Inside…

The IRM Quarterly

SPRING 1995, VOL. 5, NO. 1 INSTITUTE FOR ROCK MAGNETISM

Photo: Christoph Geiß, IRM

The IRM*'s* ***Chris Hunt*** *conducting a mini-workshop on rock magnetism for archaeologists* ***Ann Ramenofsky, Ana Steffen,*** *and* ***Jeff Cox*** *as part of the recent Society of American Archaeology meeting in Minneapolis.*

IRM is Fulfilling its Educational Mission

Subir Banerjee
IRM

The IRM *plays an important role in the education of the many people who spend time at our facilities. This article provides a brief overview of our teaching functions, which encompass everything from undergraduate training to graduate-student theses to visitor projects to service for the rock-magnetic community and the broader scientific world in general.*

THE *IRM* AND EDUCATION

The name "*IRM*" conjures up, or should conjure up, a picture of getting interesting research done and publishing the findings. This is an accurate picture: our annual reports to the NSF and the Keck Foundation are replete with details of work by *IRM* members and visitors. (At last count, the impressive tally was 25 reviewed papers and dozens of presentations for the last twelve months.) But we are also a teaching entity—a true "college of scholars" in medieval European terminology.

Undergraduates

We have had undergraduate research assistants from the University of Minnesota (UM), and more numerous, undergraduate visitors from nearby institutions (mainly four-year colleges). Based on research done at the *IRM*, senior theses have been written by students from Carleton College and from the University of Wisconsin (UW)–Eau Claire. Other work has been done by undergraduates from Macalester College, Gustavus Adolphus College, other UW and UM campuses, and even distant Franklin and Marshall College in Pennsylvania! We are currently talking with Carleton College both to formalize an on-going relationship revolving around senior thesis research, and to establish specialized rock-magnetism coursework at Carleton.

Graduate Students

The bulk of our external instructional activity, however, involves graduate student visitors, who come to us from the U.S. and Canada, and sometimes from Europe and Japan. Often the problems that they bring us pose intellectual challenges; other times the problems pose more instrumental or technical obstacles. We genuinely enjoy these conundrums, and usually continue to discuss all of the problems even after the students have returned home. I like to say that it is somewhat like being a proverbial grandparent (though I am not one yet, in real life!): one does not have to worry about the whole dissertation—one can just enjoy being part of the project.

Conferences

Our most far-reaching educational efforts have been in establishing the Santa Fe Conferences. At the last two meetings (1992 and 1994), which had support from the Earth Sciences Division at the NSF, about 40% of the attendees were graduate students or fresh PhDs. Some of these young scientists not only came to the conferences, but also were featured lead-speakers at various

Education *continued on page 7…*

Visiting Fellows' Reports

We have had quite a cosmopolitan set of guests recently. In February, Richard Harrison came over from England to look at his magnetite–spinel solid-solution series. Then in March, Pavel Šroubek, who is originally from the Czech Republic, appeared from Houghton to study more of his cave sediments. Simultaneously, Archana Pawse, a native of India, came from Houghton to characterize her volcanic ash. Also in March, Darcy Van Patten, a graduate student of Paul Johnson's, traveled from Seattle to do elevated loops on zero-age oceanic basalts. And in April, James Gagwane King, who was born and bred in Botswana, flew from Scotland to investigate the arrays of artificial magnetite that he and his advisor, Wyn Williams, had made. Below is a summary of their work at the *IRM*. As in earlier issues, the Fellows' profuse thanks are unprintable (due to space considerations, of course!), but we are most appreciative.

Richard Harrison
Cambridge University

Magnetic Properties of the Magnetite–Spinel Solid-Solution Series

The solid-solution series between magnetite (Fe_3O_4) and spinel ($MgAl_2O_4$) may be used to study the interaction between exsolution microstructures and magnetic properties since there is a high-temperature miscibility gap which allows spinodal decomposition to be produced on a laboratory timescale. A suite of compositions across the solid solution has been synthesized, and six samples of intermediate composition have been annealed to yield microstructures that correspond to the various stages of spinodal decomposition. Hysteresis loops and susceptibilities of all samples have been studied at the *IRM* using the Lake Shore, Kappabridge, MPMS, and VSM.

