The IRM Quarterly

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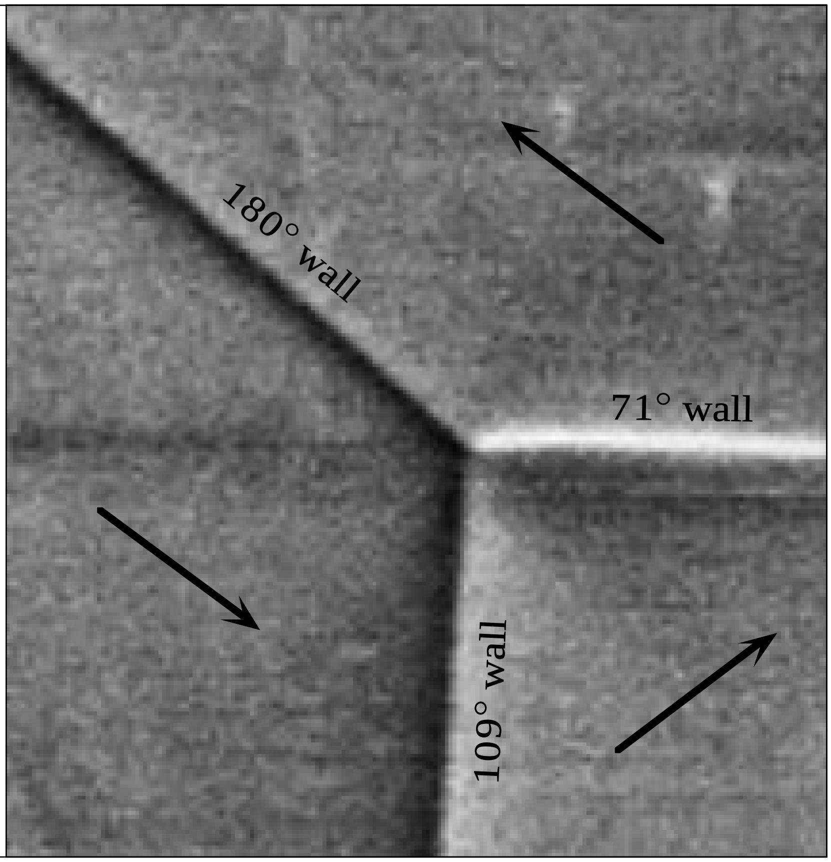
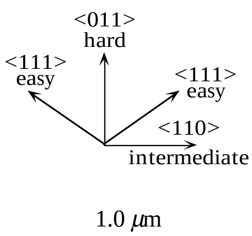


An 8.4-µm square MFM image of three domain walls typical of a magnetite single-crystal in the (110) plane. Each wall is along a different magnetic axis. The orientation of the crystallographic and magnetic axes is shown below. Parallel to one of the easy axes is a 180° domain wall; parallel to the intermediate axis is a 71° domain wall; perpendicular to the 71° wall and parallel to the hard axis is a 109° wall. The bold arrows indicate the direction of magnetization in each domain along an easy axis.



MFM Image: Sherry Foss, MMC

Magnetic Microscopy Center is Flourishing

E. Dan Dahlberg
MMC Director

The IRM *has had a long collaboration with the Physics Department at the University of Minnesota in the form of shared lab space and graduate students. The magnetic microscopy group, which has helped us so much with our magnetic force microscope, has now come into its own as the Magnetic Microscopy Center (*MMC*).*

MAGNETIC MICROSCOPY CENTER

The *MMC* was created, last year, for two reasons: first, to provide experimental data for the testing and development of micromagnetic models and second, to further our capabilities in magnetic microscopy. On November 1, the *MMC* celebrated its first birthday, marking a year of growth and progress. We started out with one home-built magnetic-force microscope (MFM), and through our collaboration with the *IRM*, we produced a great many interesting results using the *IRM*'s MFM. Now we have four MFMs of our own: our original; another home-built microscope specialized for low-temperature studies; and two commercial MFMs—one from Park Scientific Instruments (PSI) and a Nanoscope III from Digital Instruments (DI). Despite our riches, we still like to sneak downstairs to the *IRM* to collaborate as much as possible.

Having this variety of instruments is of great help in the pursuit of our long list of goals. For example, being able to employ both DI's and PSI's different techniques for the separation of topography and magnetism aids in our general interpretation of MFM images. And having the home-built units is beneficial, too, in that they offer additional flexibility: one affords variable temperature capability, and both are able to operate under vacuum.

Personnel

The staff of the *MMC* consists of Director E. Dan Dahlberg of the Physics Department at the University of Minnesota [phone: (612) 624-3506], and Associate Director Roger Proksch of the Physics Department at St. Olaf College in Northfield, MN. There are currently four physics graduate students pursuing research at the *MMC*: Sherry Foss and Katerina Moloni, who work closely with members of the *IRM*, and George Skidmore and Chris Merton, who started with us this past summer. Also with us last summer was Brian Walsh, an undergraduate student from St. Olaf. In addition, we are fortunate this year to have Jim Eckert visiting from Harvey Mudd College in Claremont, CA, who is working with us on a couple of projects.

