The IRM
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Inside...

Photo: Chris Faust, Space Science Graphics

Performing Tasks at the *IRM* Takes Time

Stefanie Brachfeld, Jens Henrickson, Chris Hunt, Gin Kletetschka, Jim Marvin, Bruce Moskowitz, Roger Proksch, Scott Rubin, Mitra Sahu, Peat Solheid, Weiwei Sun
IRM

In order to plan visits to the *IRM*, many people have asked what is entailed in making given measurements. The answer consists of a series of short lab notes by the people who most often do the work. This first of two installments on real-world data-gathering at the *IRM* deals with lab orientation, susceptibility measurements, and planning.

Learning/Orientation

One should plan to spend a few hours for orientation and learning when budgeting time at the *IRM*. Even though some of the equipment is already familiar to many visitors, a bit of time must be allowed to gain familiarity with the *IRM*'s particular machines. Of course, the amount of time depends on the user and on the machine. For example, mastering the Bartington bridge requires a good 20 seconds of learning time! In contrast, the Curie point set-up often requires an hour of study.

Procedures

Susceptibility

One of the fastest and easiest magnetic measurements to make is low-field room-temperature magnetic susceptibility on the Bartington bridge. One-inch rock cores are measured as they are, and sediments are packed into plastic boxes for standardization. On the bridge's more sensitive scale, an actual measurement (consisting of a background reading, a sample reading, and another background reading) takes about 30 seconds. However, readings must then be converted to susceptibility by multiplying by shape-dependent calibration constants, and then normalized either to mass or to volume. (Volumes can be estimated in seconds either from the sample shape, or by submersion; masses can be determined in a few seconds on a nearby electronic scale.) The Bartington is the *IRM*'s last non-computerized instrument; measurements must therefore be recorded by hand (!) and entered into a spreadsheet for subsequent calculations. Once a rhythm is established, hundreds of samples can be measured and processed in a few hours—but please, hundreds of samples should not be brought!

Frequency Dependence

Low-field room-temperature frequency dependence of susceptibility is measured at the nearby Limnological Research Center's Core Facility (in a windowless lab six floors underground!) on a Bartington bridge which *is* computerized. The measurements are made exactly as are the susceptibility measurements above, but the results and calculations are tabulated automatically in a computer data file by the control software. Measurement time is theoretically only double that for normal susceptibility (each sample is measured twice), but in practice it takes closer to three times as long because the unforgiving software allows no errors: making only one mistake means starting the samples over again. Furthermore, it is often a good idea to make multiple measurements on a given sample to reduce inherent errors and improve confidence in the results. (A quicker solution might be to record the values by hand to circumvent the com-

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Visiting Fellows' Reports

We enjoyed working with a record number of Visitors this summer. We also enjoyed the occasional breaks between visits! Özden Özdemir and David Dunlop made their annual pilgrimage from Toronto. Christoph Geiß arrived from Germany with two weeks worth of samples packed into a tiny wooden box. Weixin Xu came from the University of Michigan to investigate Paleozoic magnetic spherules. Then Baoxing Zhang flew in from Toronto to determine the magnetic properties of cloudy feldspars from the Canadian shield. Andy Roberts from UC–Davis did some groundbreaking work on greigite. And finally, Barbara Maher from the U.K. measured everything under the sun from Chinese dust to human bones. As usual, we have prevailed upon each our visitors to contribute a summary of work done here at the *IRM*:

Chemical remanence in goethite and the remanence properties of magnetite

Özden Özdemir
David Dunlop
University of Toronto

Özden Özdemir carried out magnetic and Mössbauer studies to identify phases formed during the dehydration of goethite. Samples included pure goethite, partially dehydrated goethites, and hematite. CRM acquisition and hysteresis measurements on these samples were carried out in an earlier visit to the *IRM*. Low-temperature induced magnetization was measured as a function of temperature from 10 K to 300 K with the MPMS superconducting susceptometer for the dehydrated goethite samples. Isothermal remanent magnetization (IRM) acquisition curves were determined with the Vibrating Sample Magnetometer (VSM) and the Superconducting Rock Magnetometer (SRM). With invaluable help from Jim Marvin, Mössbauer spectra were successfully determined not only for the pure mother and daughter phases, but also for the mixed phases. These were particularly valuable in helping identify the exact mixture of phases in the dehydration products.

