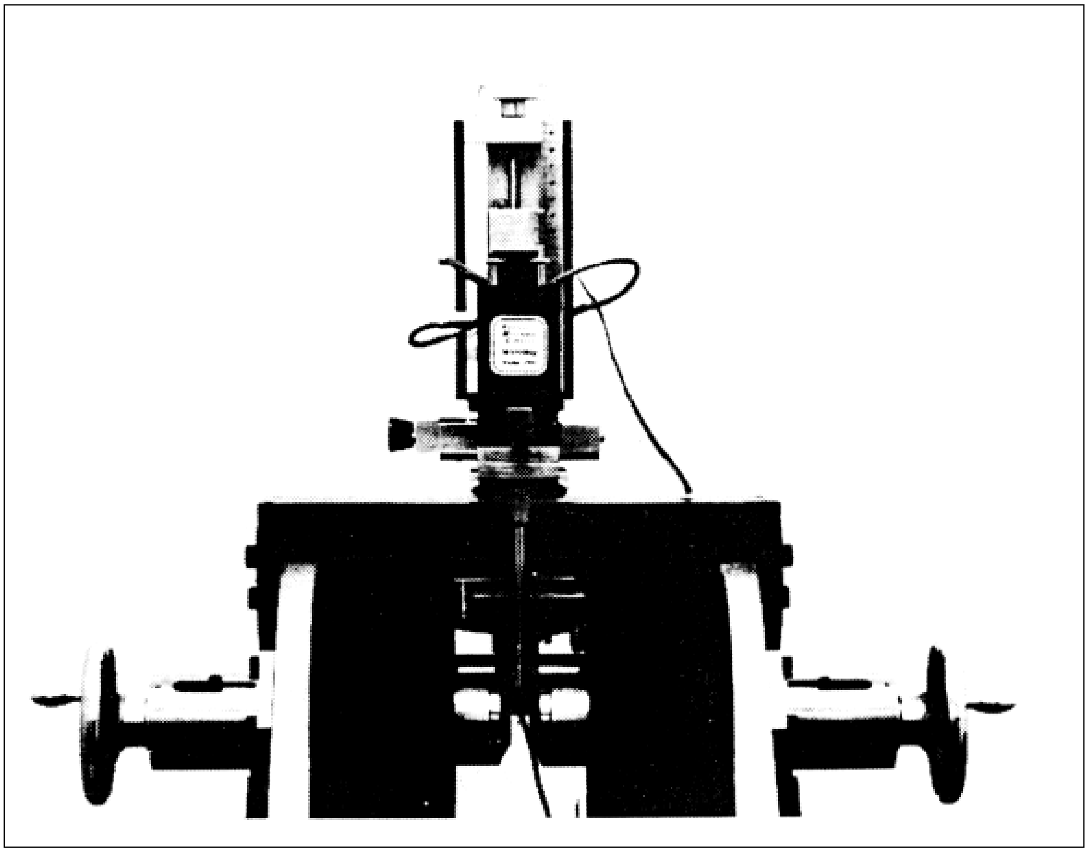
The IRM Quarterly

SPRING 1992, VOL. 2, NO. 1 INSTITUTE FOR ROCK MAGNETISM



New Equipment at *IRM* Allows Novel Measurements

Chris Hunt
IRM

The arrival of several new pieces of equipment during the past year has added significantly to the capabilities of the IRM. *This article is the first in a series that will explain their usefulness as well as how to use them. All this in the hopes of both removing some of the mystique that surrounds them, and of fostering ideas for new experiments afforded by their existence. We'll start with the MicroMag and the MPMS:*

THE MICROMAG

Our one-year-old Princeton Measurements Corporation Alternating Force Gradient Magnetometer, or "MicroMag," has impressed visitors with its speed and sensitivity. The primary use of the MicroMag is to measure hysteresis properties (such as J_s, J_{rs}, H_c, H_{cr}, and high- and low-field χ), but it can also measure IRM acquisition, and pseudo-AF demagnetization, all without remounting the sample.

Applications

A flashy demonstration of the MicroMag's capabilties was given by Tony Cumbo, the installer of our machine, and has been recreated here by your enterprising editor (see page 6): The United States Treasury Department uses magnetic ink in its paper money. Even the dot on the "i" in the signature of the Treasurer of the United States has plenty of a certain familiar—well, perhaps I shouldn't go on, lest all of you potential counterfeiters out there get any ideas—anyway, it has plenty of pseudo-single-domain magnetic material to get a good hysteresis loop. (So does Scotch tape by the way, so use non-magnetic masking tape for your low-tech sample mounts.)

In addition to such whimsical excursions, the MicroMag has successfully measured 1) the presence of about 1% magnetite within individual biotite grains, 2) characteristics of pathetically weak carbonate chips and sediment samples, as well as 3) properties of magnetic dust particles from the room when the sample holder didn't get cleaned well enough.

How?

Many MicroMag studies involve the determination of hysteresis parameters, which can be used for magnetic granulometry, as well as for mineral identification. For example, mixtures of coarse and fine magnetic grains (with corresponding low and high coercivities, respectively) can produce constricted, or "wasp-waisted," loops. Such loops have been diagnostic in carbonate remagnetization studies where small grains of new magnetic material are associated with the chemical changes that are responsible for the remagnetization.

Principles of Operation

The MicroMag works something like a Vibrating Sample Magnetometer (VSM). The sample is placed in a magnetic field, but here with a small magnetic field gradient added on. The resulting force, which is proportional to the magnetization of the sample, is detected by a piezo-electric sensor at the ends of the tiny quartz rods on which the sample is mounted. The temperature is limited to ambient, but the applied field

continued on page 6...

