Inside...
Visiting Fellow Reports 2
Current Abstracts 6
New Visiting Fellows 11
Position Available 12

The IRM Quarterly
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Weigle Hall on the campus of St John's College in Santa Fe

Santa Fe VI

Mike Jackson
Subir Banerjee
IRM

38 participants from the US, Canada, France, Germany and Japan assembled at St John's College from June 3 to 6 for the sixth NSF-sponsored Santa Fe Conference on Rock Magnetism

After productively integrating with the MAG-NET symposium in Erice, Sicily in 2002, the IRM's biennial conference on rock magnetism returned home to Santa Fe this year to delve into two major topics:

(1) Characteristics of nanophase and other not-yet-well-understood magnetic minerals, and interdisciplinary approaches for analyzing them.

(2) New approaches to data collection, storage, processing and analysis in rock- and environmental magnetism.

Dynamic and insightful keynote lectures by **Jim Rustad** (*UC-Davis*) and **Roy Roshko** (*U of Manitoba*) opened the doors to day-long explorations of each of these topics before the workshop closed with a half-day assessment of future trends in research and funding, and an introspection on education and training of students.

Dirty Little Magnets: Nanophases, Oxyhydroxides, Lamellar Magnets, and Other Unusual Suspects

In environmental magnetism and sedimentary paleomagnetism, the signal often originates not only in "textbook" carriers like stoichiometric magnetite, but also in complex, metastable fine-grained mineral assemblages, which involve a rich set of additional physical phenomena, including weak antiferromagnetism of surficial iron oxides and oxyhydroxides; ordering of nanoscale structures and kinetics of nanoparticle assemblages; and core-shell dynamics in partially-oxidized magnetite.

The behavior of materials at the nanoscale is fundamentally different from their familiar macroscopic-scale behavior. Surface energies and processes dominate; quantum mechanical effects become significant; and even the distinctions between amorphous, disordered and crystalline solids become blurred. Similarly, the distinctions between physics, chemistry, biology, and materials science begin to break down at the nanoscale. In Earth's surface environment, this is where the action is. According to the report of the NSF-sponsored Nanogeoscience workshop at Lawrence Berkeley Lab in 2002, although nanoparticles constitute just a tiny fraction of the total mass of material in the surficial environment, they nevertheless represent most of its surface area, and consequently they also account for most of its chemical activity.

Metal oxide and sulfide nanoclusters are actively produced, consumed and transformed by bacteria and other biogeochemical and geomicrobiological agents. Such activity, in combination with inorganic surface chemistry, is the ultimate origin of many environmental magnetic signals, as well as a root cause of paleomagnetic overprints and/or destruction of paleofield records. Beyond that, these processes play key roles in the biogeochemical evolution of soils and sediments, because of the vigorous participation of colloidal iron oxide particles in electron transfer and metabolic reactions. Fundamental work still needs to be done, and is being done, on understanding the processes by which the mineral-water interface evolves in nature, in the laboratory, and, as **Jim Rustad** explained, *in silico* (i.e., in computer models). Molecular-dynamics simulations play an essential part in understanding aqueous interfacial chemistry, providing a means of "observing" proton transport and transfer reactions. Jim and his colleagues examine these processes by (e.g.) numerically splitting bulk virtual magnetite along (001) and observing the interaction of the digital Fe cations in tetrahedral and octahedral surface sites with numerical molecules of water and electrolytic solutions [Rustad et al., 2003].

Following the first keynote lecture, a working session on "unusual" magnetic carriers (organized and chaired by **Ken Kodama**, *Lehigh University*, and **Christoph Geiss**, *Trinity College*) was kicked off by three invited talks. Low-crystallinity, nanophase iron oxyhydroxides such as ferrihydrite, goethite, and lepidocrocite are common environmentally-relevant magnetic minerals. **Yohan Guyodo** (*LSCE/CNRS , Gif-sur-Yvette)* discussed the dramatic evolution of magnetic properties that accompanies growth of nano-oxyhydroxides in the lab and in nature, making low-temperature magnetometry a sensitive probe for characterizing these phases. Yohan also showed evidence that in some cases ferrihydrite (a common precursor in the formation of other phases such as goethite) may remain magnetically ordered at temperatures much higher than its conventionally designated Néel temperature (~120 K), up to room temperature and above. Nanoscale magnetic phenomena also occur at exsolution interfaces in the hemoilmenite series, and **Laurie Brown** (*UMass-Amherst*) reviewed the evolution of the concept of lamellar magnetism (complex interaction of cation ordering, magnetic ordering and subsolvus

Santa Fe *continued on p. 10...*

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Magnetic parameters of rivers sands: tracers of rocks? Sands of La Martinique Island

The aim of this project is to compare the magnetic properties of rivers sands and the associated rocks and particularly mass normalized susceptibility χ [m^3/kg]. One may consider that magnetic susceptibility reflects the temporal evolution of detritic contribution in marine sediments. If we want to trace the sources of the sediments, it is important to assess if and how the weathering has an effect on the magnetic properties.

This is why we chose to achieve systematically magnetic measurements on rivers sands and parent rocks of La Martinique Island (Caribbean Sea). The lithologies are for most of them andesitic and all sampled sites are chosen monolithological.

The preliminary results obtained for χ, SIRM and ARM show that the values of sands and rocks stay in the same range of magnitude. At the first order, sand seems to be a good tracer of its source.

For a detailed study, it is important to assess if the magnetic mineralogy of sands and rocks is similar or diverse. One of the different ways is the measurement of thermomagnetic curves at low temperature (10-300K) as well as warming and cooling curves of SIRM produced by a 2.5 T field (FC-ZFC and RT-SIRM). I measured also the frequency dependence of AC susceptibility.

First results obtained at the IRM show that, for the majority of sites (especially the youngest lithologies), rocks and sands have the characteristic behavior of titanomagnetite. It seems that the content of Ti is smaller in sands than in rocks (Fig.1). This is surprising since Ti has a low solubility (J. Gaillardet, pers. com.), the content of Ti should be similar or greater in sands. Taking thermomagnetic curves at high temperature (20-700°C) into account, one may wonder if the behavior of sands at low temperature (Fig.1-B) is not characteristic of titanomaghemite with the same content of titanium than for rocks. But it is difficult to be sure of this assumption because there aren't any reference curves of AC susceptibility for titanomaghemite and FC-ZFC curves do not allow concluding really to the presence of titanomaghemite. If this assumption proves true, this will mean that a phenomenon of low oxidation happens between sands and rocks.

For two sites (Fig.2), rocks have characteristic behavior of titanohematite with content of Ti over to 83% but sands, collected in river flowing over the rocks, have titanomagnetite behavior. This phenomenon is not yet very well understood.

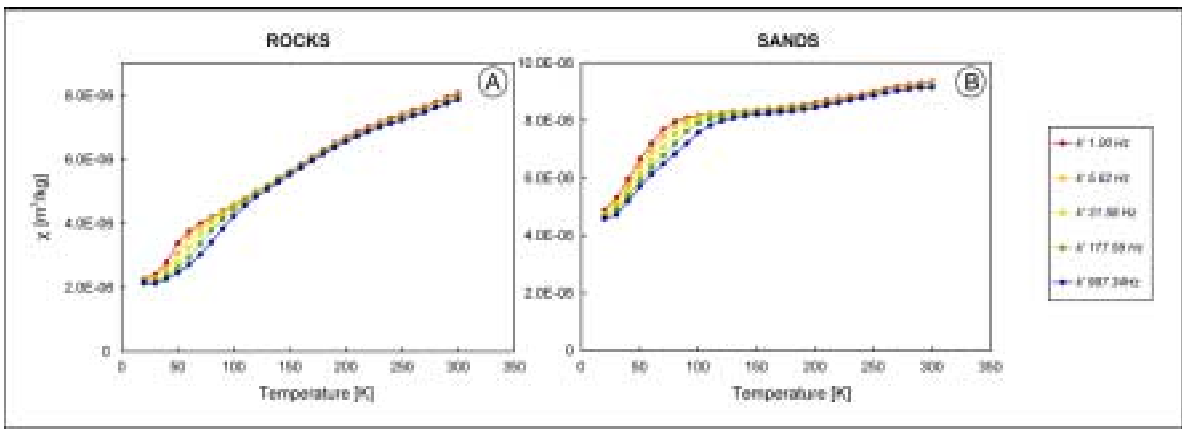

Fig.1: Temperature and frequency dependence of AC susceptibility for sands and rocks samples (samples of the youngest lithology).