R&D: Development

The *MMC* has a program for the development of the magnetic film coatings on MFM cantilevers. In fact, even before the establishment of the *MMC*, the initial studies of the coating of cantilevers was a collaborative effort between the MFM group at Minnesota and a local company, Advanced Research Corporation (ARC), owned and operated by Matt Dugas. This company is cur-

MMC *continued on page 2…*

Visiting Fellow's Report

This summer was an uncharacteristically quiet one at the *IRM*. In fact, only one Visiting Fellow graced our halls. In August, Kaushik Katari arrived from Lancaster, PA, to study ancient hearth material. Below is a summary of his work here.

Kaushik Katari
Franklin and Marshall College

Rock-Magnetic Study of Clinker and Archaeomagnetic Hearth Samples

Although archaeomagnetic research has a wide range of applications, including secular variation studies, archaeomagnetic dating techniques, *etc.*, very little work has been done on the rock-magnetic properties of archaeomagnetic samples. The main purpose of my visit was to investigate these properties using unoriented, burnt clay samples from hearths and from burnt walls and floors from two sites in Israel, Tel Ashkelon and Bet Shean. In addition to these, I also intended to look into the rock magnetism of a number of samples from the red "Clinkers" of Montana, because my advisor, Rob Sternberg, had noticed some peculiarities in their behavior.

My visit started off with a "grand tour" of the *IRM*. The first thing I did was to prepare a chunk of Clinker sample and mount it on the Mössbauer set up, mainly to investigate the mineralogy of the sample. Since this did not need constant supervision, I could devote myself, in the mean time, to measuring hysteresis loops of the Israeli samples on the VSM. (Because the samples were not very strongly magnetized, the MicroMag would have been much better suited for the measurements; unfortunately, the MicroMag was out of order during my stay.) Although I had initially planned to measure a number of high temperature loops, the signals became increasingly noisy at higher temperatures, and so I had to restrict myself to room-temperature runs. Fortunately, at room temperature, the VSM could accommodate a big chunk of the sample, so a strong signal was detected. The resulting loops were mostly long and thin, indicating that the dominant mineral was probably magnetite. The varying thicknesses of the loops indicated a mixture of single- and multi-domain states. I also tried to measure the Curie temperatures of some furnace-sized chips on the VSM, but because of the noise-level problems previously mentioned, these results did not come out very well. Furthermore, for some mysterious reason, the furnace in the VSM always acted as a reducing environment, so the cooling curve in the Curie temperature graphs always indicated an altered product, not the original mineralogy. No matter what color sample was put in, it always came out black.

I also used the Roly-Poly to do anisotropy measurements on a batch of samples from Bet Shean. The results showed very little anisotropy, which was reassuring because we had always treated the samples as being free of anisotropy.

I also measured hysteresis loops for the Clinker samples, and this attracted a lot of attention. Weiwei Sun was particularly interested in the results, and he did a Fourier analysis of the data, which seemed to indicate varying ratios of hematite and magnetite in the samples. The Mössbauer results also seemed to indicate a predominance of hematite, and, contrary to our expectations, no "mysterious" mineral showed up. All the Mössbauer runs were done at room temperature, and Peat Solheid, my friend-philosopher-guide at the *IRM*, said he would try a low-temperature run to see if anything else showed up.

Thanks a lot to all members of *IRM* for making my visit a very memorable experience. Although it was very flattering to see my name in the list of Visiting Fellows, I nevertheless felt a little intimidated owing to my undergraduate status. And even though Peat and his friends said that their favorite pastime was to pick on undergrads, their attitude was quite the contrary. I would also like to thank my advisor, Rob Sternberg, who made this visit possible by writing the proposal. Thanks again for everything; I hope more undergraduates will take advantage of this wonderful opportunity in the future. ■

…MMC *continued from page 1*

rently the world's supplier of MFM tips; when you see MFM images in DI ads, or when you buy tips for your own MFM, they come from ARC. We are continuing to develop novel coatings for the investigation of a variety of magnetic samples, because the same tip coating is not necessarily appropriate for all specimens or investigations. In other words, the magnetic characteristics of the MFM tip should be suited to the sample: one sample may require a magnetically soft low-coercivity coating, whereas another needs a magnetically hard high-coercivity coating, and yet another is best examined with a low-moment tip.

Also in the area of development is a collaborative effort among DI, ARC, and the *MMC*. We are using the materials and processes developed from one of our other research programs—understanding the origin of the recently discovered Giant Magnetoresistance phenomenon—to develop alternative scanning magnetic probes. Although less sensitive spatially, these new probes would have the advantage of being easy to calibrate for direct magnetic field measurements.