David Dunlop measured weak-field TRM and ARM, and saturation IRM properties of seven sized magnetite samples ranging from submicron PSD to coarse (100–150 µm) MD. The main experiments were: AF demagnetization of TRM, ARM, and SIRM of all grains sizes to provide a set of reference coercivity spectra as a means of magnetic granulometry; thermal demagnetization of all remanences in all grain sizes to study the evolution of the unblocking temperature distribution from nearly SD to large MD size particles; low-temperature demagnetization (LTD) of all remanences in all grain sizes for comparison with recently published data by Heider *et al.* (*J. Geophys. Res.*, *97B*, 9371-9381, 1992); AF and thermal demagnetization of the memory fraction of TRM and SIRM in selected grain sizes. The main results of this marathon undertaking, apart from the exhaustion of the experimenter, were that TRM, ARM and hysteresis parameters (measured by Özden Özdemir on the VSM) fell nicely on expected trends of data measured by earlier workers. The AF coercivity spectra became progressively harder as grain size decreased, as one would expect, and the set of curves will serve as a good standard reference set for magnetite. Thermal demagnetization curves evolved in a systematic way, with large grains developing an abundance of low unblocking temperatures, but also having the highest ultimate temperatures for total cleaning of TRM or SIRM. Our samples—which were crushed, sieved or centifugally sized, and annealed—yielded Lowrie-Fuller test results of the so-called single-domain type up to grain sizes of about 100 µm. Heider *et al.* (1992) obtained the same results with hydrothermally produced magnetites. Memory after LTD did cleanly separate the low AF coercivity fraction from the harder fraction. Memory contained mainly coercivities above 20 mT. The separation was not so clean on thermal demagnetization. Both memory and TRM or SIRM before LTD contained unblocking temperatures almost as high as the Curie point, but the memory had relatively few low unblocking temperatures. We will be working in the coming months to understand and interpret theoretically these data, particularly for the MD and larger PSD magnetites.

Hysteresis properties of ash particles from the Kerguelen plateau in the Indian Ocean

Christoph Geiß
Universität München

I spent most of my two weeks at the *IRM* using the MicroMag system for my measurements on volcanic ash particles that were extracted from carbonate sediments from the Kerguelen plateau, ODP Leg 120. Petrographic studies showed that the ashes consisted of three distinct compositonal groups. The first group consisted of so-called lithic clasts. These were grains containing titnomagnetite and ilmenite crystals in a matrix of clinopyroxene and alkaline feldspars. The ore crystals ranged from some 10 µm down to submicroscopic size. The second group of particles were relatively unaltered tachylytes containing titanomagnetite inclusions smaller than 0.5 µm in size. These could be subdivided into two subgroups: completely opaque particles, and shards that showed somewhat translucent, brownish edges. The third group were altered ash particles. In addition to the main groups, there was a range of translucent brownish glass particles that were found in all samples except the highly altered ones.

I tried to pick characteristic grains from each of these groups and measure their hysteresis parameters with the MicroMag. Although the machine was not sensitive enough to run single grains (each about a hundred microns in size), measurements of a group of five particles showed good results.

The opaque tachylytes showed distinctive SD properties, while those with brownish, translucent edges displayed a mixture of SD and SP behavior with constricted loops, lower J_{rs}/J_s ratios, and somewhat higher H_{cr}/H_c ratios. IRM acquisition was slow for both types of glass particles: the opaques saturated at 500 mT, the brownish grains at 600 mT, and the lithic clasts at 200–300 mT. They produced loops typical for

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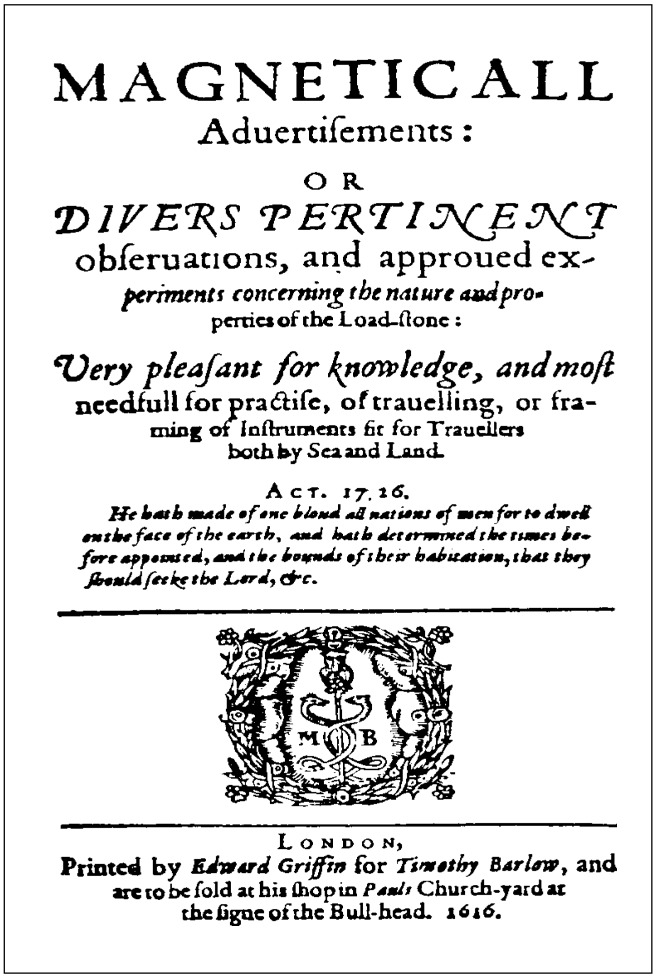
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both by Sea and Land.
ACT. 17.26.
He hath made of one blood all nations of men for to dwell on the face of the earth, and hath determined the times before appointed, and the bounds of their habitation, that they ſhould ſeeke the Lord, &c.
LONDON,
Printed by Edward Griffin for Timothy Barlow, and are to be ſold at his ſhop in Pauls Church-yard at the ſigne of the Bull-head. 1616.