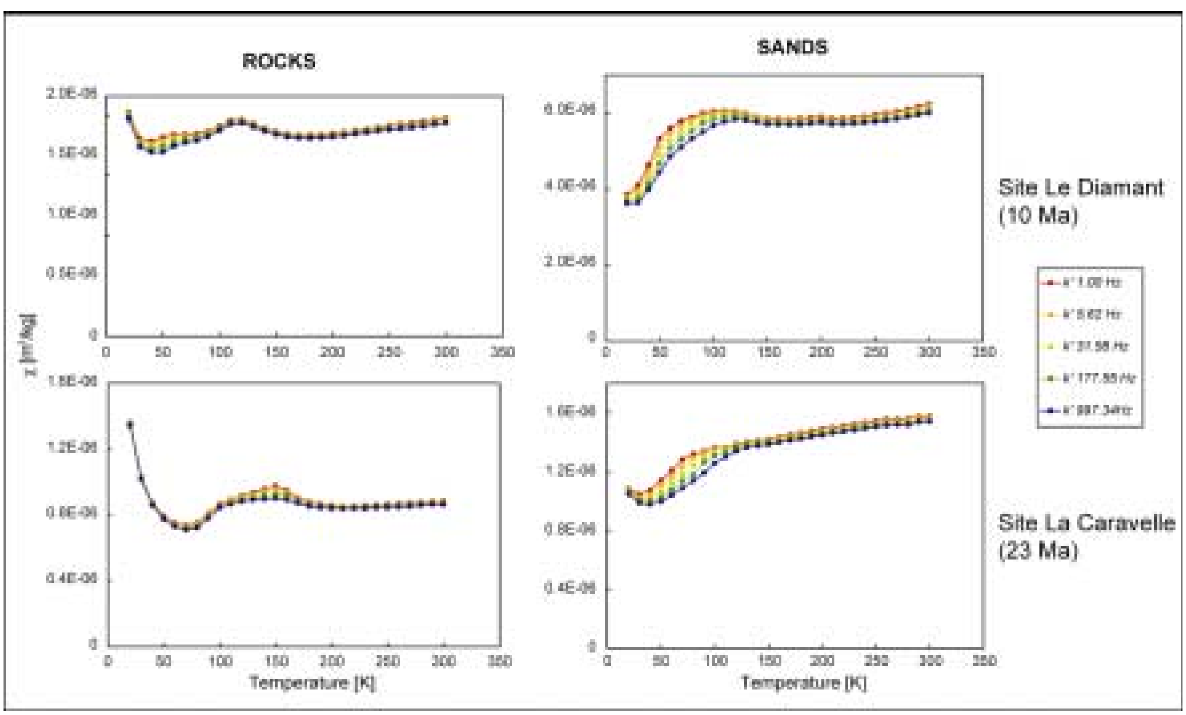

Fig.2: Temperature and frequency dependence of AC susceptibility for sands and rocks samples (the oldest lithologies Site La Caravelle and Site Le Diamant).

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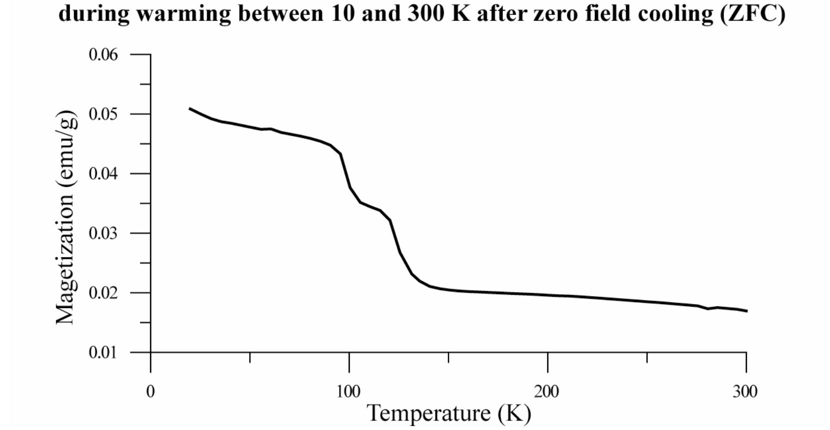
Superparamagnetic Contribution to the Magnetic Properties of Shocked Rocks from the Vredefort Meteorite Crater

I am studying the paleomagnetism and rock magnetism of meteorite impact craters for my Ph.D. thesis at IPGP. The Vredefort impact crater in South Africa has proven a very interesting case. The dominant magnetic mineral in the Vredefort rocks is Fe-rich magnetite with Curie points ranging from 570 to 580°C. Hysteresis parameters suggest that the samples are dominated by pseudo-single domain and multi-domain grain sizes (Hcr/Hc >3; Jrs/Js <0.15). Interestingly, the same samples have the highest Koenigsberger (Q) ratios in the world for similar rocks types (Hart et al., 1995). I have found in my own studies that lightning cannot be the cause of the elevated NRM intensities. As the susceptibility dependence on this ratio is important, I wanted to quantify the contribution of SP grains in the Vredefort rocks, which was the reason for my stay at the IRM.

I measured the low-field magnetic susceptibility both as a function of frequency and temperature (between 20 and 300 K) for 24 specimens (10 using the MPMS and 14 using the LakeShore Low Temperature AC Susceptometer). I also measured the remanent magnetizations of 47 specimens during warming between 10 and 300 K after zero field cooling (ZFC) using the MPMS. I measured the remanent magnetizations of 4 specimens after field cooling (FC) in a 2.5 T field between 300 and 10 K, or a partial FC between 300 and 110 K and a ZFC between 110 and 20 K for 2 specimens.

The low-field susceptibility measurements showed no frequency dependence, meaning that the Vredefort rocks are virtually void of SP grains! Of note, 32 of the 47 ZFC measurements show two distinct, well-isolated "Verwey" transitions— one around 100 K (102.8±3.6 K) and another at 120 K (124±2.9 K) (see figure). In theory, FC experiments can help deduce the relative contributions of single and multi-domain grains; however, my new results will require a more complicated interpretation, which is the focus of my present research.

Specimen V2121A showing two distinct "Verwey" transitions at 101 and 126 K during warming between 10 and 300 K after zero field cooling (ZFC)



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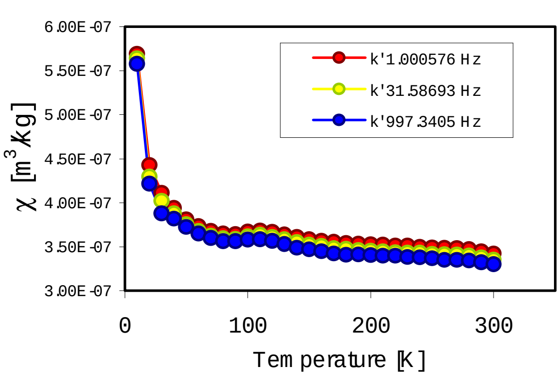
Identification of Magnetic Authigenesis in drill-cuttings from Venezuelan Oil Fields

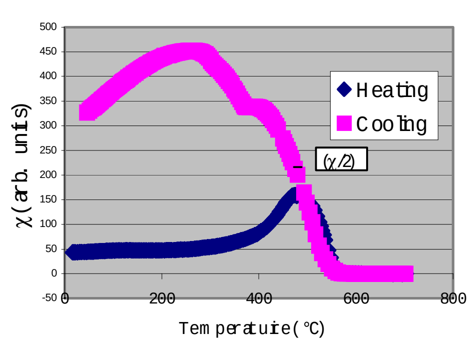
During the last years, our Paleomagnetic and Rock Magnetic Laboratory at the Simón Bolívar University, Venezuela, has focused its research to the oil industry. Particularly we have studied magnetic surface contrasts as an alternative means of assessing hydrocarbon reservoirs. It has been proposed that surface magnetic contrasts can be the result of the presence of a subjacent reservoir. The magnetic anomalies measured at shallow levels could be a direct indicator of the existence of hydrocarbons, as they have been interpreted as the result of the presence, at shallow depths, of authigenic low coercivity magnetic minerals (e.g. magnetite). These minerals could be the result of the alteration of primary Fe oxides due to a reducing environment, induced by the underlying reservoir. In the last few years, we have examined the possible causal relationship between magnetic minerals and hydrocarbons via rock magnetic and electron paramagnetic resonance (EPR) analyses of drill cuttings. To better understand the nature of the chemical processes involved in the hydrocarbon-induced magnetic authigenesis, it is necessary to carry out a precise characterization of the magnetic mineralogies involved.

In this sense, the main purpose of my visit to the IRM was to perform low (at the MPMS2 cryogenic Susceptometer) and high (at the Geofyzika KLY-2 KappaBridge AC Susceptibility Bridge) temperature magnetic susceptibility measurements in order to identify the main magnetic mineralogies present at anomalous levels. Particularly, low temperature MS measurements could indicate the presence (magnetite as the chief magnetic mineral, suggesting a reducing process), absence (possible existence of maghemite and, then, an oxidation process) or shift (partial oxidation of magnetite) of the Verwey transition. Also we wanted to study the grain size distribution of magnetic minerals with hysteresis loops measurements at room temperature, using the VSM. To do so, I have selected 17 samples from producer and non-producer wells of three Venezuelan oil fields. These samples correspond to the anomalous MS levels, previously identified at these wells.

Most of the analyzed samples show the Verwey transition (around 120 K), indicating the presence of magnetite. In some cases this transition is weak

Figure 1.- Low and High Temperature Susceptibility of sample GF142050





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indicating partial oxidation of magnetite. This observation agrees with maximum unblocking temperatures of 580ºC in the thermomagnetic runs (see figure 1). In some cases, these measurements display the formation of magnetic phases, as magnetite, during heating. The possible presence of titanomagnetite, indicated by the low temperature MS increase (see Rock Magnetic Bestiary, IRM) was also observed (see figure 2).