R&D: Research

In order for MFMs to become maximum-utility instruments for explorations in physics, the process of quantifying MFM data is mandatory. Thus, one of our primary undertakings is the transformation of MFM images into maps of magnetization. This effort, led by Roger Proksch, has been very successful in a number case studies. The high resolution and sensitivity of the MFM make it easy for the images to show the micromagnetic state of a single-domain particle or the presence of a domain wall; still, a great deal more must be done in order to turn the MFM data, which is actually the second derivative of the magnetic field above the sample, into the quantifiable sample magnetization. Our first significant success came as a result of collaboration with the *IRM*'s Bruce Moskowitz as well as with Richard Frankel (California Polytechnic State University, San Luis Obispo, CA), Dennis Bazylinski (Virginia Polytechnic Institute and State University, Blacksburg, VA), and a cooperative microscopic organism. We first obtained an image of a magnetosome chain in an isolated magnetotactic bacterium and then calculated the

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Frontispiece from Athanasius Kircher's Magnes, sive de Arte Magnetica, *1641.*

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 edited 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 2300 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

Anisotropy

Borradaile, G. J.
Paleomagnetism carried by crystal inclusions: the effect of preferred crystallographic orientation, *Earth Planet. Sci. Lett.*, *126*, 171–182, 1994.
Randomly oriented phlogopite crystals contained microscopic magnetite inclusions that had oblate magnetic fabrics. Alternating field demagnetization of individual crystals showed that the remanence was influenced by the crystal symmetry of the phlogopite host. Therefore, coarse-grained igneous and metamorphic rocks can record a paleofield direction accurately only if there is a suitable orientation distribution of the rock-forming minerals that host the ferromagnets.

Biomagnetism

Farina, M., *et al.*
The observation of large magnetite (Fe_3O_4) crystals from magnetotactic bacteria by electron and atomic force microscopy, *J. Microsc.*, *173*, 1–8, 1994.
Electron and atomic-force microscopy of large magnetite crystals inside magnetotactic bacteria revealed that, despite laboratory treatment, the crystals remained strongly attached in chains, which was likely due to the strong field between crystals as well as to the large contact areas. When crystals were not in chains, the linear dimensions and the presence of well-defined edges and faces were important features, since the crystalline habits seemed to be species-specific.

Hsu, C.-Y., and C.-W. Li
Magnetoreception in honeybees, *Science*, *265*, 95–97, 1994.
In magnetoreceptive species other than honeybees, magnetite had been shown to be necesary for the primary detection of magnetic fields. In bees, whose comb-building and homing-orientation activities were affected by the geomagnetic field, it was shown that trophocytes contained superparamagnetic magnetite. Since trophocytes were innervated by the nervous system, they were probably responsible for magnetoreception.

Polk, C.
Effects of extremely-low-frequency magnetic fields on biological magnetite, *Bioelectromagn.*, *15*, 261–270, 1994.
The conclusion of an earlier study—that effects of certain magnetic fields on biological structures holding magnetite were much smaller than those from thermal agitation and hence could not be biologically significant—was questioned because it seemed to be based on a model that had very limited validity for pertinent biological systems. Reported experimental results indicated effects in mammals of 50-Hz fields at the 1-μT level.

Chemistry

Cui, Y.-L., K. L. Verosub, and A. P. Roberts
The effect of low-temperature oxidation of large multi-domain magnetite, *Geophys. Res. Lett.*, *21*, 757–760, 1994.
It was shown that multidomain-size magnetite exhibited PSD behavior upon partial surficial oxidation; three possible mechanisms were offered to explain this behavior which may have important implications for paleomagnetism: this type of oxidation may provide a mechanism whereby a stable chemical remanent magnetization can be acquired.

Wiesendanger, R., I. V. Shvets, and J. M. D. Coey
Wigner glass on the magnetite (001) surface observed by scanning tunneling microscopy with a ferromagnetic tip, *J. Vac. Sci. Technol. B*, *12*, 2118–2121, 1994.
Using ferromagnetic probe tips on a well-ordered (001) surface of a single crystal of magnetite, the authors saw an atomic-scale contrast in the different magnetic iron ions on the octahedrally coordinated B sites. These ions formed static arrays of pairs with short-range order and appeared to be in a Wigner glass state even at room temperature; electron pairs localized on adjacent ions were the basic unit.

Climate Change

Banerjee, S. K.
Contributions of fine-particle magnetism to reading the global paleoclimate record, *J. Appl. Phys.*, *75*, 5925–5930, 1994.
Theories of superparamagnetism and magnetic domains were used to explain the physical basis of magnetic proxy recording of paleoclimate changes. These changes are indicated by variations in magnetic minerals in sediments. Examples were provided of applications that validated the Milankovitch theory of climate change and delineated the glacial and interglacial stages of the last 1 Ma.

Maher, B. A., R. Thompson, and L.-P. Zhou
Spatial and temporal reconstructions of changes in the Asian palaeomonsoon: a new mineral magnetic approach, *Earth Planet. Sci. Lett.*, *125*, 462–471, 1994.
Paleoprecipitation across the Chinese Loess Plateau was estimated by correlating the concentration of ferrimagnetic iron-oxide minerals in nine modern soil types with the contemporary rainfall gradient to construct a rainfall *vs.* magnetic susceptibility climofunction. Past variations of iron-oxide content, established through magnetic susceptibility measurements, were then used to reconstruct the rainfall of earlier periods.

Crustal Magnetization

Gee, J., and D. V. Kent
Variations in layer 2A thickness and the origin of the central anomaly magnetic high, *Geophys. Res. Lett.*, *21*, 297-300, 1994.
From basalts dredged on and near the East Pacific Rise axis, the authors obtained magnetic remanence data which were compatible with a rapid magnetization reduction (~20 ka to decay to l/*e*). Together with near-bottom magnetic profiles, these data suggest that previous estimates of the alteration time-constant inferred from slow-spreading ridges (0.5 Ma) may be more than an order of magnitude too high.