Title page from Timothy Barlow's Magneticall Aduertisements, *1616.*

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 the* IRM Quarterly. *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 2000 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

AMS

Hodych, J. P.
Can remanence anisotropy detect paleomagnetic inclination shallowing due to compaction?: a case study using Cretaceous deep-sea limestones, *J. Geophys. Res., in press*, 1993.
In a suite of fine-grained magnetite-bearing limestones from the Pacific Ocean, sediment compaction resulted in remanence inclination shallowing and ARM anisotropy. Results of this study suggest that, under certain conditions, compaction-induced inclination shallowing in sediments can be both detected and corrected by comparing the above rock-magnetic properties.

Housen, B. A., C. Richter, and B. A. van der Pluijm
Composite magnetic anisotropy fabrics: experiments, numerical models, and implications for the quantification of rock fabrics, *Tectonophys., 220*, 1-12, 1993.
Magnetic fabrics from rocks with multiple mineral preferred orientations can have anisotropy ellipsoids whose shapes and orientations arise from the addition of two or more component fabrics. Numerical models and experiments demonstrated that such composite magnetic fabrics do not directly reflect the individual mineral fabrics. Criteria were provided for the recognition and interpretation of composite fabrics in natural rocks.

Richter, C., B. A. van der Pluijm, and B. A. Housen
The quantification of crystallographic preferred orientation using magnetic anisotropy, *J. Struct. Geol., 15*, 113-116, 1993.
The correlation between the strains obtained from X-ray goniometry and the magnetic parameters obtained from AMS analysis demonstrated that AMS was a fast alternative method, using relatively simple equipment, for obtaining and quantifying crystallographic preferred orientations in rocks. This method also has the advantage of using large sample volumes rather than the essentially 2-D slices used in optical and X-ray methods.

Chemistry

Furuta, T.
Magnetic properties and ferromagnetic mineralogy of oceanic basalts, *Geophys. J. Int., 113*, 95-114, 1993.
Results of rock-magnetic and electron-probe micro-analysis studies indicated that the diverse chemical composition of primary titanomagnetites was controlled by changes in temperature, oxygen fugacity, and volatile pressure during crystallization. Subsequent oxidation did not consist of a simple exchange of ferrous with ferric ions, but was associated with migration of iron ions in the lattice.

CRM

Sweetkind, D. S., *et al.*
Effects of hydrothermal alteration on the magnetization of the Oligocene Carpenter Ridge tuff, Bachelor caldera, San Juan mountains, Colorado, *J. Geophys. Res., 98B*, 6255-6266, 1993.
Analysis of the Carpenter Ridge tuff showed the oxide phenocrysts to be titanomagnetite and ilmenite. However, as revealed by thermal demagnetization unblocking temperatures and Curie temperatures between 580°C and 620°C, the strong, high-coercivity, reverse magnetizations appeared to be controlled by microcrystic titanomaghemite. The effect of potassic metasomatism on rock-magnetic properties was also studied.

Crustal Magnetization

Kelso, P. R., S. K. Banerjee, and C. Teyssier
The rock magnetic properties of the Arunta Block, central Australia, and their implication for the interpretation of long-wavelength magnetic anomalies, *J. Geophys. Res., in press*, 1993.
Rock-magnetic and petrologic studies of deep-crustal rocks revealed that granulites had very large remanences which were relatively resistant to thermal demagnetization. Thus, remanence may have contributed significantly to the observed long-wavelength magnetic anomalies, the source of which resides at a depth and temperature where a thermoviscous remanence along the present-day field is likely to dominate.

Data Manipulation

von Dobeneck, T.
Neue Ansätze zur Messung und Interpretation der magnetischen Hysterese von Tiefseesedimenten [*New approaches to the measurement and interpretation of magnetic hysteresis of deep-sea sediments*], 190 pp., Verlag Marie L. Leidorf, Buch am Erlbach, 1993.
A computerized method was developed for a multi-component mathematical analysis of whole-sediment hysteresis loops and back-field curves. Data processing included iterative fitting of experimental curves to yield relative concentrations of coercivity-dependent magnetic fractions. Applications were made to sediment cores from the Atlantic and Pacific Oceans. [The monograph is in German, but the author promises an article in English soon—Ed.]

Geology

Borradaile, G. J., N. Chow, and T. Werner
Magnetic hysteresis of limestones: facies control?, *Phys. Earth Planet. Inter.*, *76*, 241-252, 1993.
The hysteresis properties of many non-red, marine limestones indicated that remanence was carried by magnetite of PSD and small MD size. Most limestone facies (subtidal, lagoonal, shelf, and reef) had diamagnetic matrices and smaller PSD magnetite, making them good recorders of stable remanence. But pelagic limestones had paramagnetic matrices and larger PSD or MD magnetite, making them somewhat less suitable recorders.

Borradaile, G. J.
Changes in magnetic remanence during simulated deep sedimentary burial, *Phys. Earth Planet. Inter.*, *77*, 315-327, 1993.
Macroscopic hydrostatic compaction of granular rocks causes grain-scale differential stresses as the externally applied load is transmitted through grain contacts. Compaction of rock analogs—calcite with either stress-free or pre-stressed magnetite—at pressures up to 220 MPa produced irreversible changes in the coercivity of the initially stress-free magnetite samples, but only minimal changes in the pre-stressed magnetite samples.