The trend in T_C versus composition extrapolates to zero K at 28% Fe_3O_4. This behaviour may be due to Fe cations being located exclusively on tetrahedral sites in samples containing < 28% Fe_3O_4. This cation distribution prevents super-exchange interactions between Fe cations via a common oxygen and gives rise to the observed drop in T_C. AC susceptibilities are non-reversible at high temperatures due to the process of exsolution that occurs on the timescale of the heating runs. Typically, a sample with a starting composition within the miscibility gap will undergo complete exsolution to produce a phase with an approximate composition of 90% Fe_3O_4. Measurements on previously exsolved samples were complicated by further exsolution occurring during the run. However, the results do offer some indication of the relative extent of transformation in different samples and the nature of the magnetic intergrowth. Room-temperature hysteresis properties of the solid solution indicate multi-domain behaviour. Coercivities are typically $\mu_0 H < 1$ mT, and the ratio J_{rs}/J_s is typically < 0.05. The hysteresis properties of exsolved samples show a distinct transition to single-domain behaviour with coercivities increased to a maximum of $\mu_0 H = 27$ mT and J_{rs}/J_s to around 0.3. A sample in the initial stages of spinodal decomposition showed a relatively low coercivity and a slightly constricted hysteresis loop. Curie-temperature runs on the VSM have revealed a large interaction between the state of cation order and the magnetic ordering transition, which results in a variation of about 100°C in the Curie temperature, depending on the degree of cation order.

Pavel Šroubek
Michigan Technological University

Mineral Magnetic Study of Clastic Cave Sediments from the Moravian Karst, Czech Republic

I was continuing my last year's work on samples from a clastic sedimentary profile, which is found in the interior of the Spirálka Cave. [See *IRM Quarterly*, vol. 4, no. 1, p. 2 (Spring 1994).] Measurements of total magnetic susceptibility (χ) throughout the sediments (0–400 years B.P.) show sinusoidal variations which correlate with the temperature record measured in Prague, 200 km away.

What is the cause of the magnetic susceptibility variations from the mineral-magnetic point of view? That was the question to be answered by measurements at the *IRM*.

Measurements of thermal demagnetization of low-temperature (20 K) SIRM (done on the MPMS) indicate a high percentage of SP grains in the samples (80–90% of all ferromagnetic grains). The Verwey transition does not appear in the results, suggesting that larger grains of magnetite (MD, SD?) are nearly absent in the sediments. Measurement of χ above room temperature (using the Kappabridge) show the presence of magnetite. IRM acquisition curves are characteristic of a mixture of "magnetite" and "hematite." The above-stated results are in good agreement with Mössbauer spectra at room temperature measured on [not the purest] magnetic separates. Pete Solheid, who ran the measurements, kindly explained to me that the data show a significant portion of SP grains as well as magnetite, maghemite, and hematite.

Having all these results, I assumed that SP grains are probably the dominant source of the χ signal. However, after measuring several hysteresis loops, I was surprised to see that the paramagnetic susceptibility contributes about 50% to the total χ. Therefore, I calculated ferrimagnetic χ for selected samples and observed that its time variation is similar to that for total χ. Variation in concentration of SP grains is thus probably the primary cause of variations in both total and ferrimagnetic χ.

The measurements obtained allow me to estimate the proportion of SP grains from the values of χ/J_s and from the hysteresis parameters (J_{rs}/J_s). It will be interesting to compare these values with the concentration of SP grains determined from the low-temperature SIRM measurements.

The next step in my work will be to explain the processes which led to variations in the amount of SP grains. The Moravian Karst has been intensively studied for many years, and thus data about rainfall, river discharge, forest clearance, and other human activities are available.

VF Reports *continued on page 6…*

"Lecturing before a select group of students, Ørsted, in the spring of 1820, noticed that the needle of a nearby magnetic compass deviated when the circuit of a voltaic pile was completed. On 21 July the discovery of electromagnetism was announced." Lithograph by Pontenier, from Figuier, L., Les Merveilles de la Science, *Paris, ca. 1870, as reprinted in Dibner, B.,* Oersted and the Discovery of Electromagnetism, *Norwalk, CT, Burndy Library Press, 1961.*

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 2600 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

Aubourg, C., P. Rochette, and F. Bergmüller
Composite magnetic fabric in weakly deformed black shales, *Phys. Earth Planet. Inter., 87*, 267–278, 1995.
Results of a study of shale revealed that the matrix contributed to both susceptibility and AMS. The separation of two magnetic sub-fabrics by joint analysis of low-field AMS, high-field AMS, and anisotropy of ARM, demonstrated the existence of a competition between two magnetic lineations as well as an interchange of the intermediate and minimum AMS axes. This was the first evidence of the so-called "intermediate fabric."