Kent, D. V., and J. Gee
Grain-size-dependent alteration and the magnetization of oceanic basalts, *Science*, *265*, 1561-1563, 1994.
The fact that unblocking temperatures of natural remanent magnetization were found to extend well above the dominant Curie points in samples of oceanic basalts was attributed to the natural presence in the basalts of three related magnetic phases with different magnetic properties. This model was consistent both with evidence from the mid-ocean ridges that the initial magnetization that oceanic basalts acquired upon cooling is rapidly altered, and accounts for the lack of sensitivity of bulk-rock magnetic parameters to the degree of alteration of the remanence carrier in oceanic basalts.

Dynamo

McFadden, P. L., and R. T. Merrill
History of the Earth's magnetic field and possible connections to core-mantle boundary processes, *J. Geophys. Res. B*, in press 1994.
Velocity field estimates of the core fluid at the top of the outer core appeared to be sensitive to conditions at the CMB. In the paleomagnetic record, variations with periods longer than about 1 Ma may reflect changes in CMB conditions. Because these boundary conditions are controlled primarily by mantle dynamics, there have been speculations regarding causal links between changes in the Earth's lithosphere and changes in the Earth's magnetic field. Finally, the evidence linking lateral variations at the CMB to perceived systematics in polarity transition data was found to be intriguing, but insufficient.

Merrill, R. T., and P. L. McFadden
Dynamo theory and paleomagnetism, *J. Geophys. Res. B*, in press 1994.
Because of considerable difficulties in mathematics and many uncertainties in physics surrounding dynamo theory, paleomagnetism can provide valuable constraints to narrow the range of viable dynamo models. For example, paleomagnetism ultimately could: provide constraints on the velocity and magnetic-field symmetries of dynamos; determine whether the geodynamo is in the weak-, intermediate-, or strong-field regime; determine if there is a fundamental difference in dynamo processes during superchrons when reversals of the magnetic field essentially cease; and provide valuable information on the growth of the inner core and its possible stabilizing effects on geodynamo processes.

Environmental Magnetism

Flanders, P. J.
Collection, measurement, and analysis of airborne magnetic particulates from pollution in the environment, *J. Appl. Phys.*, *75*, 5931–5936, 1994.
Results of a study of environmental magnetic particulates, collected from surfaces and directly from the atmosphere, showed that a significant percentage of magnetic material in many airborne samples consisted of 2–10-μm spherical magnetite particles from coal-burning utilities and from iron- and steel-manufacturing plants. The amount of airborne magnetic material that settled to the ground varied inversely with distance from its source.

Geophysics

Baksi, A. K.
Concordant sea-floor spreading rates obtained from geochronology, astrochronology and space geodesy, *Geophys. Res. Lett.*, *21*, 133–136, 1994.
Two different dating techniques—magnetic field reversals in igneous rocks and Milankovitch forcing frequencies in the sedimentary environment—yielded dates for the geomagnetic polarity time-scale that were in good agreement. Furthermore, sea-floor spreading rates calculated from the resultant time-scale were in agreement with rates of plate movement that were calculated using space geodetic measurements. Therefore, sea-floor spreading estimates—fundamental to plate tectonics—were corroborated by three independent techniques.

Bassinot, F. C., *et al.*
The astronomical theory of climate and the age of the Brunhés–Matuyama magnetic reversal, *Earth Planet. Sci. Lett.*, *126*, 91–108, 1994.
A study was made of a high-resolution oxygen-isotope record in which precession-related oscillations in $\delta^{18}O$ were particularly well expressed, due to the superimposition of a local salinity signal on the global ice-volume signal. The precession peaks found in the record were in excellent agreement with climatic oscillations predicted by the astronomical theory of climate. Thus, this record, tuned to orbital forcing functions, permitted the development of an astronomical time-scale: the Brunhés-Matuyama reversal was dated at 775±10 ka.

Mandeville, C. W., *et al.*
Paleomagnetic evidence for high-temperature emplacement of the 1883 subaqueous pyroclastic flows from Krakatau Volcano, Indonesia, *J. Geophys. Res. B*, *99*, 9487–9504, 1994.
The 1883 eruption of Krakatau volcano in Indonesia discharged at least 6.5 km^3 of pyroclastic material into the shallow waters of the Sunda Straits. Paleomagnetic evidence for high emplacement temperatures (>350°C) supported the hypothesis that proximal 1883 submarine pyroclastic deposits resulted from entrance of hot, subaerially generated pyroclastic flows into the sea. The Krakatau deposits thus serve as an important historic analog for the study of pyroclastic-flow/seawater interactions.

Paleointensity

Lin, J.-L., K. L. Verosub, and A. P. Roberts
Decay of the virtual dipole moment during polarity transitions and geomagnetic excursions, *Geophys. Res. Lett.*, *21*, 525–528, 1994.
Analysis of paleointensity data from five polarity transitions and from geomagnetic excursions recorded by lava flows indicated that the logarithm of the virtual dipole moment correlated significantly with the angle between the virtual geomagnetic pole and the Earth's rotation axis. This correlation implied that any physical model for geomagnetic field behavior during transitions and excursions must address the question of how changes in direction are linked to changes in intensity.