Visiting Fellows' Reports

Many Visiting Fellows have been here during the recent months. In the dead of a Minnesota winter, Ms. ***Tomoko Ogishima****, from the University of Tokyo, came all the way from Japan to measure her experimentally-altered synthetic titanomagnetites. Then, in April, Dr.* ***Chad McCabe****, from Louisiana State University, and Prof.* ***Jim Channell****, from the University of Florida, arrived to measure their very weak carbonates. Jim gets the coveted* IRM *Hand-is-Quicker-than-the-Eye Award for dexterously catching the Micromag sample holder as it slipped it moorings—nothing broke! Later in the month, Dr.* ***Özden Özdemir*** *and Prof.* ***David Dunlop****, both from the University of Toronto, made a reprise visit to study VRM and CRM. Each Visiting Fellow has contributed a summary of work done here at the* IRM*:*

Tomoko Ogishima
Earthquake Research Institute, University of Tokyo, Japan

Effect of hydrothermal alteration on synthetic titanomagnetite

In order to understand what is happening in oceanic basalt under hydrothermal conditions, synthetic titanomagnetite powders were altered at the Earthquake Research Institute, University of Tokyo. Experiments were done on samples initially having x-values (relative Ti content) of 5%, 60%, or 80%. Each 200 mg sample was sealed in a gold sample holder with 0.4 ml fluid whose pH value was either 3 (H_2SO_4), 7 (pure water), or 12 (NaOH). The samples were kept in a vapor-pressure vessel for 3.5 days at 350°C. The magnetic characteristics of these altered samples, as well as the original ones, were measured at the *IRM*.

Hysteresis loops and high-temperature J_s–T measurements in vacuum were made on the Vibrating Sample Magnetometer (VSM). The fact that the thermocouple junction was touching the sample directly allowed for better temperature control and faster runs. Low-temperature J_s–T measurements were performed using the Quantum Design Magnetic Property Measurement System (MPMS). Each sample was thus measured from a temperature of l0 K to about 1000 K.

Contrary to my expectations, the VSM detected no differences in magnetic characteristics between the original and any of the altered samples. All of them showed reversible J_s–T curves. It is possible that the pressure used for alteration had not reached vapor pressure, and that the lower pressure had induced less change in the magnetic characteristics; or that the volume of water used was insufficient to produce much alteration.

Low-temperature results from the MPMS revealed changes of magnetic properties in all altered samples, but they were quite difficult to interpret. At an *IRM* lab meeting, the possibility of decomposition into two phases was discussed. To check this, x-ray diffraction measurements were performed with the kind help of Rick Knurr in the Geology Department. A general scan (at 2 degrees/min) found no apparent difference between the original and the altered samples. Now, more consideration, speculation, and suggestions are needed.

Finally, I would like to thank heartily all of the people at the *IRM* for their warm and helpful cooperation, discussions, and troubleshooting.

Chad McCabe
Louisiana State University
Jim Channell
University of Florida

Magnetic properties of remagnetized Paleozoic carbonates from Europe

Recent research by Mike Jackson and others at the *IRM* suggests that magnetite-bearing limestones in eastern North America that were chemically remagnetized in Late Paleozoic time share a very unusual set of magnetic properties, including "wasp-waisted" hysteresis loops. It has been suggested that these properties could be useful in predicting the presence or absence of remagnetization in advance of a full-scale paleomagnetic investigation. In a week-long stint at the *IRM*, we studied hysteresis and other rock magnetic properties in two very different kinds of limestone: (1) Lower Carboniferous limestones from the Craven basin in northern England, which have suffered remagnetization synchronous with the Hercynian folding that deformed the basin; and (2) Cretaceous "Maiolica" limestones from central and northern Italy which have yielded high-quality magnetostratigraphies that have been integral in correlating the M-sequence oceanic anomaly record to nannofossil and calpionellid biozonations. Preliminary results obtained at the *IRM* suggest that the remagnetized Craven basin limestones have the same peculiar set of properties as those from North America. In contrast, the Maiolica limestones show behavior which is more typical for rocks containing fine-grained magnetite. These results suggest that rock magnetic criteria may be a very powerful way of predicting the outcome of a paleomagnetic study involving sedimentary carbonates.

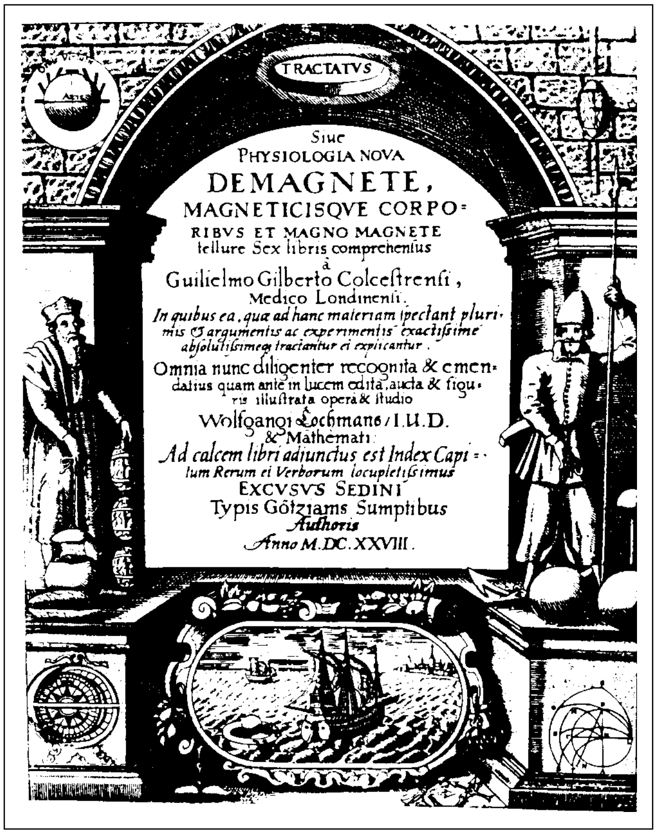
Özden Özdemir
David Dunlop
University of Toronto

Chemical remanence in hematite and viscous remanence in magnetite

Özden's main experiments concerned the acquisition of chemical remanent magnetization (CRM) by hematite (α-Fe_2O_3) when it forms by the dehydration of goethite (α-FeOOH) in the presence of a weak magnetic field. Samples of dispersed synthetic goethite were heated quickly in zero field to a variety of temperatures between 150˚C and 500˚C, and were then held for 2.5 hr in a 1 Oe (100µT) field. After heating, the field was zeroed and the samples were cooled quickly to room temperature. The CRMs were measured and their stability to AF demagnetization was determined using the superconducting rock magnetometer (SRM). The CRM intensity was a maximum after the 250˚C run, which is close to the spontaneous dehydration temperature of the particular goethite used. After CRM experiments, room-temperature hysteresis was measured for each sample using the vibrating-sample magnetometer (VSM) and the MicroMag system.