The analysis of the hysteresis parameters via a Day´s plot reveals predominantly PSD grain size (see figure 3). Some points present an anomalous behavior that should be analyzed.

Presently I am working on the interpretation of the IRM results. In combination with the previously obtained results, these will be a great aim to understand the possible mechanism of magnetic authigenesis.

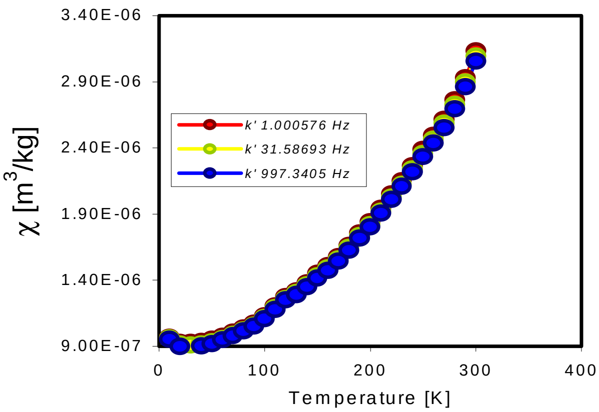

Figure 2.- *Low Temperature Susceptibility of sample GF3X2950*

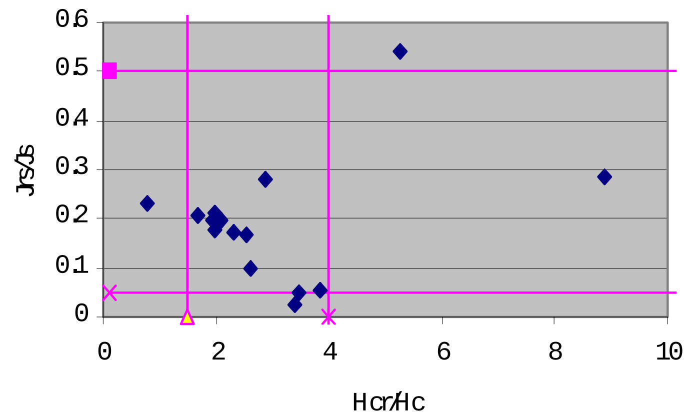

Figure 3.- *Day´s plot of the analyzed samples*

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Detecting oxidation state of magnetite-bearing basalts from China using low-temperature magnetic data

INTRODUCTION

Magnetite has been extensively studied in rock magnetism and paleomagnetism, as it is the most abundant magnetic mineral in carrying natural remanent magnetization in rocks. Among various methods to study the magnetic properties of magnetite, the study of low–temperature phase transition in magnetite, the Verwey transition, has been increasingly utilized in rock- and paleomagnetism. For nominally stoichiometric magnetite, the Verwey transition occurs at about 120K. For natural samples, the observed Verwey temperature often ranges from 115 to below 100K. The transition temperature is reported to decrease with presence of vacancies, impurities, and elevated pressures (see Kosterov, 2002, Muxworthy and McClelland 2000). Of special interest is the effect of oxidation on low-temperature magnetization of magnetite (Özdemir et al., 1993; 2002) and an apparent suppression of the Verwey transition in oxidized magnetites has been reported (Özdemir et al., 1993). Mössbauer spectra have also been used to charaterize the oxidation state of magnetite samples. For stoichiometric magnetite, previous studies have shown that zero field room temperature Mössbauer spectrum consists of two spectral components, related to Fe-cations in tetrahedrally corrdinated (A) and octahedrally coordinated (B) sites of the inverse spinel lattice and the relative ratio (A/B) should be close to 1:1.88 (Da Costa et al., 1995). For oxidized (cation-deficient) magnetite, the ratio increases with oxidation parameter (Da Costa et al., 1995).

During our work on two groups of Late Cretaceous basalt samples from localities in China, we have done paleomagnetic directional analysis on them. These rocks record faithfully the magnetic field that existed at the time of their eruption, are fresh enough for isotopic dating, and behave nicely during laboratory heating experiments. The salient observations of the two groups of basalts are outlined below:

<u>1). 121 Ma basaltic samples from Liaoning, NE China</u>

The demagnetization behavior of these basalt samples was straightforward: vector diagrams for both AF and thermal demagnetization show a decrease of remanence straight to the origin. Thermomagnetic curves on the dated basalt are dominated by low-titanium magnetite with a Curie temperature between 560-585°C. Good reversibility of heating and cooling curves suggesting no distinct magnetic mineralogical alteration occurs during heating, which is desirable for paleointensity studies. Preliminary paleointensity determination indicates that the field in China just prior to the Cretaceous Normal Superchron was about half the present day virtual dipole moment (VDM).

<u>2). 80 Ma basalts from Inner Mongolia, NE China</u>

Preliminary data from IRM acquisition experiments, unblocking temperatures, and coercivity determinations suggest that fine-grained magnetite and titanomagnetite are the most likely magnetic carriers in these samples. Visual inspection of the rocks and some thin section observations show almost no evidence of anything but low-temperature alteration in the rock. We have obtained a number of preliminary results with paleointensity values significantly lower at 80 Ma (compared with today's VDM).

Thus, it would be important to carry out a comparative experimental study of low-temperature measurements on samples from these two groups, particularly in cycling through the Verwey transition. One prediction of this work may be that if the 121 Ma basalt samples from NE China correspond to nearly stoichiometric magnetite, their Verwey transition temperatures should be characterized by a dominant peak at 120 K. On the other hand, Verwey transitions for those 80 Ma samples that went through low-temperature alteration should have a broad derivative peak that is below 120 K. Testing this prediction was the main propose of my visit.

EXPERIMENTS PERFORMED AT THE IRM

(1) Low-temperature measurements for several representative samples with the Quantum Design Magnetic Property

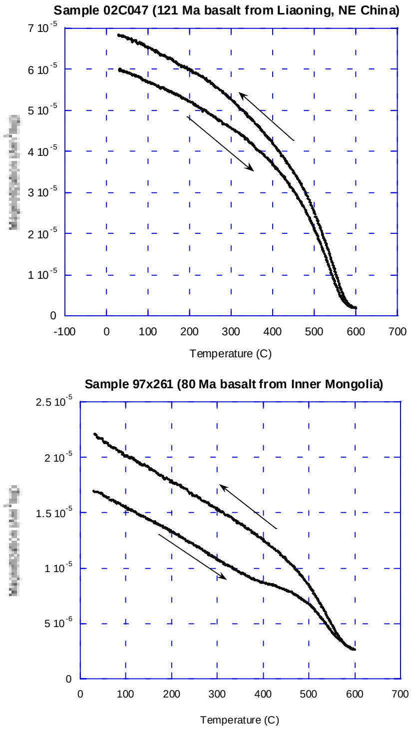

Figure 1. Typical thermomagnetic curves for the Cretaceous basalts from China. (A) 121 Ma basalt sample 02C047 from Liaoning, NE China, (B) 80 Ma basalt sample 97X261 from Inner Mongolia. Arrows show direction of heating and cooling.

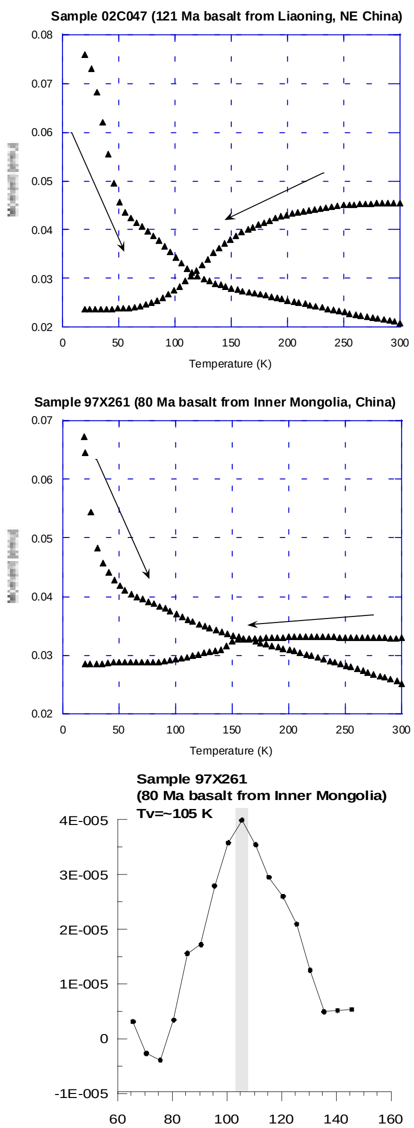

Figure 2 Low-temperature heating curves of saturation remanence for several representative samples (1 emu = 10-3 Am2, SI). (A) 121 Ma basalt sample 02C047 from Liaoning, NE China, (B) 80 Ma basalt sample 97X261 from Inner Mongolia, and (C) Verwey transition for 80 Ma basalt sample 97X261 from Inner Mongolia, obtained by using the new method recently proposed by Liu and Banerjee (2004). The methods involve the following steps: 1) calculate the first-derivative of the low temperature thermal demagnetization of the saturated isothermal remanent magnetization acquired at 20 K (LT-SIRM), which enhances the behavior related to the Verwey transition, and 2) fit a forth-order polynomial background to the data between both 50-70 and 150-300 K, and then subtracting this background from the total derivative curves. The area under the background-corrected derivative curves represents the absolute intensity drop associated with the Verwey transition.