Meynadier, L., *et al.*
Asymmetrical saw-tooth pattern of the geomagnetic field intensity from equatorial sediments in the Pacific and Indian Oceans, *Earth Planet. Sci. Lett.*, *126*, 109–127, 1994.
Features of records of relative paleointensity from marine sediments from the equatorial Indian and Pacific Oceans spanning the last 4 Ma agreed on an overall saw-tooth intensity pattern across every field reversal. The short-term fluctuations superimposed on the slow intensity decrease preceding the reversals also appeared to be similar at both sites. The global character of these features reinforced their interpretation in terms of changes in dipole field intensity and provided new important constraints on models of the geodynamo.

Valet, J.-P., *et al.*
Relative paleointensity across the last geomagnetic reversal from sediments of the Atlantic, Indian, and Pacific Oceans, *Geophys. Res. Lett.*, *21*, 485–488, 1994.
Paleointensity records from marine sediments from the Atlantic, Indian, and Pacific Oceans showed coherent and reproducible signals across the Brunhés-Matuyama reversal. The low-field susceptibility signals were predominantly anti-correlated between the Indo-Pacific and the Atlantic sites, and normalization of the NRM by rock-magnetic parameters yielded identical results, establishing the worldwide character of the triangular pattern displayed by the decay and recovery phases of the field intensity variations.

Paleomagnetism

Zhu, R.-X., C. Laj, and A. Mazaud
The Matuyama-Brunhés and Upper Jaramillo transitions recorded in a loess section at Weinan, north-central China, *Earth Planet. Sci. Lett.*, *125*, 143–158, 1994.
The paleomagnetic records of the Matuyama-Brunhés (MB) and Upper Jaramillo (UJ) polarity reversals were obtained from a loess section at Weinan, Shaanxi province, in China. Because the transitional virtual-geomagnetic-pole paths were situated in two longitudinal bands—over eastern Asia and Australia (MB), and over the Americas (UJ)—the results supported the hypothesis, suggested from the study of marine and lacustrine sediments, of two preferential longitudinal bands for reversing transitional VGPs.

Physics

Castro, J., *et al.*
An analysis of the high-temperature relaxation in polycrystalline magnetite, *J. Appl. Phys.*, *75*, 6100–6102, 1994.
Magnetic relaxation measurements were performed on vacancy-doped magnetite in order to understand the important relaxation peaks that had been observed. The main features of peak I (T = 400–600 K), at which isothermal measurements were made for up to 10^5 s, were compatible with a dislocation relaxation.

Hejda, P., E. Petrovsky, and T. Zelinka
The Preisach diagram, Wohlfarth's remanence formula and magnetic interactions, *IEEE Trans. Magn.*, *MAG-30*, 896–898, 1994.
In order to study magnetic interactions in weak magnetic samples, a generalized Preisach diagram was applied to experimental data and verified using differential remanence derived from Wohlfarth's remanence formula. It was shown that introducing the mean interaction field improved the Preisach diagram, and that negative, positive, and oscillating interactions, as observed using Wohlfarth's remanence formula, could be interpreted.

Kotzler, J., *et al.*
Fluctuation effects on the magnetization dynamics below the Curie temperature of ferro- and ferrimagnets, *IEEE Trans. Magn.*, *MAG-30*, 828–833, 1994.
Measurements of susceptibility (1 Hz to 20 GHz) were reported for strongly uniaxial and weakly anisotropic cubic model magnets. The contributions of the homogeneous magnetization and of the wall motion were separated. The most significant effects of magnetization fluctuations occurred in the wall mobility of uniaxial materials near the Bloch-wall disordering temperature, T^*, and in the stability region of linear walls, $T^* < T < T_C$.

Lederman, M., S. Schultz, and M. Ozaki
Measurement of the dynamics of the magnetization reversal in individual single-domain ferromagnetic particles, *Phys. Rev. Lett.*, *73*, 1986–1989, 1994.
The authors measured the spontaneous thermal switching of the magnetization of individual single-domain ellipsoidal γ-Fe_2O_3 particles. Because the statistics of the reversal could not be described by activation over a single-energy barrier, they suggested that a complex theoretical approach would be required to describe a thermally activated magnetization reversal. [Ed: See also Lederman, M., *et al.*, Measurement of thermal switching of the magnetization of single domain particles, *J. Appl. Phys.*, *75*, 6217–6222, 1994.]

Linderoth, S., *et al.*
On spin-canting in maghemite particles, *J. Appl. Phys.*, *75*, 6583–6585, 1994.
The alignment of magnetic moments in maghemite particles was studied in samples with induced magnetic texture. (These samples were prepared by freezing ferrofluids, containing 7.5-nm maghemite particles, in a magnetic field.) Mössbauer spectroscopy studies of the samples in large magnetic fields demonstrated that the lack of full alignment was not an effect of large magnetic anisotropy, but was due instead to canting of individual spins.

Proksch, R., and B. M. Moskowitz
Interactions between single-domain particles (magnetotactic bacteria application), *J. Appl. Phys.*, *75*, 5894–5896, 1994.
A variation of the Wohlfarth-Henkel technique was presented for studying interactions in single-domain particles in which samples were prepared in different remanent states. By analyzing the resulting series of switching-field distributions, it was possible to separate the effects of positive (magnetizing) and negative (demagnetizing) interactions, even when one type dominated the other. The method was applied to two types of samples containing bacterial magnetite.

