time efficient, that approach also allows one to specifically focus on the irreversible part of the FORC diagram, which is equivalent to the second-order reversal curve distribution.

Paleomagnetic and rock magnetic studies of the Sakurajima 1914 and 1946 andesitic lavas from Japan: a comparison of the LTD-DHT Shaw and Thellier paleointensity methods

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Paleomagnetic and rock magnetic measurements have been made on samples from the 1914 and 1946 Sakurajima andesitic lava flows in order to investigate the suitability of andesite to record both paleodirection and paleointensity. The lava flows were split in to three sites, each of which consists of two or three sub-sites. A range of rock magnetic experiments have been made on multiple samples per flow and the samples can be split into two broad rock magnetic categories (I and II).

Paleodirection was determined by stepwise thermal demagnetization and the mean direction determined from both flows is very close to that expected from IGRF-10. Paleointensity was determined using the LTD-DHT Shaw technique and the Thellier method on sister samples of the same cores. 64 out of 72 LTD-DHT Shaw paleointensity experiments were successful and there are no differences between the sub-sites. 70 out of 71 Thellier paleointensity experiments were successful; however, for sub-sites in two out of the three sites there are large differences between the mean paleointensities.

When all paleointensities are normalized to the expected value from IGRF-10, the mean is 0.98±0.11 (±σ) for the LTD-DHT Shaw method and 1.12±0.13 (±σ) for the Thellier method. These means are statistically distinguishable and this is related to the different rock magnetic properties of the samples. If only category I samples are considered the LTD-DHT Shaw mean is 1.05±0.07 (±σ) compared with the Thellier mean of 1.08±0.08 (±σ). In contrast there is a much larger spread in the means determined from category II samples: 0.94±0.11 (±σ) from the LTD-DHT Shaw experiments and 1.15±0.15 (±σ) from the Thellier experiments. This spread could be caused by magnetic interactions between magnetic domains. Assuming high temperature oxidation of titanomagnetite grains on natural cooling, we suggest a scenario that can qualitatively explain the difference between the LTD-DHT Shaw and Thellier paleointensity results.

Magnetostatic interactions in Pacific deep-sea sediments inferred from FORC diagrams: Implications for magnetic grain-size proxy and relative paleointensity normalization

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Characterization of magnetic grains in deep-sea sediments was carried out using first-order reversal curve (FORC) diagrams and iso-thermal remanent magnetization (IRM) acquisition curves. The sediment samples are taken from widely separated regions of the Pacific: the central North Pacific, the Ontong-Java Plateau in the equatorial Pacific, and the Manihiki Plateau in the south Pacific. The FORC diagrams revealed that the magnetic grains consist mainly of a non-interacting single-domain (SD) component and an interacting SD component, and additionally of a multi-domain (MD) component. Relative abundance of these components were estimated semi-quantitatively by curve fitting of cross-sections along a line parallel to the axis of local interaction fields (H_u) and passes through a peak in the coercivity (H_c) with three components assuming a Gaussian distribution. The IRM acquisition curves of the sediments from all regions could be described by two dominant components assuming a log-Gaussian distribution, and the mean coercivities of the two components are ~40 and ~100 mT, respectively. It is estimated that the former component is carried by biogenic magnetite, and roughly corresponds to the non-interacting SD component derived from the FORC diagrams, and the latter is carried by eolian maghemite, corresponding to the interacting SD component. The ratio of anhysteretic remanent magnetization (ARM) to saturation IRM (SIRM) decreases with an increase in the proportion of the interacting SD component. This implies that the ARM/SIRM ratio is significantly affected by magnetostatic interactions, and does not necessarily reflect magnetic grain size although it is often used as such a proxy. In relative paleointensity estimations, ARM is often used as a normalizer to correct for the difference in magnetizability of sediments. The effect of magnetostatic interaction on detrital remanent magnetization (DRM) acquisition is not well understood, but if it is similar to that on SIRM, normalization by ARM may overcompensate the non-interacting SD component, and cause a significant coherence between the normalized intensity and the normalizer, which has been sometimes reported in literature.