Raposo, M. I. B., and M. Ernesto
Anisotropy of magnetic susceptibility in the Ponta Grossa dyke swarm (Brazil) and its relationship with magma flow direction, *Phys. Earth Planet. Inter., 87*, 183–196, 1995.
Measurements of anisotropy of magnetic susceptibility in mafic dikes revealed two main types of magnetic fabric. Type I fabric (plane K_1-K_2 parallel to the dike plane) represented magma flow within the dikes, whereas Type II (plane K_1-K_3 parallel to the dike plane) reflected vertical compaction of the magma column. Type I flow-direction information was used to suggest magma sources.

Chemistry

Kaczmarek, W. A., I. Onyskiewicz, and B. W. Ninham
Structural and magnetic characteristic of novel method of Fe_2O_3 implies Fe_3O_4 reduction by magnetomechanical activation, *IEEE Trans. Magn., MAG-30*, 4725–4727, 1994.
A magnetomechanical activation technique was used to produce magnetite fine particles from hematite. X-ray diffraction and scanning electron microscopy methods were used to observe the crystallography and morphology of magnetite formation as a function of processing time. A correlation was established between magnetic hysteresis parameters and the observed crystal structure evolution.

Lochner, E., *et al.*
Studies of the stoichiometrical variation of epitaxial $Fe_{3(1-\delta)}O_4$ thin films, *IEEE Trans. Magn., MAG-30*, 4912–4914, 1994.
Structural and magnetic studies of $Fe_{3(1-\delta)}O_4$ films showed that, with decreasing iron content, the Verwey transition broadened and moved to lower temperatures (it is absent in γ-Fe_2O_3). Various parameters showed that stable growth over a broad range of conditions resulted in stoichiometric Fe_3O_4, although variation of growth parameters could produce $Fe_{3(1-\delta)}O_4$ "defect-spinels."

Crustal Magnetization

Hall, J. M., C. C. Walls, and S. L. Hall
Viscous magnetization at 300 K in a profile through Troodos type oceanic crust, *Phys. Earth Planet. Inter., 88*, 101–116, 1995.
The principal result of an investigation of the Troodos ophiolite was that viscous magnetization (VM) did not dominate magnetization in older oceanic crust, and was often relatively negligible. VM acquisition varied irregularly with depth, with predicted maximum values equivalent to about one-third of the total magnetization, and it did not display any simple relationships with primary lithology, alteration history, magnetic properties, or magnetic history.

Johnson, H. P., and M. A. Tivey
Magnetic properties of zero-age oceanic crust; a new submarine lava flow on the Juan de Fuca ridge, *Geophys. Res. Lett., 22*, 175–178, 1995.
Specimens from a recent volcanic eruption on the Juan de Fuca Ridge had unusually high magnetizations, compared with older samples from the off-axis Juan de Fuca Ridge and other Pacific sites. These data, plus data from other young oceanic basalts, indicated that decay of magnetization of oceanic crustal rocks may have two distinct stages, with only the later stage caused by the progressive oxidation of the magnetic minerals.

Tivey, M. A., and H. P. Johnson
Alvin magnetic survey of zero-age crust: coaxial segment eruption, Juan de Fuca ridge 1993, *Geophys. Res. Lett., 22*, 171–174, 1995.
Magnetic profiles across a newly erupted lava flow on the Juan de Fuca Ridge showed strong magnetic anomaly fields and high crustal magnetization relative to the surrounding older lavas. In the central high-amplitude magnetic anomaly, there was a deep, "notch-like" magnetic low, which indicated either thermal demagnetization associated with a subsurface feeder dike, weakly magnetized intrusives, or altered extrusive rock.

Dating

Gradstein, F. M., *et al.*
A Mesozoic time scale, *J. Geophys. Res. B, 99*, 24,051–24,074, 1994.
An integrated geomagnetic polarity and stratigraphic time scale was presented for the Mesozoic, with age estimates and uncertainty limits for stage boundaries. This framework involved the observed ties (1) among radiometric dates, biozones, and stage boundaries, and (2) between biozones and magnetic reversals on the seafloor and in sediments. Interpolation techniques included maximum likelihood estimation, smoothing cubic-spline fitting, and magnetochronology.