Salling, C., *et al.*
Investigation of the magnetization reversal mode for individual ellipsoidal single-domain particles of γ-Fe_2O_3, *J. Appl. Phys.*, *75*, 7989–7992, 1994.
Measurements of the angular dependence of the switching-field of individual ellipsoidal single-domain γ-Fe_2O_3 particles provided insights into the magnetization reversal for individual ellipsoidal particles of known morphology. The functional form of the switching-field data indicated that the particles reversed by curling over a narrow range near 0 degrees and by coherent rotation at all larger angles.

Rock Magnetism

Forster, T., M. E. Evans, and F. Heller
The frequency dependence of low field susceptibility in loess sediments, *Geophys. J. Int.*, *118*, 636–642, 1994.
For estimates of the magnetic grain sizes present in loess, the F-factor (χ_{fd}) was shown to be rather misleading or flawed when variable grain sizes of minerals were present. The authors introduced a new concentration-independent F-factor (F_c) which took the influence of the mineral fractions with frequency-independent susceptibility on the total susceptibility into consideration. F_c was fairly constant in all the investigated sections. This result was explained theoretically using fine-particle theory and modeling of various single-domain grain distributions.

Hejda, P., *et al.*
Analysis of hysteresis curves of samples with magnetite and hematite grains, *IEEE Trans. Magn.*, *MAG-30*, 881–883, 1994.
Magnetic hysteresis loops of mixtures of hematite and magnetite particles dispersed in diamagnetic NaCl were examined. Through the introduction of a residual hysteresis curve, it was shown that the overall hysteresis loop of a mixture did not represent a simple sum of contributions corresponding to individual components, but was affected by interactions between magnetite and hematite grains.

Snowball, I. F.
Bacterial magnetite and the magnetic properties of sediments in a Swedish lake, *Earth Planet. Sci. Lett.*, *126*, 129–142, 1994.
Comparison of the magnetic properties and TEM examinations of lake sediments to those of catchment materials indicated that single-domain magnetite in gyttja was of bacterial origin, containing cells and magnetosomes. This finding emphasized the complex effects of post-depositional processes on mineral magnetic assemblages and natural remanent magnetization, and demonstrated how mineral magnetic measurements may be used to identify magnetic grain-size changes brought about by sediment diagenesis.

Stephenson, A., and J. C. Shao
The angular dependence of the median destructive field of magnetite particles, *Geophys. J. Int.*, *118*, 181–184, 1994.
The median destructive field (MDF) of sized anisotropic magnetite particles was smallest when AF demagnetization was applied parallel to the alignment axis and greatest when applied perpendicular to the axis; hence, coherent reversal did not occur. The angular variation of the MDF for all the particle sizes was described quite well by a function derived for single-domain particles. The MDF at $\theta = 0$ was found to be inversely proportional to the square root of the particle size.

Techniques

Tsunakawa, H., and J. Shaw
The Shaw method of palaeointensity determinations and its application to recent volcanic rocks, *Geophys. J. Int.*, *118*, 781–787, 1994.
In order to find a reliable criterion with which to select samples for paleointensity determinations, various versions of the Shaw method were tested on recent volcanic samples for which well-determined paleointensity values exist. The best results were obtained using a new modification: After heating the specimen twice in the same field, the measured intensity from the second heating was compared with the laboratory field intensity; when the difference was larger than the experimental error, the sample was rejected.

Recording Materials

This time, there was a wealth of papers dealing with the synthesis and magnetic properties of magnetic particles for use in industry, which nevertheless may be of use to rock- and paleomagnetists. In lieu of all of the abstracts, below is a list of titles for those interested:

Cherkaoui, R., *et al.*
Static magnetic properties at low and medium field of γ-Fe_2O_3 particles with controlled dispersion, *IEEE Trans. Magn.*, *MAG-30*, 1098–1100, 1994.

Han, D.-H., J.-P. Wang, and H.-L. Luo
Crystallite size effect on saturation magnetization of fine ferrimagnetic particles, *J. Magn. Magn. Mater.*, *136*, 176–182, 1994.

Ishii, O., A. Terada, and S. Ohta
Aging effect on coercivity of iron oxide thin films, *IEEE Trans. Magn.*, *MAG-30*, 1291–1295, 1994.

Kaczmarek, W. A., and B. W. Ninham
Preparation of Fe_3O_4 and γ-Fe_2O_3 powders by magnetomechanical activation of hematite, *IEEE Trans. Magn.*, *MAG-30*, 732–734, 1994.

Liz, L., *et al.*
Preparation of colloidal Fe_3O_4 ultrafine particles in microemulsions, *J. Mater. Sci.*, *29*, 3797–3801, 1994.

Lochner, E., *et al.*
Studies of stoichiometric variations of epitaxially grown $Fe_{3-\delta}O_4$, *J. Appl. Phys.*, *75*, *612*4, 1994.

Morales, M. P., *et al.*
Magnetic viscosity of uniform γ-Fe_2O_3 particles with different degrees of cationic ordering, *IEEE Trans. Magn.*, *MAG-30*, 772–774, 1994.