Instrumentation

O'Grady, K., V. G. Lewis, and D. P. E. Dickson
Alternating gradient force magnetometer: applications and extension to low temperatures, *J. Appl. Phys.*, *73*, 5608-5613, 1993.
The capabilities of a commercially produced alternating gradient force magnetometer [the *IRM*'s MicroMag—Ed.] were studied, and modifications to improve the sensitivity were discussed. A noise base of 2×10^{-11} $A{\cdot}m^2$ was achieved with an averaging time of 1 s. Reproducibility was within 6% for most samples, but 20% for low-moment samples. The alternating field-gradient had significant effects on samples with low coercivities.

Models

Hrouda, F.
Theoretical models of magnetic anisotropy to strain relationship revisited, *Phys. Earth Planet. Inter.*, *77*, 237-249, 1993.
Mathematical modeling of the relationships between low-field magnetic anisotropy and strain were redeveloped, and the calculated data were compared with the degree of anisotropy for various rock types. The strengths and weaknesses of the passive, ductile, line/plane, and viscous models were discussed.

Ricard, Y., G. Spada, and R. Sabadini
Polar wandering of a dynamic Earth, *Geophys. J. Int.*, *113*, 284-298, 1993.
The rotational behavior of a stratified, visco-elastic planet submitted to changes in its inertia tensor was studied in a viscous, quasi-fluid approximation. The resulting model was suitable for investigating true polar wander (as detected by paleomagnetic studies), the effects of non-steady-state convection on the Earth's rotation, and the amount of excess polar flattening that can be related to tidal deceleration.

Paleointensity

Pick, T., and L. Tauxe
Holocene paleointensities: Thellier experiments on submarine basaltic glass from the East Pacific Rise, *J. Geophys. Res.*, *in press*, 1993.
Submarine basaltic glass proved to be nearly ideal for paleointensity determinations: Thellier experiments had high success rates; multiple experiments on sample splits were reproducible; and paleointensities for zero-age glasses matched the corresponding current field intensity. The availability of glass throughout the world's oceans holds great potential for a better distribution of paleointensity data through time and space.

Tauxe, L.
Sedimentary records of relative paleointensity: theory and practice, *Rev. Geophys.*, *in press*, 1993.
A study of sedimentary sequences provided information about variations in the relative paleointensity of the Earth's magnetic field, including dipolar and non-dipolar behavior. Results showed that the purported 40-ka oscillation in the geomagnetic field is probably not an inherent feature, and the correspondence of this period of oscillation to that of obliquity is likely coincidence.

Yang, S., J. Shaw, and Q. Y. Wei
A comparison of archaeointensity results from Chinese ceramics using Thellier's and Shaw's paleointensity methods, *Geophys. J. Int.*, *113*, 499-508, 1993.
Archaeointensity measurements were made on a collection of Chinese ceramics covering the time period 2700–7500 BP. Several rock-magnetic parameters and procedures were employed to select or reject samples as suitable for use in adaptations of both the Thellier-Thellier and the Shaw paleointensity techniques.

Physics

Harker, S. J., and R. J. Pollard
A study of magnetite at 4.2 K and subject to strong applied magnetic fields, *Nucl. Inst. Meth. Phys. Res.*, *76*, 61-63, 1993.
Mössbauer spectra of a powdered sample of magnetite were taken at 4.2 K and in applied fields of 0–14 T. They were fitted in accordance with specific crystallographic models of magnetite below the Verwey transition. At least five octahedral Fe^{3+} sites and four octahedral Fe^{2+} sites were needed to obtain both good fits and parameters which varied consistently with applied field strength.

Hendriksen, P. V., *et al.*
Particle interaction effects in systems of ultrafine iron oxide particles, *Nucl. Inst. Meth. Phys. Res.*, *76*, 138-139, 1993.
The superparamagnetic relaxation of ultrafine maghemite particles was studied by means of Mössbauer spectroscopy and magnetic susceptibility measurements. The effects of pressing the samples and of coating the particles with oleic acid were investigated. The observed differences were ascribed to the difference in the strength of the magnetic interaction between the particles in the samples.

Kuiper, P., *et al.*
X-ray magnetic dichroism of antiferromagnet Fe_2O_3: the orientation of magnetic moments observed by Fe 2p X-ray absorption spectroscopy, *Phys. Rev. Lett.*, *70*, 1549-1552, 1993.
In hematite, the relative difference in absorption between light polarized parallel to and perpendicular to the magnetic moment was as high as 40%. The magnetic origin of this dichroism was demonstrated by the Morin transition near –10°C, where the moments in Fe_2O_3 rotated by 90°. Magnetic linear dichroism can be applied to measure the spin orientation in thin films and multilayers, and to image magnetic domains.

Parshin, A. S., B. E. Blekher, and K. P. Rolyakova
Auger-electron spectroscopy and magnetic properties of Fe-O epitaxial layers, *Int. J. Mod. Phys. B.*, *7*, 550-554, 1993.
Epitaxial layers of Fe-O ($\delta < 1$ µm) were created by chemical transport reactions on a MgO substrate. By comparing the low-energy regions of the Auger spectra with reference iron-oxide spectra, the layers were assigned to γ-Fe_2O_3. Quantitative interpretations were made of experimental temperature dependences of magnetic moment layers in the framework of Néel's model for collinear ferrimagnetism.