David's central experiments were the acquisition and stepwise thermal demagnetization of viscous magnetization (VRM) acquired at temperatures of 283˚C and 404˚C by equidimensional single-domain magnetite. Several partial thermoremanent magnetizations (pTRMs) ac-

continued on page 8…



TRACTATVS
Siue
PHYSIOLOGIA NOVA
DE MAGNETE,
MAGNETICISQVE CORPO-
RIBVS ET MAGNO MAGNETE
tellure Sex libris comprehensus
à
Guilielmo Gilberto Colcestrensi,
Medico Londinensi.
In quibus ea, quæ ad hanc materiam spectant pluri-
mis & argumentis ac experimentis exactissime
absolutissimeq tractantur et explicantur.
Omnia nunc diligenter recognita & emen-
datius quam ante in lucem edita, aucta & figu-
ris illustrata opera & studio
Wolfgangi Lochmans, I.U.D.
& Mathemati
Ad calcem libri adiunctus est Index Capi-
tum Rerum et Verborum locupletissimus
EXCVSVS SEDINI
Typis Götzianis Sumptibus
Authoris
Anno M.DC.XXVIII.

Title page from Gilbert's De Magnete, *second edition, 1628.*

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 geological journals are included, but 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 the* IRM Quarterly. *An extensive reference list of articles primarily about rock magnetism, paleomagnetism, and the physics and chemistry of magnetism is continually updated at the* IRM. *This list, with more than 1600 references, is available free of charge. As always, your contributions both to the Abstracts section of the* IRM Quarterly *and to the reference list are welcome.*

Anomalies

Toft, P. B., and J. Arkani-Hamed
Magnetization of the Pacific Ocean lithosphere deduced from MAGSAT data, *J. Geophys. Res., in press*, 1992.
Based on MAGSAT anomalies over the Pacific, calculations of the magnetization of volcanic plateaus are made, with good results. MAGSAT anomalies over parts of the Pacific where no plateaus exist may be explained by including uppermost mantle remanent magnetization.

Data Manipulation

Tsunakawa, H.
Bayesian approach to smoothing paleomagnetic data using ABIC, *Geophys. J. Int.*, *108*, 801-811, 1992.
A Bayesian spline regression for l-D time series is useful for smoothing paleointensity data, but this method is not applicable to directional data composed of inclination and declination values. Therefore, a new spline regression, based on Bayesian statistics, is developed for smoothing a time series of unit vectors subjected to the Fisher distribution. These methods are applied successfully to archaeomagnetic data in Japan for the period 200-2000 yr BP.

Dynamo

Hoffman, K. A.
Long-lived transitional states of the geomagnetic field and the two dynamo families, *Nature, 354*, 273-277, 1991.
Paleomagnetic data from lavas produced at the Hawaii and Society Islands hotspots suggest that at least one specific, long-lived field configuration recurs during successive polarity reversals spanning several million years. The apparent quasi-stationarity of these states and the relative location of the two recording sites offer a rare opportunity to explore the fundamental geometrical properties of traditional fields.

Igneous Rocks

Audunsson, H., S. Levi, and F. Hodges
Magnetic property zonation in a thick lava flow, *J. Geophys. Res.*, *97B*, 4349-4360, 1992.
Grainsize- and composition-dependent magnetic properties of titanomagnetites are used as indicators of intraflow structures and magmatic evolution in a thick, basaltic lava flow. Modification of the initially symmetric equilibrium titanomagnetite compositions was caused by subsolidus high-temperature oxidation; the titanomagnetites of the basal layer of the flow remain essentially unaltered.

Hargraves, R. B., D. Johnson, and C. Y. Chan
Distribution anisotopy: The cause of AMS in igneous rocks?, *Geophys. Res. Lett.*, *18*, 2193-2196, 1991.
The distribution of magnetite grains will be relatively anisotropic if the grains grow in residual melt liquid within a preferably-oriented (by magma flow) silicate "template." Experiments involving the casting of magnetic-epoxy mixtures in various foliated or lineated glass templates have yielded samples with the expected AMS symmetry, *i.e.*, K_3 perpendicular to glass plates of K_1 parallel to glass rods.

Sempere, J.-C.
High-magnetization zones near spreading center discontinuities, *Earth Planet. Sci. Lett.*, *107*, 389-405, 1991.
Over the propagating limbs of large spreading center discontinuities, three-dimensional inversions of the magnetic field reveal zones of high magnetization associated with highly-differentiated, iron-enriched basalts. The enrichment in iron associated with increased differentiation may be accompanied by an increase in the concentration of titanomagnetite within the basalts.

Metamorphic Rocks

Rochette, P., G. Menard, and R. Dunn
Thermochronometry and cooling rates deduced from single sample records of successive magnetic polarities during uplift of metamorphic rocks in the Alps (France), *Geophys. J. Int.*, *108*, 491-501, 1992.
Sequences of successive polarities have been recorded by pyrrhotite-bearing metamorphic calcschists and can be unravelled by detailed thermal demagnetization. Polarity versus temperature profiles on single samples are compared to the polarity time-scale, allowing estimation of a cooling rate of 50˚C/Ma at the time of TRM acquisition (20-25 Ma).