Measurement System (MPMS);

(2) Examination of alternating current (AC) susceptibility measurements as a function of field amplitude and of frequency to see if curves resemble those of synthetic (titano)magnetites;

(3) Curie temperature determination using high applied field with the Princeton MicroMag Vibrating Sample Magnetometer (VSM1).

(4) Mössbauer spectroscopy on a representative sample to help identify the magnetic minerals (titanomagnetite, maghemite or titanohematite, etc).

PRELIMINARY RESULTS

Results for the 121Ma basalt samples show Curie temperatures between 560º and 580ºC, compatible with that of Ti-poor titanomagnetites. The thermomagnetic curves of these samples exhibit very little difference between heating and cooling of the samples (Fig. 1a). Samples with titanomagnetite also exhibit a strong Verwey transition in the vicinity of 110 K (Fig. 2a), and with frequency-dependent susceptibility curves that resemble those of synthetic Ti-poor titanomagnetites (Jackson et al., 1998). These results are in good agreement with the hysteresis ratios that suggest that the bulk magnetic grain size is in the pseudo-single-domain boundary. Mössbauer spectrum of a representative sample also shows sign of abundant presence of magnetite, corroborating the rock magnetic observation mentioned above.

The second group (the 80 Ma basalt from Inner Mongolia) has more than one Curie temperature, thus suggesting the presence of multiple magnetic phases (Fig. 1b). The thermomagnetic signature indicates the inversion of titanomaghemite to a strongly magnetized magnetite, as showing by the irreversible cooling curve. Low temperature curves do not show the Verwey transition clearly (Fig. 2b). When applying the improved rock magnetic method of Liu et al. (2004), which quantitatively separates the behavior related to the Verwey transition of magnetite against the strong maghemite and superparamagnetic magnetite background, only one sample yielded a clear Verwey transition around 105 K. The frequency-dependent relationships are distinctively different from those in the first group, with a much sharper peak of k' around 50 K, suggesting the existence of some ilmenite in the sample.

In summary, the preliminary results I obtained at the IRM have revealed important information about the origin of remanence and on the magnetic minerals present in these two groups of basalt from China. The rock magnetic data obtained at IRM favor our predictions that titanomagntites are the dominant mineral and the primary remanence of the 121 Ma group of basalt, and multiple magnetic phases are present in the 80 Ma group with signs of less pure titanomagnetite characteristics. It does not appear to show, however, that there is a relationship between suppression of the Verwey transition and degree of oxidation in these basaltic samples. In future, I plan to use scanning electron microscope to further define the magnetic minerals.

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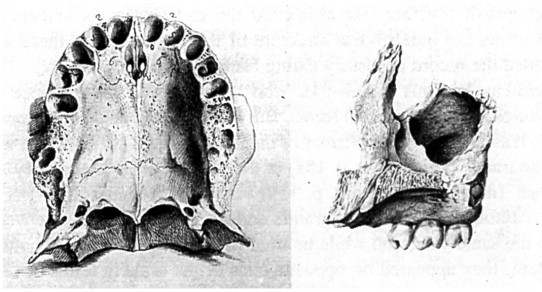

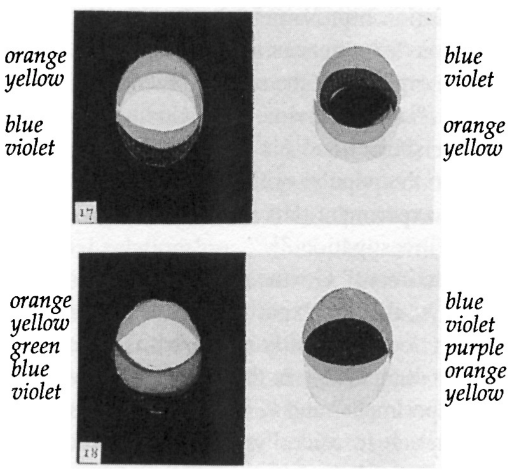

(top) intermaxillary bone in the human skull drawn by Goethe in his studies of comparative anatomy;
(bottom) Goethe's color experiments involving black-and-white figures viewed through a prism; green and purple are produced by additive and subtractive color mixing in the overlap areas in the lower figure;
both from Goethe's Die Schriften zur Naturwissenschaft, *reproduced in* Goethe's History of Science, *by K. J. Fink, Cambridge University Press, 1991.*

Current Abstracts

A list of current research articles dealing with various topics in the physics and chemistry of magnetism is a regular feature of the IRM Quarterly. *Articles published in familiar geology and geophysics journals are included; special emphasis is given to current articles from physics, chemistry, and materials-science journals. Most abstracts are culled from* INSPEC *(© Institution of Electrical Engineers),* Geophysical Abstracts in Press *(© American Geophysical Union), and* The Earth and Planetary Express *(© Elsevier Science Publishers, B.V.), after which they are subjected to Procrustean editing and condensation for this newsletter. An extensive reference list of articles (primarily about rock magnetism, the physics and chemistry of magnetism, and some paleomagnetism) is continually updated at the* IRM. *This list, with more than 5200 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

Alteration & Remagnetization

Zegers, T. E., Dekkers, M. J. and Bailly, S., 2003, **Late Carboniferous to Permian remagnetization of Devonian limestones in the Ardennes: role of temperature, fluids, and deformation**: *Journal of Geophysical Research, v.108*, no.B7, p.1-19.
Hysteresis measurements and low paleotemperatures (<55° C) indicate that component B is a primary Middle Devonian NRM. Postfolding Early Permian component P is carried by pyrrhotite and Carboniferous component C is carried by a magnetite mix that straddles the SD-MD grain-size range (10-30 nm). The relative intensity factor, Ri, defined as ln(intensity P/intensity C), shows a marked spatial correlation with the southern of two Mississippi Valley-type (MVT) ore districts. This, in combination with the timing of remagnetization, suggests that component P pyrrhotite formed as a result of percolation of MVT fluids through these carbonates. Fine-grained magnetite formation, as a by-product of smectite-to-illite conversion in the presence of host-rock-buffered internal fluids during deformation, is the most likely remagnetization mechanism for component C. Pressure solution deformation processes may have enhanced the smectite-to-illite conversion and hence remagnetization.

Anisotropy

Raposo, M. I. B., D'Agrella-Filho, M. S. and Siqueira, R., 2003, **The effect of magnetic anisotropy on paleomagnetic directions in high-grade metamorphic rocks from the Juiz de Fora Complex, SE Brazil**: *Earth and Planetary Science Letters, v.209*, p.1-2.
A complex mixture of magnetic minerals with low and high coercivity are respectively associated with coarse-grained (titano)magnetite and either fine-grained (titano)magnetite or 'titanohematite' grains. The ChRM was acquired after the strong magnetic foliation was formed. The paleomagnetic directions from each specimen within a site tend to approach its AMS or ARM foliation plane. These directions were corrected, specimen-by-specimen from the sites, taking into account the pole of AMS or ARM foliation (K_{min} or ARM_{min}) and the value of the degree of anisotropy (P). Our data set suggests that AMS is a powerful tool to correct the ChRM deviation from paleofields in rocks with complex magnetic mineralogy such as those from the Juiz de Fora Complex.

Biogeomagnetism

Frankel, R. B., 2003, **Biological permanent magnets**: *Hyperfine Interactions, v.151*, no.1, p.145-153.
Magnetotactic bacteria orient and migrate along magnetic field lines. Each cell is essentially a self-propelled magnetic dipole. The magnetic properties of these bacteria have been determined by a variety of techniques, including pulsed hysteresis measurements on single cells.

Environmental Magnetism and Paleoclimate Proxies

Chen, F. H., *et al.*, 2003, **Stable East Asian monsoon climate during the Last Interglacial (Eemian) indicated by paleosol S1 in the western part of the Chinese Loess Plateau**: *Global and Planetary Change, v.36*, no.3, p.171-9.
High-resolution data (2-cm interval, ca. 150 years) of the particle size distribution and the frequency-dependent magnetic susceptibility show that the summer monsoon was strongest and the winter monsoon weakest in the late part of the Eemian interglacial. Contrary to previous reports from the central part of the Chinese Loess Plateau, our results show that the East Asian monsoons in the western part of the Plateau were quite stable during the last interglacial. However, our data do exhibit four abrupt events of intensified winter monsoon during the transition from the penultimate glacial to the last interglacial, and also a time lag between the decline of the winter monsoon and the sudden strengthening of the summer monsoon during the transition from MIS 6 to MIS 5e.

Moreno, E., *et al.*, 2003, **Biomonitoring of traffic air pollution in Rome using magnetic properties of tree leaves**: *Atmospheric Environment, v.37*, no.21, p.2967-2977.
Leaves of evergreen species, like *Quercus ilex*, present much higher magnetic intensities than those of deciduous species, like *Platanus sp*., suggesting that leaves accumulate magnetic pollutants during their whole lifespan. Leaves from *Q. ilex* and *Platanus sp*. trees, both very common in Rome, have been used to monitor traffic emission pollution in two different periods and to construct detailed pollution distribution maps from the south of Rome. High magnetic concentrations and larger magnetic grainsizes are observed in trees located along roads with high vehicle traffic and in the vicinity of railways, showing that magnetic properties of leaves are related to air pollution from vehicle emissions.