Remagnetization

Jackson, M. J., *et al.*
Rock magnetism of remagnetized Paleozoic carbonates: low-temperature behavior and susceptibility characteristics, *J. Geophys. Res.*, *98B*, 6217-6225, 1993.
Rock-magnetic experiments were conducted on samples of remagnetized Paleozoic carbonates from eastern North America. Designed to investigate the origin of the unusual hysteresis behavior of these rocks, these experiments measured the low-temperature behavior of saturation isothermal remanence. The results indicated that the pyrrhotite magnetic transition at 32 K was absent.

Sun, W.-W., M. J. Jackson, and J. P. Craddock
Relationship between remagnetization, magnetic fabric, and deformation in the midcontinental Paleozoic carbonates, *Tectonophys.*, *221*, 361-366, 1993.
The magnetic fabric of Paleozoic carbonates from the North American midcontinent were compared with both paleomagnetic behavior and calcite twinning strains. The results suggested that diagenetic/authigenic magnetites formed independently of any pre-existing fabric of precursor sulfides and host rock, and that the magnetic fabric of the whole midcontinent was partially affected by Alleghenian syn-orogenic activity.

Rock Magnetism

Halgedahl, S. L.
Bitter patterns versus hysteresis behavior of small single particles of hematite, *J. Geophys. Res.*, *in press*, 1993.
To establish links among domain images, volume changes in magnetization, and mechanisms for PSD behavior, Bitter patterns of single platelets of natural hematite were compared with measured hysteresis behavior. The results showed that the same magnetic fields that caused large changes in a particle's Bitter pattern also caused large changes in a particle's magnetic moment.

Moskowitz, B. M.
Micromagnetic study of the influence of crystal defects on coercivity in magnetite, *J. Geophys. Res.*, *in press*, 1993.
A one-dimensional micromagnetic model was used to calculate the thermal dependence of microcoercivity produced by the unpinning of a domain wall from various types of defects in magnetite. The dependence calculated for grains with low defect densities agreed with experimental data for recrystallized magnetites; the dependence for grains with high defect densities was consistent with data from crushed and glass ceramic magnetites.

Newell, A. J., W. Williams, and D. J. Dunlop
A generalization of the demagnetizing tensor for non-uniform magnetization, *J. Geophys. Res.*, *in press*, 1993.
The demagnetizing tensor for ferromagnets was generalized to include interactions between uniformly magnetized bodies. The tensor was then used to develop an expression for the macroscopic magnetic field in non-uniformly magnetized bodies of arbitrary shape. Finally, the expression was applied to a block model of magnetization, and explicit formulae for the tensor components were given.

Ozima, M., *et al.*
Self-reversal of thermoremanent magnetization in pyroclastics from the 1991 eruption of Mt. Pinatubo, Philippines, *J. Geomagn. Geoelectr.*, *44*, 979-984, 1992.
At one site, NRM directions of dacite pumice fragments were random—these fragments settled after their temperature reached their Curie points. At another site, almost all NRM directions were reversed—these settled before their temperature reached the Curie point and acquired a self-reversed TRM. Almost all the dacite pumice samples from both localities acquired self-reversed TRMs in the laboratory.

Yang, Z.-J.
Effects of several kinds of anisotropy on the coercivity behaviors of iron oxides, *J. Appl. Phys.*, *73*, 6665-6667, 1993.
Coercivity behaviors of iron oxides during phase changes between Fe_3O_4 and γ-Fe_2O_3 were investigated. The difference in lattice constants produced a tensile stress on γ-Fe_2O_3, and a compressive stress on Fe_3O_4 at interfaces. These stresses caused an increase in the coercivity Hc for spherical particles and thin film samples, but a decrease for acicular particles which were affected by shape anisotropy.

Sediments

Bloemendal, J., *et al.*
Origin of the sedimentary magnetic record at Ocean Drilling Program sites on the Owen Ridge, Western Arabian Sea, *J. Geophys. Res.*, *98B*, 4199-4219, 1993.
A 3.2-Ma whole-core magnetic susceptibility record demonstrated the ability of rock-magnetic measurements to yield paleoceanographically significant information. Despite postdepositional alteration of the magnetic minerals, there was a strong relationship between magnetic susceptibility and terrigenous content.

Itota, C., M. Hyodo, and K. Yaskawa
Separation of paleomagnetic secular variation components: a method and its application to a sedimentary record from Japan, *J. Geomagn. Geoelectr.*, *44*, 943-957, 1992.
A new method was introduced to analyze paleosecular variations of the Earth's magnetic field direction. The method was applied to the sedimentary secular variation record from Japan: results indicated two main periodic motions of the field vectors, the slower component of which was dominated by smooth clockwise rotation, suggesting that westward drift has persisted almost steadily for the last 12,000 years.