Meteorites

Morden, S. J., and D. W. Collinson
The implications of the magnetism of ordinary chondrite meteorites, *Earth Planet. Sci. Lett.*, *109*, 185-204, 1992.
Because the magnetic fabric in the majority of eleven ordinary chondrites was continuous, and the NRM was randomly oriented, it was concluded that the magnetic carriers were magnetized before emplacement in the meteorite, and that these meteorites are, therefore, not fine-scale breccias. This makes hot accretion the preferred mechanism for producing chondritic textures, rather than metamorphic reheating, which would tend to erase the random magnetization.

Microscopy

Heider, F., and V. Hoffmann
Magneto-optical Kerr effect on magnetite crystals with externally applied magnetic fields, *Earth Planet. Sci. Lett.*, *108*, 131-138, 1992.
Magnetic domain structures of a multi-domain magnetite crystal were observed as a function of applied magnetic field using a MOKE system. Hysteresis determined from the domain patterns on the surface of a single crystal was inconsistent with bulk hysteresis measurements. This was interpreted as a surface phenomenon concealing magnetic domains in the interior of the grain.

Salling, C., *et al.*
Measuring the coercivity of individual sub-micron ferromagnetic particles by Lorentz microscopy, *IEEE Trans. Magn.*, *MAG-27*, 5184-5186, 1991.
The Foucault mode of Lorentz microscopy has been applied to detect the polarity of the magnetic field produced by ferromagnetic particles in the single-domain size range. The authors demonstrate the ability to detect the polarity and measure the coercivity of nearly ellipsoidal γ-Fe_2O_3 particles which have a moment of approximately 10^{-13} emu (10^{-16} $A \cdot m^2$).

Wiesendanger, R., *et al.*
Topographic and magnetic-sensitive scanning tunneling microscope study of magnetite, *Science*, *255*, 583-586, 1992.
The topographic and magnetic surface structures of a natural single crystal of magnetite (Fe_3O_4) have been studied from the sub-micron scale down to the atomic scale with a scanning tunneling microscope. Imaging of the Fe B-sites, and even a selective imaging of the Fe^{2+} and Fe^{3+} ions, has been achieved, demonstrating for the first time that magnetic imaging can be realized at the atomic level.

Wiesendanger, R., *et al.*
Magnetic imaging at the atomic level, *Z. Phys. B*, *86*, 1-2, 1992.
Magnetic contrast at the atomic level has been observed for the first time in scanning tunneling microscopy experiments on a magnetite ‹001› surface using in-situ prepared ferromagnetic Fe tips. A periodic corrugation with a 12 Å periodicity is clearly observed along the rows of Fe B-sites which corresponds to the repeat period of Fe^{2+} and Fe^{3+} along these rows.

Models

Tarashchan, S. A., and V. P. Shcherbakov
The thermoremanent magnetization of multidomain grains with allowance for the inductive component, *Geofiz. Zh. (J. Geophys.)*, *10*, 429-435, 1991.
The theory of the formation of TRM in a multidomain grain containing magnetically hard and soft regions is explored. A model incorporating allowances for the coercive force of the “hard” phase and for the screening effect of the inductive component of the “soft” phase is shown to be consistent with previous hysteresis models.

Paleomagnetism

Hilgen, F. J.
Extension of the astronomically-calibrated (polarity) time scale to the Miocene/Pliocene boundary, *Earth Planet. Sci. Lett.*, *107*, 349-368, 1991.
The astronomically calibrated time scale is extended to the Miocene/Pliocene boundary by correlating a detailed record of $CaCO_3$ cycles to the astronomical record. This correlation allows the construction of an astronomically calibrated Geomagnetic Polarity Time Scale for the major part of the Gilbert and Gauss Chrons. An age of 5.32 Ma is obtained for the Miocene/Pliocene boundary.

Piper, J. D. A.
The quasi-rigid premise in Precambrian tectonics, *Earth Planet. Sci. Lett.*, *107*, 559-569, 1991.
The proposition that movements between multiple continental fragments have taken place in the Precambrian is tested and confirmed for the late Archean and Proterozoic poles (2850-590 Ma). A random distribution is found when the collective paleomagnetic poles are rotated into any quasi-rigid reconstruction. This elementary test surmounts the limitations of poorly-known Precambrian ages.

Prévot, M., and M. Perrin
Intensity of the Earth’s magnetic field since Precambrian from Thellier-type palaeointensity data and inferences on the thermal history of the core, *Geophys. J. Int.*, *108*, 613-620, 1992.
A compilation of paleointensity data, obtained by the Thellier method from magmatic rocks up to 3.5 Ga old, shows no apparent long-term variation since the Early Precambrian. Compatibility of the incomplete data set with dynamo histories is discussed.

Tauxe, L., *et al.*
Pinning down the Brunhés/Matuyama and upper Jaramillo boundaries: A reconciliation of orbital and isotopic time scales, *Earth. Planet. Sci. Lett.*, *109*, 561-572, 1992.
“Chronogram technique” and “astronomical technique” estimates for the age of the last reversal are reconciled by (1) presenting new magnetostratigraphic data tied to high-quality $^{40}Ar/^{39}Ar$ dates, and (2) employing a new method for estimating the uncertainties of chronogram technique ages. A date of 0.992 ± 0.039 Ma was obtained for the upper Jaramillo boundary, and an age of 0.746 ± 0.009 Ma for sediments immediately overlying the Brunhés/Matuyama boundary.

Physics

Ayoub, N. Y.
The effect of dipolar interactions on the susceptibility peaks in a solidified ferrofluid, *Jpn. J. Appl. Phys.*, *30*, 3381-3385, 1991.
The temperature dependence of the initial susceptibility in frozen magnetite ferrofluid samples is measured. T_p, the temperature at which the initial susceptibility reaches a maximum, increases with the concentration of the ferrofluid. This behavior can be accounted for using a theoretical model of a non-interacting fine particle system in a fixed matrix combined with a hypothesis for the effect of interparticle interactions on the anisotropy constant.