Orgeira, M. J., *et al.*, 2003, **Environmental magnetism in fluvial and loessic Holocene sediments and paleosols from the Chacopampean plain (Argentina)**: *Journal of South American Earth Sciences, v.16*, no.4, p.259-274.
Variations in the magnetic signals observed in paleosols in the units were ascribed to pedogenic processes that occurred at different stages of soil development. An extensive process of dissolution of detrital ferrimagnetic minerals was recognized. In one paleosol, dissolution was accompanied by the appearance of a SP fraction, which may indicate subsequent formation of ferrimagnetic minerals in the same paleosol, due to abundant rainfall and absence of $CaCO_3$ in the parent material. In the loessic sediments (Tapalque locality), dissolution could be associated with the genesis of a high coercive fraction. The presence of high coercivity minerals may indicate a climate with a distinctly dry season, though their lack does not necessarily imply the absence of a dry season.

Extraterrestrial Magnetism

Rochette, P., et al., 2003, **Impact Demagnetization By Phase Transition on Mars**: *EOS, v. 84*, no. 50, p. 561, 567.
The ferrimagnetic iron sulfide pyrrhotite (Fe_7S_8) is one candidate mineral as carrier of the Martian crustal remanent magnetization. Experiments indicate that pyrrhotite undergoes a high-pressure transition to a nonmagnetic state above 2.8 GPa. The absence of strong magnetic anomalies around the major impact basins Hellas and Argyre can be explained by enhanced shock demagnetization of pyrrhotite, involving transient compression to 3 GPa or more.

Magnetic Field Records and Paleointensity Methods

Benson, L., *et al.*, 2003, **Age of Mono Lake excursion and associated tephra**: *Quaternary Science Reviews, v.22*, p.3-4.
Dating of this event at its locality, the Mono Basin of California has yielded controversial results with the most recent effort concluding that the MLE may actually be the Laschamp excursion. We show that a volcanic tephra (Ash #15) that occurs near the midpoint of the MLE has a date (not corrected for reservoir effect) of 28,620 ± 300 ^{14}C yr BP (32,400 GISP2 yr BP) in the Pyramid Lake Basin of Nevada. Given the location of Ash #15 and the duration of the MLE in the Mono Basin, the event occurred between 31,500 and 33,300 GISP2 yr BP, an age range consistent with the position and age of the uppermost of two paleointensity minima in the NAPIS-75 stack that has been associated with the MLE. The lower paleointensity minimum in the NAPIS-75 stack is considered to be the Laschamp excursion.

Clement, B. M., 2004, **Dependence of the duration of geomagnetic polarity reversals on site latitude**: *Nature, v.428*, no.6983, p.637-40.
Estimates of the duration of geomagnetic polarity reversals range from a few thousand up to 28,000 years. Analysis of the available sediment records of the four most recent polarity reversals yields an average estimate of about 7,000 years for the time it takes for the directional change to occur. The variation about this mean duration is not random, but instead varies with site latitude, with shorter durations observed at low-latitude sites, and longer durations observed at mid- to high-latitude sites. Such variation of duration with site latitude is predicted by simple geometrical reversal models, in which non-dipole fields are allowed to persist while the axial dipole decays through zero and then builds in the opposite direction, and provides a constraint on numerical dynamo models.

Horiuchi, K., *et al.*, 2003, **^{10}Be record and magnetostratigraphy of a Miocene section from Lake Baikal: re-examination of the age model and its implication for climatic changes in continental Asia**: *Geophysical Research Letters, v.30*, no.12, p.4-1.
We determined the concentration of the cosmogenic radionuclide ^{10}Be in the Miocene section of a sediment core (5-12 My BP) retrieved from Lake Baikal (BDP98-hole2) that had been previously dated by the magneto-stratigraphic (MS) method. Using our new ^{10}Be geochronology we reexamined the MS age-depth assignments and found inconsistencies. We therefore reexamined the MS record and propose a new model which is consistent with the ^{10}Be data, with an age of 8.4 My BP at a depth of 600 metres. Accepting the revised MS ages, we found the profile of the decay-corrected ^{10}Be concentration, which shows ca. 50% decreases of ^{10}Be during the periods 0-2.7 My BP and 5.3-5.8 My BP. We also detected considerable increases of the ^{10}Be flux into sediments before 4.5 My BP.

Smirnov, A. V. and Tarduno, J. A., 2003, **Magnetic hysteresis monitoring of Cretaceous submarine basaltic glass during Thellier paleointensity experiments: evidence for alteration and attendant low field bias**: *Earth and Planetary Science Letters, v.206*, no.3-4, p.571-585.
Cretaceous SBG samples from ODP Site 1203 have very low NRM intensities (< 50 nAm^2/g) and TEM analyses indicate a correspondingly low concentration of crystalline inclusions. Thellier experiments on samples with the strongest NRM (> 5 x 10^{-11} Am^2) show a rapid acquisition of TRM with respect to NRM demagnetization. Taken at face value, this behavior implies magnetization in a very weak (< 17 μT) ambient field. But hysteresis properties change change systematically over the same temperature range. We suggest that these experimental data record the partial melting and neocrystallization of magnetic grains in SBG during the thermal treatments required by the Thellier method, resulting in paleointensity values biased to low values.

St-Onge, G., Stoner, J. S. and Hillaire-Marcel, C., 2003, **Holocene paleomagnetic records from the St. Lawrence Estuary, eastern Canada: centennial- to millennial-scale geomagnetic modulation of cosmogenic isotopes**: *Earth and Planetary Science Letters, v.209*, p.1-2.
Two long Holocene piston cores (MD99-2220 and MD99-2221) were raised from the St. Lawrence Estuary, eastern Canada because of the expanded Holocene sediment sequence this location provides. A u-channel-based paleomagnetic study, supported by an accelerator mass spectrometry (AMS) ^{14}C chronology, rock-magnetic and sedimentological data, indicates that these sediments provide a paleomagnetic directional secular variation (PSV) and relative paleointensity (RPI) proxy records for the last 8500 cal BP. Sedimentation rates vary from 1.2 to 4.2 m/kyr. Comparison of inclination and declination features with other North American Holocene PSV records are generally consistent and temporal offsets are within chronological uncertainties. The normalized natural remanent magnetization intensity record, a RPI proxy, from the postglacial sediments of core 2220 compares favorably with North American and European Holocene RPI records at millennial and even some centennial timescales. Comparisons between core 2220 RPI proxy and the ^{10}Be flux record from the Greenland Summit (GISP2) ice core and a ^{14}C production rate record [Bond et al., (2001)] suggest that geomagnetic modulation may control the millennial- and even some centennial-scale variability within cosmogenic isotope records. This implies that the core 2220 RPI record reflects changes in global-scale geomagnetic field at these timescales.

Wilson, D. S. and Gans, P. B., 2003, **Magnetostratigraphy of the Eldorado Mountains volcanic complex and the calibration of the early to middle Miocene polarity time scale**: *Geophysical Research Letters, v.30*, no.12, p.37-1.
Magnetic polarity measurements from a well dated (15.6-13.7 Ma) volcanic section in southern Nevada allow resolution of controversies in the calibration of the Middle Miocene polarity time scale. A sequence of lavas yielding exclusively reversed polarities dated at 15.5-14.9 Ma can be confidently identified as C5Br, and the C5Cn.ln(y) reversal is bracketed between 15.67 and 15.48 Ma (relative to TC = 27.92 Ma). Integration with other recent studies shows that polarity chrons C5Cr-C5ABr are now confidently correlated with lava flows dated from 16.9 to 13.4 Ma by the $^{40}Ar/^{39}Ar$ method.

Zhu, R., *et al.*, 2003, **Evidence for weak geomagnetic field intensity prior to the Cretaceous normal superchron**: *Physics of the Earth and Planetary Interiors, v.136*, p.3-4.
19 lava flows at Sihetun (NE China) give K/Ar ages that span 124–133 Ma, i.e., just prior the CNS. Thermomagnetic curves and hysteresis loops show the primary NRM carrier to be PSD magnetite. Thellier–Thellier palaeointensity experiments with systematic pTRM checks were conducted on 66 samples from 13 lava flows. Results from the 29 samples (44%) which met strict reliability criteria indicate a range of virtual dipole moments (VDMs) from 2.83 to 4.17×10^{22} A m^2 with an average of $(3.53\pm0.02)\times10^{22}$ A m^2. This finding helps confirm that a weak geomagnetic field probably occurred just prior to the CNS.

Magnetic Microscopy and Spectroscopy

De Souza, P. A., Bernhardt, B., Klingelhofer, G. and Gutlich, P., 2003, **Surface analysis in archaeology using the miniaturized Mössbauer spectrometer MIMOS II**: *Hyperfine Interactions, v.151*, no.1, p.125-130.
A miniaturized Mössbauer spectrometer (MIMOS II) which was designed and constructed for extraterrestrial applications, such as iron-containing rock and soil analysis on the planet Mars, has been employed to investigate the iron-containing constituents in the paintings of a Lekythos Greek vase. Greek pottery is commonly painted with black figures. The Mössbauer backscattering spectra recorded with MIMOS II at room temperature show that the hand-painted black figures contain hematite.