Roberts, A. P., and G. M. Turner
Diagenetic formation of ferrimagnetic iron sulphide minerals in rapidly deposited marine sediments, South Island, New Zealand, *Earth Planet. Sci. Lett.*, *115*, 257-273, 1993.
Analyses of siliciclastic sediments indicated that greigite and pyrrhotite were responsible for a stable and intense magnetic remanence in fine-grained sediments, whereas titanomagnetite was the only remanence-bearing mineral identified in coarser-grained, less strongly and less stably magnetized sediments. Geochemical arguments about the evolution of the observed magnetic mineralogy were made.

van Velzen, A. J., M. J. Dekkers, and J. D. A. Zijderveld
Magnetic iron-nickel sulphides in the Pliocene and Pleistocene marine marls from the Vrica section (Calabria, Italy), *Earth Planet. Sci. Lett.*, *115*, 43-56, 1993.
The rock-magnetic properties of certain open-marine marls had pointed to magnetic sulfide as the main magnetic mineral and remanence carrier. But, the maximum blocking temperatures were too high for stoichiometric monoclinic pyrrhotite. So, microprobe analyses of the sulfides were made: they yielded a large range of compositions, and many had an unusual, high Ni content which could be the cause of the high blocking temperatures.

Techniques

Suresh, K., and K. C. Patil
A combustion process for the instant synthesis of gamma-iron oxide, *J. Mater. Sci. Lett.*, *12*, 572-574, 1993.
Samples of γ-Fe_2O_3 were prepared by the combustion of iron(III) nitrate and malonic acid dihydrazide at 350°C in less than five minutes. The magnetic properties of the batch of γ-Fe_2O_3 prepared by this process were compared with those of γ-Fe_2O_3 prepared by the precursor method. ■

…*VF Reports continued from page 2*

PSD grains, a result that was confirmed by Bitter observations in Germany. The altered grains had a very weak magnetization, and plotted in the PSD range, too. The highly translucent shards were so weak that all my grains together could hardly be distinguished from the signal of the empty sample holder.

After more than ten days in constant fear of breaking the delicate (and expensive) sample holder, I spent my last few days at the less delicate MPMS to measure hysteresis loops at low temperatures. These measurements confirmed the Micromag results: an SP fraction in bulk samples with a high fraction of tachylytes, and no SP particles in the other samples. Finally, I want to thank Peat Solheid, who shared his 1.5-m^2 office with me, Chris Hunt for not making me too scared of the quartz-glass holder, and all the rest of the *IRM* staff and students for their friendly welcome and support.

Hysteresis properties of magnetic spherules extracted from Paleozoic limestones

Weixin Xu
University of Michigan

Magnetite spherules extracted from limestones have been considered authigenic magnetic minerals which carry the ancient secondary magnetizations in these rocks. Last summer, we made some preliminary measurements of hysteresis properties for single magnetite spherules from the Twin Creek limestone. The experiment yielded remanence ratios (saturation remanence to saturation magnetization, J_{rs}/J_s) less than 0.02, that is, ratios smaller than those of synthetic pseudo-single-domain samples. This indicated that the magnetite spherules found in magnetic extracts from limestone might *not* be the main carrier of the natural remanent magnetization. However, according to Suk and Halgedahl's report (*Eos, 73,* no. 43 suppl., 153), some magnetite spherules can have J_{rs}/J_s ratios greater than 0.3, and coercivity ratios (coercivity of remanence to coercivity, H_{cr}/H_c) less than 3, indicating that some large individual spherules are capable of carrying a stable magnetization.

The objectives of this study were to investigate the possible relationships between hysteresis properties and both spherule size and surface textures, and to characterize further the features of the pseudo-single-domain grains. The samples used in this study were from the Twin Creek formation (Wyoming) and the Leadville limestone (Colorado). Both rocks carried a remagnetization. Magnetite spherules found in these rocks had identical size and texture. Based upon scanning electron microscope observations, the magnetite spherules were grouped by grain size and surface texture. More than 100 individual spherical grains, with diameters from 10 to 85 µm, were measured on the Micromag during this visit. The initial results showed that J_{rs}/J_s decreased with increasing grain size. Most grains had J_{rs}/J_s ratios below 0.05. A few grains had J_{rs}/J_s ratios above 0.05, but below 0.2. Most grains with clear surface textures had hysteresis properties similar to single crystalline magnetite grains.

Many thanks to all *IRM* staff, especially Chris Hunt and Weiwei Sun, and students for their help and warm accommodation during my visit. I would also like to thank Subir Banerjee, Paul Kelso, and again Chris Hunt for their discussions and suggestions which hopefully will bring me back to the *IRM* in the near future.

Magnetic study of clouded feldspars from dikes in the Canadian shield in Ontario

Baoxing Zhang
University of Toronto

Feldspar cloudiness is one of the most curious phenomena of the NNW-trending Matachewan dikes, which were intruded into the high-grade metamorphic terrains of the Canadian shield. Cloudiness of feldspars has been correlated with distance from the Budd Lake Fault (BLF)—a newly-defined, late Proterozoic, SE-thrusting fault which is 500 km west of the Kapuskasing Zone in Ontario—indicating that the cloudiness of the feldspar is related to the depth at which the dikes were emplaced.