Niznansky, D., J. L. Rehspringer, and M. Drillon
Preparation of magnetic nanoparticles (γ-Fe_2O_3) in the silica matrix, *IEEE Trans. Magn.*, *MAG-30*, 821–823, 1994.

Qian, Y.-T., *et al.*
Hydrothermal preparation and characterization of ultrafine magnetite powders, *Mater. Res. Bull.*, *29*, 953–957, 1994. ■

…MMC *continued from page 2*

actual magnetization of the magnetosomes from the image. Not only was this work a breakthrough in the quantification process for the MFM, but it was also a measurement of isolated moments on the order of 10^{-16} Am^2 (10^{-13} emu), a value which is five [!] orders of magnitude below the sensitivity of a commercial SQUID magnetometer.

We are carrying this kind of success into the study of a wide variety of other magnetic systems. Of particular importance is a project led by Sherry Foss, in collaboration with Bruce Moskowitz and Sanghamitra Sahu from the *IRM*, to investigate the magnetic structures in single crystals of magnetite, an example of which is the image shown on the cover. Micromagnetic modeling such as that done by Song Xu (University of Toronto–Erindale, Mississauga, ON) predicts the presence of Néel caps which terminate Bloch walls at the surface. Hence, the measured MFM response to the walls must be compared to the response calculated for models of the predicted structure. If the two are not the same, the model must be modified until a match is achieved. Sherry is also looking at the effects of external fields on these walls and the influence of surface defects on wall motion. To take this a step further, Katerina Moloni, who has been working on the construction of the low-temperature MFM, is conducting a study of the temperature dependence of the wall structures in magnetite crystals as they pass through the Verwey transition near 118 K. Other projects on our plate include investigations of both the dynamics of other magnetic structures such as arrays of interacting and non-interacting particles, and of domain walls in single crystals of iron grown in different planes, *i.e.*, with in-plane easy axes or with easy axes canted relative to the surface. Special attention will be given to pinning effects and temperature dependences. For technical applications, the domain structures in hard materials like NdFeB or in the latest magnetic and magneto-optic media thin films are of interest. Also ahead are studies of the domain structure in magnetically soft materials (which will prove to be a real challenge for the magnetically intrusive MFM), and the domain pinning and magnetostatic coupling of thin films.

MMC *continued on page 7…*

A Tale of Two (Well…a Few) Instruments

The Worst of Times

Probably, we'd been lucky. Certainly we'd been naive. Our relatively trouble-free first years had lulled us into a feeling of invincibility. But then came 1994, the Year of the Pestilence(s). Our equipment was plagued by myriad ills: the MPMS was out of commission for several months to get an upgrade; the three MicroMag sample holders suffered acute breakage syndrome with alarming regularity (all were useless shards when Kaushik Katari was here); the MicroMag's Hall probe simply snapped one miserable morning. And that's not all! The power supplies for the AF demagnetizers and VSM magnet took to blowing various transistors at random times; the VSM furnace thermocouples never survived for more than a few months without needing to be rebuilt; the Lake Shore had to be quarantined at the shop for R&R after having developed an open circuit in its detector [too many trips to 15 K?]. To say nothing of the Kappabridge, which is only now up and running again after having lost first a temperature sensor and then a circuit board. And the computers! Every one of them was stricken or laid low at some point. In fact, your Editor's hard drive gave up the ghost just before *IRM Quarterly* press time—may it Rest in Piece(s)!

The Best of Times

But hope does spring eternal [even in fall], and we are confident of full recoveries. Moreover, we are looking forward to a robust new addition: with funds from our new W. M. Keck Foundation grant, we are about to fill in a long-standing gap in the *IRM*'s capabilities by ordering a Princeton Measurements Corporation furnace-equipped Vibrating Sample Magnetometer. (PMC also brought you the MicroMag.) In the past we measured Curie points and high-temperature hysteresis loops with a homemade furnace on our old VSM. But, as Kaushik mentioned, the restrictions that the furnace imposed on sample-size limited our signal strength. The new machine will remedy this situation because it has greater sensitivity—an attribute as desirable in machines as it is in people. Bulk samples of loess and paleosol that were generally too weak for our old system gave beautiful Curie points during window shopping at PMC. (There will be an article on this latest acquisition in an upcoming issue.)

So, all in all, we expect 1995 to be a far, far better year…. ▬

*Could this be **Jim Marvin** and **Chris Hunt** surveying the fate of those* IRM *users who broke things…?*

Actually, this is Gustave Doré's illustration for Dante's Inferno *of a scene that was inspired by a 13th-century Florentine statute that read, "Let the assassin be dragged at the tail of a mule or ass to the place of justice; and there let him be planted head downward, so that he die." [Finding an appropriate illustration from* A Tale of Two Cities *proved to be a real Dickens!]*

…MMC *continued from page 6*

Visitors

In addition to being engaged in physics investigations and developmental programs, the *MMC* is available to other researchers for help in learning about the MFM, selection of commercial units, and MFM construction or modification. Although still in our infancy, we have had scientists from Sweden and the United Kingdom come to learn about the MFM and imaging. We have also measured samples for researchers at General Motors, 3M, the University of California–Berkeley, the Naval Research Laboratory, the University of Nebraska, and the University of California–San Diego. Although one might think that service for the community would limit our own research projects, each of these extra projects actually helps in the development of our expertise with the MFM.