Kawakami, T., *et al.*, 2003, **Mössbauer spectroscopy of pressure-induced phase**

continued on p. 8...

transformation from maghemite to hematite: *Journal of the Physical Society of Japan, v.72*, no.10, p.2640-5.
Using a diamond anvil cell, ^{57}Fe Mössbauer spectroscopy has been carried out on maghemite, γ-Fe_2O_3, under high pressure up to 30 GPa. Maghemite transforms to hematite, α-Fe_2O_3, with a wide coexistent pressure range. The onset of phase transformation is 14 GPa and complete transformation to hematite is found at 26 GPa. The pressure-induced transformation is irreversible and hematite is preserved at decompression.

Korecki, P. A., Szymonski, M. A., Korecki, J. A. and Slezak, T., 2004, **Site-selective holographic imaging of iron arrangements in magnetite**: *Physical Review Letters, v.92*, no.20, p.1-4.
Complex γ-ray holograms were recorded by tuning to the nuclear absorption lines of ^{57}Fe in magnetite corresponding to different hyperfine fields. The numerical reconstruction of the holograms to real space provided three-dimensional images of local iron arrangements in octahedral and tetrahedral sublattices of magnetite. This direct site-selective imaging of atomic structure was performed using a tabletop experimental setup.

Weyland, M. and Midgley, P. A., 2003, **Extending energy-filtered transmission electron microscopy (EFTEM) into three dimensions using electron tomography**: *Microscopy and Microanalysis, v.9*, no.6, p.542-55.
TEnergy-Filtered (EF) TEM elemental distribution images approximate to true projections of structure, and, as such, can be used to reconstruct the three-dimensional distribution of chemical species. A sample holder has been modified to allow the high tilt (±60°) required for tomography and a semiautomatic acquisition script designed to manage energy-loss acquisition. Tilt series data sets have been acquired from two widely different experimental systems, Cr carbides in 316 stainless steel and magnetite nanocrystals in magnetotactic bacteria, demonstrating single-and multiple-element tomography. It is concluded that the image contrast, signal, and signal-to-noise ratio (SNR) are key to the achievable reconstruction quality and, as such, the technique may be of limited value for high energy loss/small inelastic cross section edges.

Magnetization & Demagnetization Processes

Borradaile, G. J., 2003, **Viscous magnetization, archaeology and Bayesian statistics of small samples from Israel and England**: *Geophysical Research Letters, v.30*, no.10, p.35-1.
Certain limestones remagnetize viscously and noticeably over archaeological time-intervals, after their reorientation into monuments. The laboratory demagnetization temperatures (T_{UB}) for the VRM increase with the installation age; with rates of ~0.07°C/year for Israel chalk and ~0.1°C/year for English chalk. The empirical relationship may be used to date enigmatic buildings or geomorphological features (e.g., land slips). Such correlations also give some insight into the viscous remagnetization process over time intervals $\tau \leq 4000$ years, which are unobtainable in laboratory studies. The T_{UB}-age relationship for the viscous remagnetization appears to follow a power law, linearized as $\log_{10}(\tau) \propto b \log_{10}(T_{UB})$. Different pelagic limestones follow different curves and site-specific calibration is thus required for archaeological age determinations.

Mukadam, M. D., Yusuf, S. M., Sharma, P. and Kulshreshtha, S. K., 2004, **Magnetic behavior of field induced spin-clusters in amorphous Fe_2O_3**: *Journal of Magnetism and Magnetic Materials, v.269*, no.3, p.317-26.
DC magnetization as a function of magnetic field and temperature for bulk amorphous Fe_2O_3 shows evidence of four magnetic regimes: pure paramagnetic at $T \geq 110$ K at low applied field, field induced spin clusters (superparamagnetic like) at higher applied fields over the same temperature range, starting from 110 to 325 K (the highest measuring temperature), interacting spin clusters with progressive freezing over $35 \leq T \leq 110$ K and collective freezing below 35 K has been found. In the field induced spin-clusters regime (T > 110 K), the magnetization data have been analyzed using a Langevin function with a log-normal distribution of the size of the spin-clusters, yielding a mean diameter of 30 Å.

Walton, D., 2004, **Resetting the magnetization of assemblies of nanoparticles with microwaves**: *Journal of Applied Physics, v.95*, no.9, p.5247-8.
In materials containing magnetic nanoparticles it is possible to reset the magnetization with negligible heating of the material. When nanoparticles of magnetic materials, such as magnetite are exposed to microwaves, provided certain conditions are fulfilled, a strong absorption results that generates magnons, and raises the temperature of the particles. If the particles are embedded in a nonmagnetic matrix, the energy absorption in the matrix occurs via dielectric processes that are often much weaker than the coupling of the magnetic grains to the magnetic component of the microwave electromagnetic field. Under these conditions, essentially all the energy is absorbed by the magnetic grains, and the thermal barrier between the magnetic grains and the matrix leads to a temperature difference between the two.

Zheng, R. K., Wen, G. H., Fung, K. K. and Zhang, X. X., 2004, **Giant exchange bias and the vertical shifts of hysteresis loops in γ-Fe_2O_3-coated Fe nanoparticles**: *Journal of Applied Physics, v.95*, no.9, p.5244-6.
We fabricated core/shell-structured Fe nanoparticles, in which the α-Fe core is about 5 nm in diameter and the γ-Fe_2O_3 shell is about 3 nm thick, and systematically studied their structural and magnetic properties. The magnetic hysteresis (M-H) loops, measured at low temperatures, after the particles were cooled from 350 K in a 50 kOe field, show significant shifts in both horizontal and vertical directions. It has been found that the exchange-bias field can be as large as 6.3 kOe at 2 K, and that the coercive field is also enhanced greatly in the field-cooled (FC) loops. The large exchange bias and vertical shifts of the FC loops at low temperatures may be ascribed to the frozen spins in the shells. A simple model is proposed to interpret the observations.

Mineral & Rock Magnetism

Alva-Valdivia, L. M., Goguitchaichvili, A. and Urrutia-Fucugauchi, J., 2003, **Petromagnetic properties in the Naica mining district, Chihuahua, Mexico: searching for source of mineralization**: *Earth, Planets and Space, v.55*, no.1, p.19-31.
Rock magnetic properties seem to be controlled by variations in pyrrhotite, (titano)magnetite, (titano)hematite and (titano)maghemite content, and hydrothermal alteration. Post-mineralization hydrothermal alteration seems to be the major event that affected the minerals and magnetic properties. Continuous susceptibility measurements with temperature in most cases yield Curie points close to that of almost pure magnetite. Hysteresis curves and associated IRM acquisition plots, however, in some cases points to the higher coercivity minerals. Hematite or a mixture of hematite-titanomagnetite-titanomaghemite are probably present in the Naica samples although their contribution in remanent magnetization is minor. The Koenigsberger ratio ranges from 0.05 to 34 and, generally, it is higher than 1.

Mineral Physics & Chemistry

Buerge-Weirich, D., Behra, P. and Sigg, L., 2003, **Adsorption of copper, nickel, and cadmium on goethite in the presence of organic ligands**: *Aquatic Geochemistry, v.9*, no.2, p.65-85.
Adsorption of copper, cadmium and nickel at low concentrations on goethite was studied in the presence of the simple organic ligands oxalate, salicylate, and pyromellitate. The experimental metal adsorption behavior was compared to calculations with a surface complexation model to evaluate the most important interactions. Oxalate mostly decreased Cu and Ni adsorption at high pH-values by competition between solution and surface complexation but had no effect on Cd adsorption. Cu adsorption in the presence of oxalate below pH 6 could best be described by defining a ternary complex of type A (surface-metal-ligand). Salicylate had only minor effects on metal adsorption. The adsorption of Cu in the presence of salicylate above pH 5 could be explained by a ternary complex of type A. Pyromellitate increased the adsorption of Cu and Cd in the acidic pH-range, likely by formation of ternary surface complexes of type B (surface-ligand-metal).

Isambert, I., Valet, J. P., Gloter, A. and Guyot, F., 2003, **Stable Mn-magnetite derived from Mn-siderite by heating in air**: *Journal of Geophysical Research, v.108*, no.B6, p.1-9.
After Mn-bearing natural crystalline siderite was heated in successive steps in air, the oxidation products included SD and PSD ferrimagnetic phases with 420° C < T_C <

560° C. Hematite formation was detected by XRD after heating to 480° C, while Mn-ferrite was formed at 500° C and persisted even after heating to 700° C. This final product is stable with a spinel structure and unit cell parameters intermediate between those of magnetite and maghemite. TEM and electron energy loss spectroscopy analyses confirmed the presence of Mn in the spinel ferrite phase, which contains Fe(III), Mn(III), and Mn(II) ions. This phase appears as single crystals with euhedral shapes of average grain size 90-100 nm. In comparison to pure magnetite, the addition of Mn in the crystal lattice lowers the Curie temperature and explains the stability of the spinel phase. Thus stable magnetization carried by a magnetite related phase can be generated by oxidation of Mn-siderite.