Under an optical microscope, the material responsible for the cloudiness was seen to be brown-grey, dust-like particles, which were thought to be magnetite formed by exsolution of iron from the feldspar structure at high temperature (> 475 °C). This was the first time that feldspar cloudiness and its intensity had been studied quantitatively. A total of 24 samples of both clouded and clear feldspars from the Matachewan dikes were measured on the Micromag and the MPMS at the *IRM*. The preliminary results were: (1) Almost all magnetite particles that make the cloudiness were PSD grain size, as determined from remanence and coercivity ratios ($J_{rs}/J_s = 0.2$–0.4, $H_{cr}/H_c = 1.8$–3.0). (2) Mass-normalized saturation magnetization of feldspars (J_s) varied according to the degree of cloudiness. In general, feldspars that were visibly clouded under the microscope had values of $J_s > 2\times10^{-3}$ A·m^2/kg, while those which were clear under the microscope bore $J_s < 2\times10^{-3}$ A·m^2/kg. And the change of J_s was positively correlated to the degree of cloudiness of the feldspars. (3) During low-temperature SIRM heating measurements on the MPMS, all samples had the same paramagnetic behavior below 30 K. There were two stable stages: A from 30 K to 120 K, and B from 140 K to 300 K. The A–B (Verwey) transition happened between 120 K and 140 K. The paramagnetic behavior may have represented the superfine magnetic grains contained in every sample. The transition at 120 K indicated that the magnetic material *was* magnetite. Both the A and the B stages decreased with decreasing cloudiness (A: $M_s = 8\times10^{-7}$–2×10^{-7} A·m^2; B: $M_s = 4\times10^{-7}$–1×10^{-7} A·m^2). Also, the Verwey transition became smaller in less clouded feldspars, and it finally disappeared in clear samples ($M_s = 2.5\times10^{-7}$–0 A·m^2).

In summary, the degree of feldspar cloudiness was well digitized by magnetic parameters. Considering the results of the limited clear feldspar samples (not discussed here), the author expected that perhaps feldspars from all dikes should be examined in the same way(s), no matter what the degree of cloudiness. The systematic variation of feldspar magnetic parameters will help to localize and evaluate differential crustal uplift after the dikes' intrusion.

Characterization of the magnetic properties of the iron sulfide greigite (Fe_3S_4)

Andrew P. Roberts
University of California–Davis

In recent years, greigite (Fe_3S_4) has been recognized as an important remanence carrier in sediments deposited under sulfate-reducing conditions. Despite this, greigite is a relatively poorly understood magnetic mineral in terms of its fundamental magnetic properties, geochemical stability, and even its crystal chemistry. I have a large collection of natural and synthetic greigite samples (supplied by several kind colleagues around the world), and have taken advantage of new equipment in the Paleomagnetism Laboratory at UC–Davis and a Visiting Fellowship at the *IRM* in order to better characterize the magnetic properties of greigite.

Measurement of high-field hysteresis parameters using the MicroMag Alternating Gradient Force Magnetometer (AGFM) at UC–Davis indicates that a large number of the samples display single domain behavior, with $J_{rs}/J_s > 0.5$. The remaining samples appear to lie in the fine-grained end of the pseudo-single-domain range. The high sensitivity of the MicroMag enables analysis of single crystals and aggregates of crystals, allowing measurement at a previously impossible scale. In conjunction with analysis of polished thin sections of aggregates, these measurements should make it possible to obtain a grain-size-dependent framework for the magnetic properties of greigite.

In my brief visit to the *IRM*, I was able to measure the low-temperature behavior of a large number of samples using Quantum Design's Magnetic Properties Measurement System (MPMS). These measurements confirm the findings of the few existing published studies that indicate that greigite has no low-temperature magnetic transitions, in contrast to pyrrhotite (Fe_7S_8), which has an important transition at 30–34 K. Low-temperature measurements also provide important constraints for characterizing the grain-size distribution of the samples, particularly with respect to superpara-magnetic (SP) content.

Previous work indicated that the hysteresis properties of greigite were significantly dependent on grain-size and temperature. Princeton Applied Research's Vibrating Sample Magnetometer (VSM) at the *IRM* is extremely well set up for this type of measurement. I obtained excellent hysteresis curves from liquid nitrogen temperatures to over 300°C, at which point decomposition of greigite had begun. This behavior makes it extremely difficult to determine the Curie temperature of greigite. My work indicates that temperature-dependent hysteresis measurements will provide important constraints on the thermomagnetic behavior of greigite.

The analyses described above, as well as Mössbauer determinations, enabled important characterization of the magnetic properties, grain-size distribution, and chemistry of the natural and synthetic samples studied. This preliminary work has proved to be extremely useful in determining the most profitable ways to obtain further constraints on the magnetic behavior of greigite within a grain-size-dependent framework. I am very grateful to all those at the *IRM* who helped to make my visit so profitable, particularly Chris Hunt and Jim Marvin.

A little bit of everything from human bones to glacial dust to Chinese loess

Barbara Maher
University of East Anglia

During my three-week visit to the *IRM*, I was able to join in the alliterative magnetic mode of the place, by monopolizing the MicroMag and the MPMS. I gathered data on a diverse range of materials, including Chinese loess and paleosols, dust layers from a Tibetan glacier, human bone samples, and a number of synthetic ferrimagnets, both coarse- and fine-grained.