Chantrell, R. W., M. El-Hilo, and K. O’Grady
Spin-glass behavior in a fine particle system, *IEEE Trans. Magn.*, *MAG-27*, 3570-3578, 1991.
A study of the magnetic behavior of a spin-glass suggests that spin-glass effects might arise from the clumping of impurity spins in the host material into ferromagnetic-rich clusters. This result supports the idea that spin-glass alloys can be interpreted on the basis of a Néel-type superparamagnetic blocking model.

Penicaud, M., *et al.*
Calculated electronic band structure and magnetic moments of ferrites, *J. Magn. Magn. Mater.*, *103*, 212-220, 1992.
Local spin-density functional theory is used to make a comparative study of the band structures in the ferrites Fe_3O_4, $CoFe_2O_4$, $NiFe_2O_4$, $MnFe_2O_4$, and $ZnFe_2O_4$. The saturation magnetization is obtained, and the trend of the calculated magnetic moments is interpreted and compared with experimental values.

Zhang, Z., and S. Satpathy
Electron states magnetism, and the Verwey transition in magnetite, *Phys. Rev. B*, *44*, 13,319-13,331, 1991.
In order to gain insight into the nature of the Verwey transition, the electronic structure of magnetite in the spinel crystal structure is examined using density-functional calculations. The results suggest a three-band spinless Hamiltonian for the description of the Verwey transition. The hopping integrals and the electron interaction parameters are calculated using the “constrained” density-functional theory.

Pressure, Stress, and Strain

Adnan, J., A. de Sa, and W. O’Reilly
Simultaneous measurement of the variations in the magnetic susceptibility and remanence of materials in the temperature range 10-700˚C and at elevated pressure (16-160 MPa), *Meas. Sci. Technol.*, *3*, 289-295, 1992.
The pressure- and temperature-induced phase transition (inversion) of γ-Fe_2O_3 is investigated by simultaneously measuring the susceptibility, remanence, temperature, and presssure of samples.

Borradaile, G. J., M. Puumala, and M. Stupavsky
Anisotropy of complex magnetic susceptibility as an indicator of strain and petrofabric in rocks bearing sulphides, *Tectonophys.*, *202*, 309-318, 1992.
A new method, anisotropy of complex magnetic susceptibility (ACMS), is developed for determining the petrofabric of specimens which contain conductive minerals. ACMS successfully defines the petrofabric and permits prediction of the principal directions of finite strain in artificial samples. The intensity of AMS and, to a lesser extent, of ACMS correlate with the strain ratio in selected materials.

Borradaile, G. J.
Experimental deformation of two-component IRM in magnetite-bearing limestone: A model for the behaviour of NRM during natural deformation, *Phys. Earth Planet. Inter.*, *70*, 64-77, 1992.
Room-temperature, triaxial deformation at 200 MPa and at a controlled strain rate of 10^{-5}/s is performed on three limestones containing single-domain magnetite, using a two-component IRM as a simple model of a multi-component NRM. As with previous uniaxial tests, the decrease in IRM magnitude correlates slightly better with peak stress than with strain, indicating the role of stress in deformational “demagnetization.”

Remanences

Worm, H.-U., et al.
Magnetic viscosity of single-domain magnetite particles, *J. Appl. Phys.*, *70*, 5533-5537, 1991.
The field and temperature dependence of the acquisition of viscous magnetization by a single-domain magnetite sample has been measured and calculated. Because predicted and experimental viscosity coefficients do not match—especially below the Verwey transition—one cannot explain SD viscosity by switching field and volume distributions alone. It is suspected that stress plays a prominent role.

Remagnetization

Lu, G., *et al.*
A genetic link between remagnetization and potassic metasomatism in the Devonian Onondaga formation, northern Appalachian basin, *Geophys. Res. Lett.*, *18*, 2047-2050, 1991.
Results of whole-rock chemical analyses of the Onondaga Formation in New York State indicate that changes in the K/Al ratio correlate with changes in authigenic magnetite content and with degree of diagenetic illitization. These observations suggest that Paleozoic remagnetization was triggered by a basin-wide migration of K-rich fluids during the Alleghenian Orogeny.

(See also:
Saffer, B., and C. McCabe
Further studies of carbonate remagnetization in the northern Appalachian basin, *J. Geophys. Res.*, *97B*, 4331-4348, 1992.)

Soils and Sediments

Bloemendal, J., *et al.*
Rock magnetism of late Neogene and Pleistocene deep-sea sediments: Relationship to sediment source, diagenetic processes, and sediment lithology, *J. Geophys. Res.*, *in press*, 1992.
The ability of rock magnetic properties to differentiate sediments according to factors such as lithology, geographical area, and the dominant mode of terrigenous sedimentation is poor. Factors such as the source and transport path of terrigenous sediment (and detrital magnetic minerals), together with the action of reductive diagenetic processes, are the major controls on the magnetic properties.

Dabas, M., A. Jolivet, and A. Tabbagh
Magnetic susceptibility and viscosity of soils in a weak time-varying field, *Geophys. J. Int.*, *108*, 101-109, 1992.
An attempt is made to characterize the magnetic behavior of soils in both the frequency and time domains. The aim is to understand the anomalous responses observed in many EM surveys. A wide range of soil samples has been analyzed with two instruments specially designed for harmonic (80 Hz-10 kHz) and transient (8-100 µs) low fields (50 µT).

Liu, X.-M., *et al.*
Magnetic mineralogy of Chinese loess and its significance, *Geophys. J. Int.*, *108*, 301-308, 1992.
The magnetic properties of loess and paleosol are largely controlled by fine-grained magnetite, formed in a variety of quantities and grain sizes by pedogenesis during variable paleoclimatic conditions. Therefore, regional and global paleoclimatic development during the last 2.5 Ma can be reconstructed from susceptibility records in the loess plateau.

Lund, S. P., D. S. Gorsline, and T. L. Henyey
Rock magnetic characteristics of surficial marine sediments from the California continental borderland, *Earth Planet. Sci. Lett.*, *109*, 93-108, 1992.
Interpretation of magnetic mineralogy studies of marine sediments yields a good picture of the geological processes occurring off the California coast. Comparisons of ARM, χ, and SIRM (saturation IRM) indicate that ARM/χ is very sensitive to magnetic grain-size changes and that both the quantity $(ARM^2 + \chi^2)^{0.5}$ and SIRM are good indicators of the volume of remanent magnetic material.