If you have any questions about magnetic microscopy, give us a call at (612) 626-7849; we would be happy to have you visit (unfortunately, we do not have funds to aid in your travel); or, if you have an interesting sample you would like us to measure, we will try to arrange it; we want to be of help as much as possible. ▬

IRM Logo Contest!

A quick glance at the back page makes it immediately obvious that the *IRM* suffers from the lack of a good logo. Therefore, we are having a logo-design contest to remedy to the situation. The competition is open to all, but submissions from graduate students are especially encouraged. The logo could include specific areas of *IRM* research, but the best logo would probably be simple and contain some reference to the underlying foundation of our science: the magnetism of geologic and geophysical materials. If we decide to use your logo, you will receive a yet-to-be-determined but appropriate prize. Send submissions to the *IRM* by January 15, 1995. ▬

IRM RAC Has New Membership

The *IRM*'s Review and Advisory Committee (RAC)—consisting of two rock magnetists, two paleomagnetists, one geologist, and one physicist—changes some of its membership every two years. This year, Sue Halgedahl (University of Utah–Salt Lake City) will replace Mike Fuller (University of California–Santa Barbara) in one of the rock-magnetist slots, John King (University of Rhode Island–Narragansett) will succeed Rich Reynolds (U.S. Geological Survey–Denver) as the geologist, and Dennis Kent (Columbia University/LDEO–Palisades) will take over for Chad McCabe in one of the paleomagnetist positions. Physicist Dan Dahlberg (University of Minnesota–Minneapolis) and rock-magnetist David Dunlop (University of Toronto–Erindale) will re-up for another tour of duty. Finally, paleomagnetist Bob Butler (University of Arizona–Tucson) will continue to serve, taking on the mantle of Chair. We look forward to two more years of productive research and growth under the guidance of these distinguished people. ▬

Calibration Samples Available

Ian Snowball
Lund University

Interest in following up the recent attempt to check inter-laboratory calibrations (see *IRM Quarterly*, Spring 1994, vol. 4, no. 1, pp. 6–8) has been high enough to warrant further experiments. I have now produced samples suitable for undertaking hysteresis measurements on a variety of equipment. In contrast to the original samples, which were dominated by multi-domain magnetite, the new samples contain single-domain magnetite of bacterial origin (grain size 100 nm with well-behaved and stable magnetic properties). [Ed.: See Snowball's abstract in this issue, p. 6.] The samples consist of the single-domain magnetite dispersed in hardened epoxy resin. For spinner, SQUID, and certain vibrating-sample magnetometers, the samples can be packaged in polished 2×2×2-cm perspex cubes (the size can be altered as required). For AGFMs and other VSMs, a blob of the sample (approximately 3×3×2 mm), mounted on plastic sheet, is available.

One aim of using these standards is to check the compatibility of various coercivity and MDF values obtained from ARM and IRM acquisition and demagnetization in pulsed fields, steady fields, alternating fields, and in-field hysteresis loops—all using different brands of equipment. In contrast to the magnetic properties of samples supplied as standards by most manufacturers of magnetic equipment, the ARM and SIRM of my samples are a bit weaker, and thus more comparable to natural samples. Furthermore, the samples are easy to demagnetize and can therefore for be used by students for learning or practicing. The magnetic properties of the samples have been characterized by me in Lund, and by Chris Hunt at the *IRM*. In order to encourage as many laboratories as possible to participate in this calibration effort, the samples are available free of charge, with basic coercivity and hysteresis values supplied. The experiment will not only test equipment, but will also foster scientific cooperation. Send requests to:

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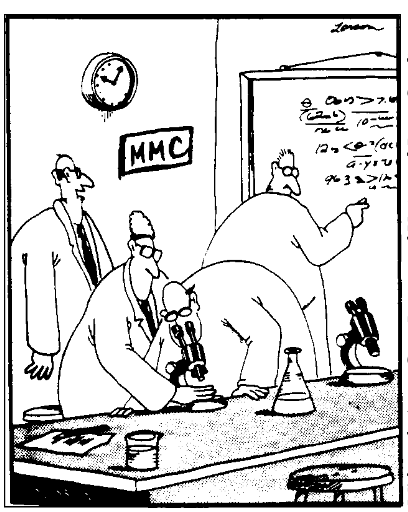

"Hey! You better get over here if you want to see a hangnail magnified 13,000 times."

With apologies to Gary Larson and Universal Press Syndicate.

☛ December 19 Deadline is Nigh!

Visiting Fellowship Applications for short stays next spring and summer are due almost immediately. Details about how to apply are in *Eos* (October 25 and November 15 issues) and in *GSA Today* (November issue). Be sure to fill out a photocopy of the Application Form from the last winter's *IRM Quarterly* (vol. 3, no. 4, p. 6) as part of your proposal; notify the Lab Manager if you need another copy. ▬

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 1–3-week period during the following half year. Shorter, less formal visits are arranged on an individual basis through the laboratory manager.

The *IRM* staff consists of Subir Banerjee, Director; Bruce Moskowitz, Associate Director; Jim Marvin, Senior Scientist; and Chris Hunt, Scientist and Lab Manager.

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The *IRM Quarterly* is published four times a year by the staff of the *IRM*, with editorial and layout assistance from Freddie Hart. 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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