In the case of the Tibetan dusts (sampled by filtering discrete stratigraphic layers from an ice-core), and the human bones, the sensitivity of the MicroMag and the MPMS enabled repeatable measurements of individual samples, albeit with mixed results. The dusts were found to contain unoxidized multidomain magnetite as their dominant magnetic component. For the bones, the good news was that there was no evidence of contamination from their sawing during sample preparation. The bad news was that there was no evidence of *anything* magnetic at all. Perseverance did pay off, however, because when I tried again more carefully, I did get a small yet repeatable signal from one of the samples. Only a small sample set was examined during my visit; further work remains to be done.

With the synthetic ferrimagnets, I was looking for information on the grain-size dependence of magnetic properties, and on the transformation of fine-grained magnetite to maghemite. The MPMS was used to examine the possible grain-size dependence of the Verwey transition in multidomain magnetite. The VSM, MPMS, and the Mössbauer equipment were used (courtesy of Jim Marvin and Peat [*sic*] Solheid) to look at the thorny question of oxidation (partial or complete) of fine-grained magnetite to maghemite. This problem has direct relevance to the magnetic properties and to the proxy climate signal of the Chinese loess plateau sequences. I had hoped to run some thermomagnetic analyses of bulk samples of the Chinese loess and soils (rather than magnetic separates), but the sensitivity of the VSM was insufficient to measure even the strongest of these. The first company to produce a sensitive yet robust Curie balance, with the capability to run in different controlled atmospheres, at a reasonable cost, would probably sell quite a few.

As I write this (it seems I'm not allowed to leave until I complete this brief report), outstanding aims are to examine possible magnetic inclusions within non-magnetic host minerals (obtained by high-gradient magnetic extraction from some deep-sea sediments) using the AFM/MFM, and to run the last five, coarsest magnetites of the MD series on the MPMS, which is a lovely machine but a little on the slow side....

Finally, one of the less tangible assets of a visit to a flourishing laboratory is the mental updating and refreshment that comes from ad hoc discussion and floating of ideas. I'm grateful to the staff and grad students at the *IRM* for nobly affording me their hospitality, academic and social, despite this summer's seasonal glut of visitors. ■

…*Time* continued from page 1

puter program.) All in all, an entire morning or afternoon should be set aside to do about thirty sam-ples (with triple measurement on each)—then a break is in order!

Whole-core

The relative susceptibility of a sediment core can also be measured in under an hour at the Core Facility. The core is placed on a conveyor belt which carries the core through a 100-mm diameter Bartington sensor ring. This process is fully automated; the user need only specify the depths of the top and bottom of each core segment, and the interval at which measurements are made. Typically, measurements are taken every 2 cm, although the smallest measurement interval is 1 cm. The user has the option of taking background readings either between each measurement, or just at the beginning and end. A typical experiment in which the susceptibility of a one-meter core is measured every 2 cm, with background readings between each measurement, takes about 45 minutes.

PLANNING AHEAD…

In an average two-week visit to the *IRM*, one can expect something like this: The first morning is devoted to orientation, a lab tour, meeting some of the staff and students, and learning how to use one major piece of equipment. The bulk of the visit is devoted to making measurements, with an occasional hour or two for discussing results with *IRM* people, for learning how to use other equipment, and even for enjoying the Twin Cities. The last half-day goes to cleaning up, transferring and copying data files, and—most important!—writing a few paragraphs for the *IRM Quarterly*.

In the Fall issue, we'll include most of the other procedures and pieces of equipment, just in time for applicants to prepare Visiting Fellowship proposals. ▬

GP E-mail List

The Geomagnetism and Paleomagnetism (GP) section of the American Geophysical Union (AGU) is interested in collecting e-mail addresses of all GP members who want to be informed of section news via e-mail. Those who want to be included should send their e-mail addresses to Sue Beske-Diehl (sbeske-d@mtu.edu). ▬

The New Visiting Fellows

The possibility of having to endure part of a Minnesota winter did not deter many intrepid scientists from applying for up to three weeks of research time at the *IRM*. For the period September 1993–February 1994, the Fellows, with their affiliations and research interests, are listed below in alphabetical order. (Watch for their reports in upcoming issues.)

N.B. The proposal deadline for visits during March–August 1994 will be shortly after the AGU meeting in December. Look for announcements in the Fall issue of the *IRM Quarterly*, as well as in *Eos* and in *GSA Today*.

Post-Ph.D.

John Geissman
University of New Mexico
Paleozoic remagnetization in the Rockies

Suzanne McEnroe
University of Massachusetts
Rock magnetism of igneous rocks

Student

Satria Bijaksana
Memorial University of Newfoundland
Inclination shallowing in deep-sea sediments

Bernie Housen
University of Michigan
Fluid flow and climate change from deep-sea sediments

Peter Jaumann
University of Iowa
Paleoclimate studies

Chris Orme and Elizabeth Schuler
University of Michigan
Multilayers on MOKE/MFM ▬

New Visitor Policy

The tremendous success of the *IRM* in attracting visitors (42 in the last year) has taught us that we also have our limits! Therefore, the *IRM* is instituting a new policy, which goes into effect immediately: Informal visitors are still welcome, but stays will be limited to just a few days; arrangements should still be made through the Lab Manager. Anyone wanting to be at the *IRM* for longer periods (up to three weeks) should apply through the Visiting Fellowship Program. ▬

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.

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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@staff.tc.umn.edu

I R M
Institute for Rock Magnetism