Maksimochkin, V. I. and Yakupova, A. M., 2003, **Shear strain effect on the magnetic properties of minerals**: *Izvestiya, Physics of the Solid Earth, v.39*, no.5, p.404-8.
The effect of pressure and high-pressure shear deformation on the magnetic properties and phase state of minerals from oceanic basalts is studied. Pressures of up to 3 GPa and torsional shear in Bridgman anvils raise the coercivity of ferromagnetic grains in basalts due to both the increasing density of dislocations in magnetic grains and their fracturing. As the angle of anvil rotation increases, the coercivity is saturated. The shear at pressures of up to 3 GPa destabilizes the primary titanomagnetite phase in the basalts. High-pressure shear produces phase transformations decreasing the amounts of hematite (Fe_2O_3) and geikielite ($MgTiO_3$).

Pasternak, M. P., 2003, **Breakdown of the Verwey-Mott localization hypothesis in magnetite**: *Hyperfine Interactions, v.151*, no.1, p.253-261.
Temperature-dependent ^{57}Fe Mössbauer spectroscopy to 40 GPa shows that Fe_3O_4 magnetite undergoes a coordination crossover (CC), whereby charge density is shifted from octahedral to tetrahedral sites and the spinel structure thus changes from inverse to normal with increasing pressure and decreasing temperature. The CC transition takes place almost exactly at the Verwey transition temperature (T_V = 122 K) at ambient pressure. While T_V decreases with pressure the CC-transition temperature increases with pressure, reaching 300 K at 10 GPa. The d electron localization mechanism proposed by Verwey and later by Mott for $T < T_V$ is shown to be unrelated to the actual mechanism of the metal-insulator transition attributed to the Verwey transition. It is proposed that a first-order phase transition taking place at T_V opens a small gap within the oxygen p-band, resulting in the observed insulating state at $T > T_V$.

Rollmann, G., Rohrbach, A., Entel, P. and Hafner, J., 2004, **First-principles calculation of the structure and magnetic phases of hematite**: *Physical Review B, v.69*, no.16, p.165107-1.
Rhombohedral α-Fe_2O_3 has been studied by using density-functional theory (DFT) and the generalized gradient approximation (GGA). For the chosen supercell all possible magnetic configurations have been taken into account. We find an antiferromagnetic ground state at the experimental volume. This state is 388 meV/(Fe atom) below the ferromagnetic solution. For the magnetic moments of the iron atoms we obtain 3.4 μ_B, which is about 1.5 μ_B below the experimentally observed value. The insulating nature of α-Fe_2O_3 is reproduced, with a band gap of 0.32 eV, compared to an experimental value of about 2.0 eV. Analysis of the density of states confirms the strong hybridization between Fe 3d and O 2p states in α-Fe_2O_3.

Sorescu, M., Diamandescu, L. and Grabias, A., 2004, **Evolution of phases during mechanochemical activation in magnetite-containing systems**: *Materials Chemistry and Physics, v.83*, p.2-3.
When a mixture of Fe_3O_4 and Fe (80-20 wt.%) was subjected to mechanochemical activation by high-energy ball milling, XRD and Mössbauer spectroscopy demonstrated a phase transformation of magnetite to hematite, accompanied by a partial oxidation of iron to hematite. Similarly, ball-milled cobalt-doped magnetite ($Fe_{3-x}Co_xO_4$ with x=0.1) undergoes a phase transformation to cobalt-doped hematite. Finally, ball-milling a mixture of Fe_3O_4 and Co (80-20 wt.%) produced cobalt ferrite (a strongly Co-substituted magnetite), with the occurrence of hematite as an intermediate product. In all three cases, the milling-induced phase transformations started with a considerable disorder of the octahedral sublattice of magnetite.

Titkov, S. V., *et al.*, 2003, **An investigation into the cause of color in natural black diamonds from Siberia**: *Gems & Gemology, v.39*, no.3, p.200-209.
Black and dark gray diamonds from Siberia, Russia, were studied by analytical scanning and transmission electron microscopy. Their color is caused by the presence of dark inclusions. Unlike some previous reports on black diamonds in which the dark inclusions were primarily graphite, the Siberian samples with the most intense black color contained predominantly magnetite inclusions, while the dark gray diamonds most commonly contained inclusions of hematite and native iron. Moreover, the black diamonds studied exhibited anomalously high magnetic susceptibility, which may serve as one criterion for determining the natural origin of black color.

Modeling and Theory

Riisager, P. and Abrahamsen, N., 2003, **Palaeomagnetic errors related to sample shape and inhomogeneity**: *Earth, Planets and Space, v.55*, no.2, p.83-91.
The point-dipole assumption greatly simplifies the inverse problem of determining the remanent magnetization (RM) from the measured magnetic field of the sample. However the magnetic field of the normally-used cylindrical rock samples is not identical to that of a dipole. A numerical test shows that for a spinner magnetometer the non-ideal sample shape has an insignificant effect (less than 0.3° error), for even the smallest possible sample-sensor distance. Inhomogeneous magnetization is a larger source of error: for the simple case of a laminated cylindrical sample with constant direction, but varying intensity of magnetization between the laminae, we find an error of 4° for typical spinner-type magnetometer and 10° for static-type magnetometers.

Nanophase and Disordered Systems

Guyodo, Y., Mostrom, A., Penn, R. L. and Banerjee, S. K., 2003, **From Nanodots to Nanorods: Oriented aggregation and magnetic evolution of nanocrystalline goethite**: *Geophysical Research Letters, v.30*, no.10, doi:10.1029/2003GL017021.
High-resolution TEM and low-temperature magnetometry of synthetic goethite nanocrystals show that when aqueous suspensions are aged at 90°C, the nanocrystals grow almost exclusively by oriented aggregation of 3-4 nm primary nanocrystals. These primary particles are superparamagnetic above about 35 K, as shown by variations of magnetic susceptibility with temperature. At low temperature (< 300 K), both remanent and induced magnetizations of primary nanoparticles are about an order of magnitude larger than for micron-sized goethite and can act as magnetic signatures of nanophase in controlled environments.

Synthesis and Properties of Magnetic Materials

Ngo, A. T. and Pileni, M. P., 2003, **Assemblies of cigar-shaped ferrite nanocrystals: orientation of the easy magnetization axes**: *Colloids and Surfaces A, v.228*, p.1-3.
Mesoscopic structures made of cigar-shaped maghemite (γ-Fe_2O_3) nanocrystals differing by their sizes are described. The structures were prepared by slow evaporation of a dilute suspension of nanocrystals, to which could be applied a magnetic field parallel to the substrate. If a magnetic field was applied, the nanocrystals rotated their long axis along the magnetic field direction to form ribbons whereas without a field the nanocrystals remained deposited on the substrate with a random orientation. The aligned nanocrystals is responsible of the anisotropy of the ribbons as evidence by the hysteresis loops. Moreover, a high demagnetizing field is observed when the magnetization measurements are made with an applied field normal to the ribbons.

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exsolution to produce a ferrimagnetic moment at the interface between hematite and ilmenite [Robinson et al, 2002]) from her collaboration with Suzanne McEnroe on remanence-dominated aeromagnetic anomalies. Satellite magnetic anomalies on Mars, and their mineral sources and mechanisms of formation, continue to excite considerable interest, and **Pierre Rochette** (*CEREGE, Aix-en-Provence*) elaborated the case for pyrrhotite as a major player. The high-pressure magnetic transition of monoclinic pyrrhotite provides a neat explanation for the absence of the Martian anomalies around major impact basins, but as Pierre showed, there is a distinct lack of evidence for monoclinic pyrrhotite in Martian meteorite samples on Earth, although hexagonal pyrrhotite is common. He went on to address two important questions that follow from this observation: can hexagonal pyrrhotite be an important remanence carrier (e.g., via Ni-rich pentlandite lamellae, monoclinic inclusions, and/or rapid quenching), and are the meteorites, which have been shocked and irradiated, representative of in-situ Martian magnetic sources?