Moukarika, A., *et al.*
Development of magnetic soil from ferroan dolomite, *Geophys. Res. Lett.*, *18*, 2043-2046, 1991.
An occurrence of maghemitic soil in association with ferroan dolomite is characterized by using x-ray diffraction, magnetization, and Mössbauer measurements. The results suggest the following weathering sequence: ferroan dolomite $\rightarrow$ calcite + poorly-crystallized ferric hydroxide $\rightarrow$ maghemite + hematite + goethite.

Shen, C.-D., *et al.*
^{10}Be in Chinese loess, *Earth Planet. Sci. Lett.*, *109*, 169-178, 1992.
The 750,000-year ^{10}Be record in Chinese loess shows features similar to those in δ^{18}O records from deep-sea sediments, which strongly reflect climatic variations. Correlation of the ^{10}Be loess records with the δ^{18}O deep-sea records yields a time scale. Calculated accumulation rates of loess and ^{10}Be are generally higher for cold, arid, and windy periods than for warm, humid, and calmer intervals. ■

Above: Illegal photocopy of the actual dollar billed used for the MicroMag demonstration. Note the missing dot on the "i" in the signature. Below: A hysteresis loop for the signature dot. Loop parameter ratios (J_{rs}/J_s = 0.108 and H_{cr}/H_c = 2.83) place this sample in the pseudo-single-domain area of a Day, et al.-type plot.

…continued from page 1

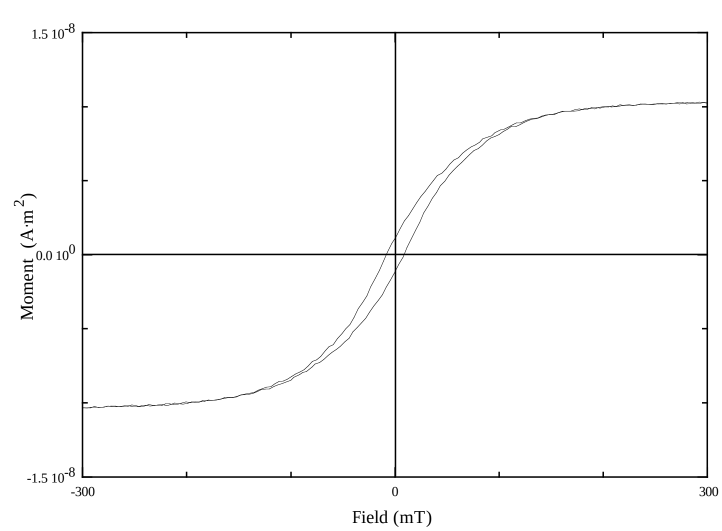
can range from 0 to ± 2.2 T (22,000 Oe), with switching between plus and minus maximum field as fast as you can press "Enter!" The manufacturer claims that the instrument has a sensitivity of about $1{\times}10^{-11}$ A·m^2 ($1{\times}10^{-8}$ emu), and the largest moment that can be accommodated is about $2{\times}10^{-4}$ A·m^2 (0.2 emu).

Nitty Gritty

Samples consist of small rock chips, soil, or powder. Because the quartz plate on which the sample must be mounted is only a few mm square, the typical sample size is limited to a few cubic millimeters, or less than 50 mg. Total preparation time is about five minutes per sample. Once the sample is centered, a hysteresis loop takes no more than a minute (this is clearly *not* a VSM!). A wealth of pre-programmed options make the system easy to use, but the user must direct every new step from the keyboard, making use of the MicroMag more labor-intensive. Data files can be made compatible with any IBM or Mac data manipulation package desired.

Pluses and Minuses

The MicroMag is impressively fast (a loop in as little as a few seconds) and sensitive (that dot from the "i" was actually rather easy); its chief disadvantages are a lack of temperature control, and the sample size limit which can sometimes be a problem if a sample is inhomogeneous on the cubic-mm scale.



Hysteresis loop for signature dot

The MPMS

Since its arrival about a year ago, the Quantum Design MPMS1 Superconducting Susceptometer has yielded some interesting results. The main use of the MPMS is to measure magnetization as a function of applied field and [low] temperature, with specific details programmed by the user.

Applications

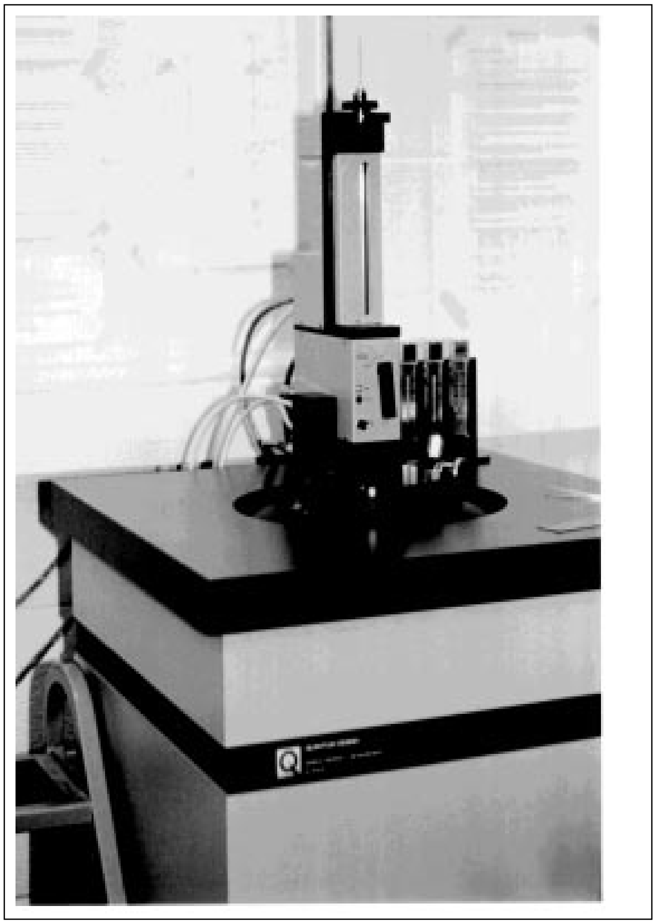
There's no end to the things you can do with this machine—it can even measure the magnetic characteristics of an ordinary drinking straw! (This seemingly bizarre activity was actually performed here a few weeks ago—not as the result of too many hours spent in a windowless lab, but because drinking straws lie at the heart of this high-tech piece of equipment, as will be seen later.)