Interdisciplinary Applications and Integration of Magnetic and Non-Magnetic Analytical Techniques

Four years ago at the last (5^{th}) Santa Fe Conference on Rock Magnetism, Glen Waychunas (*Lawrence Berkeley Lab*) provided a survey of various analytical and spectroscopic methods that can, when complemented by magnetic measurements, substantially help in the accurate identifications of submicron to nanophase (10^{-6} to 10^{-9} m in size) iron oxides and oxyhydroxides of natural origin. Since then, there have been quite a few publications on the integration of magnetic and nonmagnetic signatures of iron minerals of sedimentary and igneous origin. The session on Interdisciplinary Approaches in Rock Magnetism (organized and chaired by **Subir Banerjee,** *University of Minnesota*) featured three invited talks, all by graduate students, on three valuable nonmagnetic techniques. **Aaron Williams** (*U. of Iowa*) illustrated the use of Mössbauer spectroscopy in tracking surface chemical processes, e.g. when iron-reducing bacteria (*Shewanella*) reduce goethite (FeO.OH) to magnetite. Control of the ^{57}Fe content allows selective synthesis of phases that are visible or invisible to Mössbauer, and thereby enables observation of adsorption/diffusion of Fe(II) on mineral surfaces and electron transfer reactions. **Josh Feinberg** (*UC-Berkeley*) showcased the combined use of magnetic force microscopy and electron backscatter diffraction to elucidate the textural relationship of needle-like exsolutions of magnetite in clinopyroxene crystals from Namibia. Two elongation directions were observed for these magnetites, but the crystallographic orientations were the same for each, and moreover a consistently-oriented subgrain texture was observed, due to ulvöspinel exsolution along the titanomagnetite {100}; this is responsible for the high coercivities observed in bulk samples and crushed mineral separates. **Bob Kopp** (*Caltech*) described utilization of 9.4 Gigahertz ferromagnetic resonance (FMR) as a sensitive tool to identify the presence of biogenic magnetite crystal chains in bulk samples. Resonant absorption of these radio waves is a function of interaction and anisotropy fields as well as applied field, and is thus effective at detecting the tailored characteristics of magnetosome chains; moreover it is relatively unaffected by maghemitization during laboratory storage, which adversely affects low-T magnetometric identification of magnetosome chains [Moskowitz, 1993; Carter-Stiglitz et al., 2002]. Responses to these talks by three panelists and mini-talks by five from the audience resulted in a lively discussion on the best uses of the above three techniques as well as x-ray diffraction, high-resolution transmission electron microscopy and synchrotron radiation, especially for nanophase iron minerals. While emphasizing the demonstrable powers of each technique, the speakers drew attention to the fact that unique interpretations can only be made when multiple approaches (including magnetism) are brought to bear on the problem. This was particularly demonstrated for distinguishing 5-100 nm ferrihydrite from goethite and hematite, which are of similar composition and grain size as ferrihydrite, the "mother phase" of goethite and hematite in nature. While ferrihydrite represents relatively recent and reducing environment, goethite and hematite are usually the signatures of longer duration changes in humid and relatively arid environments, respectively.

Magnetic data analysis and dissemination

Since the last Santa Fe conference in 2000, significant advances have been made in methods of collecting and analyzing experimental magnetic data for geologic samples. For example, coercivity spectrum analysis has been improved with rigorous statistical methods to "unmix" or decompose the spectrum into constituent log-Gaussian or other monodisperse populations [Heslop et al., 2002; Egli, 2003]. Still more detailed pictures emerge from intensive measurement of first-order reversal curves (FORCs), and computation of a distribution of critical fields/energies that are interpreted to correspond with coercivities and interaction fields. The theoretical foundations of FORC analysis were methodically developed in **Roy Roshko**'s engaging and enlightening keynote lecture, which began with the essential physics of micromagnetics (the free energy functional of the magnetization vector field, comprising local anisotropy, exchange and applied field energies and a global magnetostatic energy). Minimization of the free energy is of course accomplished spontaneously and effortlessly in real materials, but it requires tremendous effort to accomplish *in silico*, due to the enormous number of possible magnetization configurations and the dependence of magnetostatic energy at any point on the details of the whole configuration. The Preisach formalism, Roy explained, treats this complex micromagnetic system on a macroscopic statistical basis, decomposing the infinite-dimensional free-energy functional into a population of elementary two-level subsystems (which may in some cases - but in general do not - correspond to discrete particles). FORC measurements under certain conditions (absence of mean-field effects and thermal fluctuations) directly map out the Preisach distribution of characteristic energies. By popular demand, Roy has generously allowed us to post his lecture notes on our web site.

The working session on data analysis and dissemination was organized and chaired by **Andrew Newell** (*U of North Carolina*). Some new twists in the processing, display and application of FORC distributions were shown by **Ken Verosub** (*UC-Davis*). For example, an interesting mode of display involves mapping the distribution from (H_C, H_B) space back into the original (M, H) space, where the contours fill the major loop. **Yong Jae Yu** (*Scripps, UCSD*) used experimental and micromagnetic model results to evaluate the merits of various hysteresis-related approaches used for magnetic granulometry, and judged the venerable and ubiquitous "Day plot" (M_{RS}/M_S vs H_{CR}/H_C) to be generally less useful than two practical alternatives. Eliminating the time-consuming H_{CR} measurements, one can plot M_{RS}/M_S vs H_C, which provides better discrimination of materials (composition, grain size, internal stress...) under temperature-dependent hysteresis. Yong Jae also documented the size dependence of magnetic transient hysteresis, which involves measurement of a single first-order reversal curve [Fabian, 2003]. **Michael Winklhofer** (*LMU München*) reviewed progress and open problems in

Goethe, Johann Wolfgang von

b. Aug 28, 1749, Frankfurt-am-Main
d. Mar 22, 1832, Weimar

The mineral goethite (α-FeOOH) is named for this many-facted poet, playwright, statesman, journalist and natural philosopher. The author of *Faust*, renowned as one of the greatest figures in world literature, had equally avid interests in botany, anatomy, meteorology, geology, mineralogy, optics, and color. His scientific writings comprise numerous volumes, among which the best known is his 1810 *Farbenlehre* (Theory of Color; see, e.g., *Physics Today, 55*(7), 43-49, 2002). He is also credited with founding and naming the science of morphology, the study of formation and transformation.

the study of biogenic magnetite, including the flagship *Magnetobacterium bavaricum*, individual cells of which contain up to 1000 single-domain magnetosomes and have magnetic moments of more than 10^{-14}Am^2. Magnetosomes in *M bavaricum* appear to grow initially elongated along the [111] axis before developing a mysterious "hook". The low-temperature remanence properties exhibit some similarities to the classic signature of *Magnetospirillum*, but do not pass the "bug test" based on δ_{FC}/δ_{ZFC} [Moskowitz et al., 1993]. The session closed with a series of presentations on the MAGiC (Magnetics Information Consortium) database under development at Scripps and IRM. **Lisa Tauxe** (*Scripps, UCSD*) reviewed the rationale for a communal rock magnetism/paleomagnetism database, enumerating the significant tangible benefits to data producers, consumers, and to the scientific community at large. Progress reports on the MAGiC efforts provided by **Cathy Constable** and **Anthony Koppers** (*Scripps, UCSD*) were greeted enthusiastically by the participants.

Looking Ahead: Trends in Research, Funding and Education

Christopher Harrison (*U. of Miami*) and **Laurie Brown** (*UMass-Amherst*) led an open discussion that touched on a variety of strategic and philosophical issues, including the potential for large intra- and interdisciplinary collaborative projects involving rock magnetism, international perspectives on education and professional preparation, and the optimal role for magnetic research in the new ocean drilling program IODP.

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IRM Visiting Fellows, July-December 2004

Franziska Brem (*ETH Zürich*), Magnetic properties of human brain tissue related to epilepsy

Christoph Geiss (*Trinity College, Hartford*), Quantifying the Mineralogy and Particle-Size Distribution of Pedogenic Magnetite

Diana Latta (*Lehigh University*), Milankovitch Cycles and Rock Magnetic Properties: Unraveling how climate is encoded in Cretaceous carbonates, Mexico

Suzanne McEnroe (*Geological Survey of Norway*), Nanomagnetics in the Hematite-Ilmenite Solid Solution

Özden Özdemir (*University of Toronto at Mississauga*), Experiments on SD Titanomagnetites/Titanomaghemites and MD Hematites

Ramesh Peelamedu (*The Pennsylvania State University*), Structural and Magnetic property variations of natural minerals treated in microwave E (electric) and H (magnetic) –fields

Guillaume Plenier (*U.C. Santa Cruz*) and **Jonathan Glen** (*U.S. Geological Survey*), Origin of complex magnetic fabrics

The *Institute for Rock Magnetism* is dedicated to providing state-of-the-art facilities and technical expertise free of charge to any interested researcher who applies and is accepted as a Visiting Fellow. Short proposals are accepted semi-annually in spring and fall for work to be done in a 10-day period during the following half year. Shorter, less formal visits are arranged on an individual basis through the Facilities Manager.

The *IRM* staff consists of **Subir Banerjee**, Professor/Director; **Bruce Moskowitz**, Professor/Associate Director; **Jim Marvin**, Senior Scientist; **Mike Jackson**, Senior Scientist and Facility Manager, and **Peat Sølheid**, Scientist.

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The *IRM Quarterly* is published four times a year by the staff of the *IRM*. If you or someone you know would like to be on our mailing list, if you have something you would like to contribute (*e.g.*, titles plus abstracts of papers in press), or if you have any suggestions to improve the newsletter, please notify the editor:

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Portrait of Goethe by Friedrich Bury, Weimar, 1800. source: Goethe's History of Science, by K. J. Fink, Cambridge University Press, 1991.

Assistant Scientist Position Available

After a remarkably successful thirty years of designing/building/maintaining the instruments, standards, and computers of the Minnesota rock magnetism laboratory (now the IRM), Jim Marvin has received a well-earned promotion to (semi-)retirement. The daunting job of filling Jim's enormous shoes has been taken on by Peat Sølheid, who has apprenticed with Jim for the past ten years. We are now in need of a "new Peat" to assist in caring for instruments and visiting researchers. We expect to hire at the "Assistant Scientist" level. For a detailed job description, required qualifications, pay range and application procedure, please see our web site.

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