In a more serious vein, the MPMS has been used to 1) measure magnetic characteristics of magnetotactic bacteria, 2) characterize the magnetic record of paleoclimate in loess, 3) determine the paleomagnetic history of remagnetized carbonates, 4) measure rock magnetic properties of single crystals, and 5) help unravel the complicated history of the topography at an archaeological site through magnetic characterization of soil types.

How?

As they did in many of the above studies, the low-temperature and high-field capability of the MPMS permit investigation of the Verwey transition near 120 K in Fe_3O_4, in which the magnetite electron spin lattice undergoes a reorganization; and of the Morin transition near –10˚C (263 K) in α-Fe_2O_3, below which hematite becomes a perfect antiferromagnet with $M_s = 0$. The presence or absence of these transitions may be useful in determing magnetic mineralogy. The transitions can be seen after imparting a saturation remanence (by applying and then removing a saturating field) below the transition temperature, and then measuring the remanence as the sample is warmed through the transition temperature in zero field. The transition appears as a step in the remanence data.

Interestingly, both the Verwey transition and the Morin transition seem to be grain-size dependent in that, at least for many natural samples, they are suppressed in very small [< 1 micron] grains. In magnetite, this might be explained by oxidation of the grain surface. Smaller grains, with higher surface-to-volume ratios, would then be more



Above: The Quantum Design MPMS1 Superconducting Susceptometer.
Below: Saturation remanence applied at 20 K as a function of temperature for various sizes of magnetite samples. The grainsize dependence of the Verwey transition at about 120 K is clearly seen. N.B.: This graph is not intended for quantitative use!

prone to this behavior. If surficial alteration of grains is important (as is probably the case in many sediments), the presence or absence of the Verwey or Morin transitions could be used as another magnetic granulometry technique. Furthermore, very small superparamagnetic grains (< 300 Å in magnetite) can carry a remanence at temperatures lower than their sub-300 K blocking temperatures. This remanence has a low-temperature dependence which is quite unlike what you see for single-domain or multidomain grains. Because some standard granulometry techniques are potentially ambiguous—both very large multidomain and very small superparamagnetic grains can have similar ARM/χ values or may plot in the same place on a J_{rs}/J_s *vs.* H_{cr}/H_c diagram—such a low-temperature method could provide the necessary extra piece of information to determine relative grainsize.

Principles of Operation

The MPMS uses liquid helium both to provide low temperatures and to run its superconducting sensors. A measurement consists of setting a temperature and a vertical applied field, and then moving the sample through the sensor coils which detect magnetization. Combinations of such measurements, strung together by the user-controlled software as sequence files, allow measurements of hysteresis loops, remanence *vs.* temperature curves, or any sequence of steps one wishes. The possibilities are limited only by one's imagination and the specs of the machine: The temperature range is from 1.7 K to about 350 K, applied fields can range from 0 T to ± 5.5 T (55,000 Oe) [the residual field is not really zero, but more like 1 to 3 Oe; for comparison, the earth's field is about 0.5 Oe], the sensitivity claimed by the manufacturer is about 2×10^{-11} A·m^2 (2×10^{-8} emu), and the largest moment that can be accommodated is about 5×10^{-3} A·m^2 (5 emu) [about the same as a minicore of the strongest oceanic basalts].

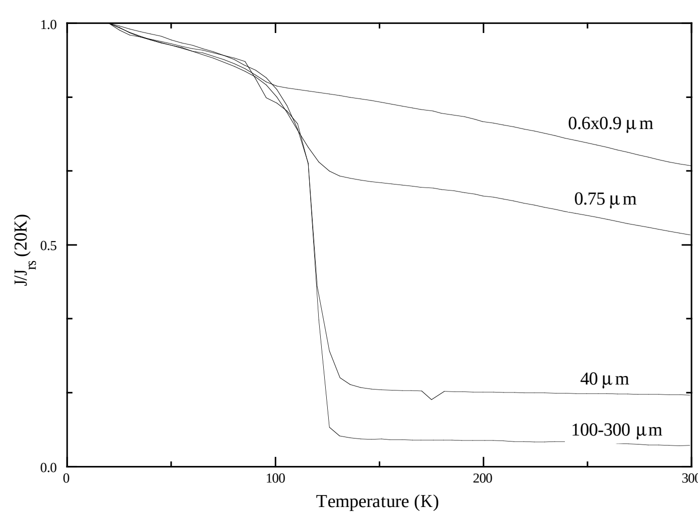
Nitty Gritty

Samples again consist of small rock chips, soil, or powder. Because they usually must fit inside a #4 gelatin capsule, typical samples are limited to 100 mg or so. The gel cap fits inside a standard drinking straw (I promised that you'd hear about this), which in turn slides on the end of the long rod that goes down inside the machine. Total preparation time is about five minutes per sample. Once the sample is centered and a sequence of commands is mapped out, the user simply presses go, and walks away until the machine is finished. Data files are in standard ASCII format, and can be made compatible with any IBM or Mac data massaging program you like.

Pluses and Minuses

The MPMS can achieve low temperatures and high fields with little effort, and is readily adaptable to specific needs or experiments; its main drawbacks are the amount of time necessary to make measurements (approximately ten minutes between temperature steps, or about three hours for a typical J_{rs}–T run between 20 K and 300 K, using 5 K steps), and the amount of helium consumed (about 40 l/week during heavy use).

Next issue: MOKE and/or Mössbauer. And why all the names of our new pieces of equipment begin with the letter "M!" ▬



Verwey transition in magnetite

…continued from page 2
quired around the same temperatures were also thermally demagnetized to test the analogy between VRM and pTRM. The main results are:

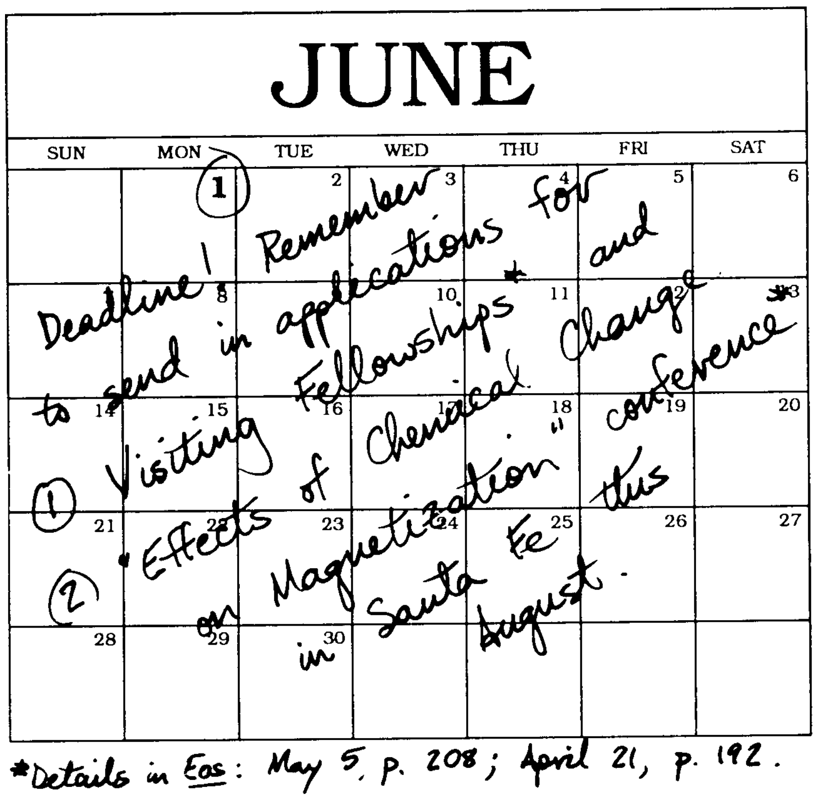
(1) VRM in single-domain magnetite is largely demagnetized within ± 25°C of it acquisition temperature;

(2) the initial state has a measurable effect on the VRM intensity and on its subsequent demagnetization [the initial states tested were thermally demagnetized and heated in zero field to T_{acq}, cooled in zero field from T_C to T_{acq}, and AF demagnetized and heated in zero field to T_{acq}];

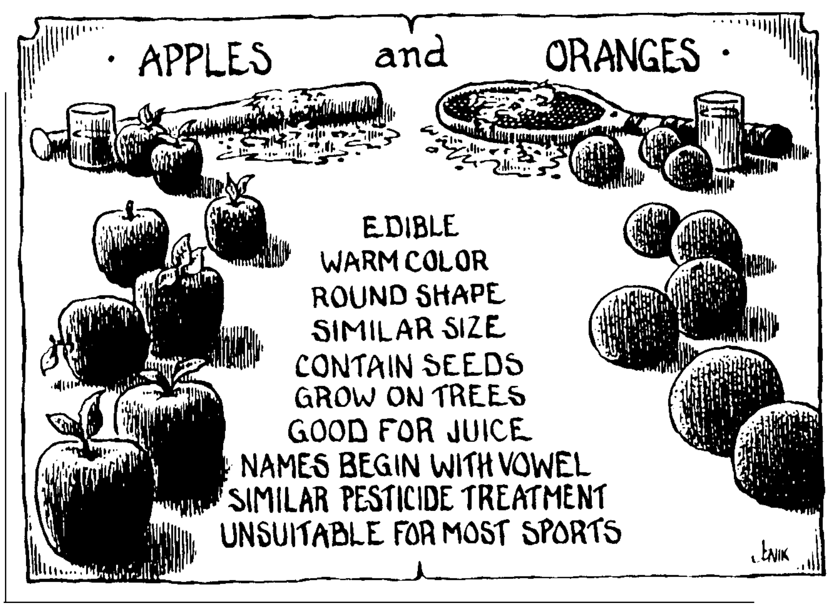
(3) pTRM is similar in intensity and thermal demagnetization behavior to VRM acquired at similar temperatures, but is less dependent on the initial state.

Without the high sensitivity of the SRM, these measurements would have been very difficult if not impossible to make. In both the CRM and VRM experiments, we had a lot of help from Jim Marvin and Chris Hunt in setting up our furnaces in zero-field shields. This helped us to accomplish the maximum of experiments in a short time.

With help from Bruce Moskowitz, we also used the superconducting susceptometer (MPMS) to look for the Verwey transition in16 magnetites ranging in grain size from ultrafine (40 nm) to mm-size crystals. This was achieved by producing a saturation remanence at 5 K, and then measuring the remanence as an almost continuous function of temperature up to 300 K. A single final cooling step back to 5 K determined memory. The Verwey transition was well expressed at *all* grain sizes, even the finest, except when there was surface oxidation. The oxidation effect may be the reason some previous studies have reported a subdued transition or no transition in fine particles. The room-temperature hysteresis of these magnetites was also measured with the VSM. ■



If you enjoy these humorous little tidbits, then send in your favorite item—we're running short….



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 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.

Funding for the *IRM* is provided by the W. M. Keck Foundation, the National Science Foundation, and the University of Minnesota.

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 [or off] 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:

Chris Hunt
Institute for Rock Magnetism
University of Minnesota
293 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455-0128
Telephone: (612) 624-5274
Facsimile: (612) 625-7502
Internet: chunt@vx.acs.umn.edu

I R M
Institute for Rock Magnetism