Dynamo

Clement, B. M., and L. Stixrude
Inner core anisotropy, anomalies in the time-averaged paleomagnetic field, and polarity transition paths, *Earth Planet. Sci. Lett.*, *130*, 75–85, 1995.
The diffusion of the dynamo-generated magnetic field into the electrically conducting inner core of the Earth provided an explanation for several problematic aspects of long-term geomagnetic field behavior. A simple model was presented which illustrated how an induced magnetization in the inner core, changing on diffusive timescales, could provide a biasing field which could produce the observed anomalies in the time-averaged field and in polarity reversals.

Hollerbach, R., and C. A. Jones
On the magnetically stabilizing role of the Earth's inner core, *Phys. Earth Planet. Inter.*, *87*, 171–181, 1995.
A solution was presented to the mean-field geodynamo equations in which a finitely conducting inner core had a stabilizing influence on the rapid dynamo processes in the outer core. Such a model might reconcile the complicated nature of the field and flow in the dynamic outer core with the simple, relatively stable nature of the externally observed dipole component of the Earth's magnetic field.

Microscopy

Blasing, J., G. Strassburger, and D. Eberbeck
Determination of particle size distribution and correlation of particles in ferrofluids under the influence of magnetic fields, *Phys. Stat. Sol. A*, *146*, 595–602, 1994.
Particle-size distribution, structure, and magnetic correlations of magnetite particles in ferrofluids were studied with X-ray diffraction methods and electron microscopy. Under the influence of a magnetic field, the ferrofluid particles aggregated into oblong, directed particle clusters. They had a small extension in the field direction, caused by the wide size distribution and high thermal energy of the particles.

Jansen, R., *et al.*
Surface structure of Fe_3O_4 (110) studied by scanning tunneling microscopy, *IEEE Trans. Magn.*, *MAG-30*, 4506–4508, 1994.
STM images of the (110) surface of magnetite showed straight terraces separated mainly by double and four-fold steps. On the terraces, rows were found, with a separation of about 25 Å. Current-versus-voltage characteristics measured on this surface displayed a gap in the conductivity of about 2 eV. Results were discussed in terms of the bulk Fe_3O_4 structure.

Proksch, R. B., S. Foss, and E. D. Dahlberg
High resolution magnetic force microscopy of domain wall fine structures, *IEEE Trans. Magn.*, *MAG-30*, 4467–4472, 1994.
Magnetic force microscope (MFM) images of domain-wall structures were analyzed. The systems studied included single crystals of magnetite (Fe_3O_4) and a 0.5-μm single-crystal iron (Fe) film. The observed structures were explained in terms of a bulk Bloch wall terminated at the surface by a Néel cap. A model of the MFM response to such a structure was fit to the measured response, demonstrating the utility of MFM data for testing micromagnetic models.

Paleoclimate

Forster, T., and F. Heller
Loess deposits from the Tajik depression (central Asia): magnetic properties and paleoclimate, *Earth Planet. Sci. Lett.*, *128*, 501–512, 1994.
The susceptibility variations of Quaternary eolian sediments in southern Tajikistan correlated excellently with those of the Chinese loess record at Xifeng. Close correlation with the astronomically tuned oxygen-isotope record enabled refined dating of the loess sequence at Karamaidan and demonstrated the global significance of the recorded paleoclimatic variations, especially with respect to paleoprecipitation on land during the Quaternary.

Heller, F., and M. E. Evans
Loess magnetism, *Rev. Geophys.*, in press, 1995.
This review of the state of magnetic loess research pointed out that, in certain places, loess has recorded the polarity history of the geomagnetic field, and that this magnetostratigraphy has subsequently been used for dating. Comparisons among profiles of susceptibility, other magnetic parameters, ^{10}Be, and oceanic oxygen-isotope records have been used to estimate climate-change variables such as temperature, rainfall, and wind direction.

Hartl, P. D., L. Tauxe, and T. Hebert
Earliest Oligocene increase in productivity as interpreted from "rock magnetics" at DSDP site 522, *Paleoceanogr.*, in press, 1995.
Results of a study of South Atlantic sediments showed that an early Oligocene increase in thermohaline circulation increased the organic carbon transport to the sediments. This led to chemical dissolution of the finest magnetite, hence a reduction in the superparamagnetic component and a change in rock-magnetic parameters. In this way, rock magnetics were sensitive indicators of environmental changes that might otherwise have left little trace in the sedimentary record.

Xiao, J.-L., *et al.*
Grain size of quartz as an indicator of winter monsoon strength on the loess plateau of central China during the last 130,000 yr, *Quat. Res.*, *43*, 22–29, 1995.
Quartz grain-size values for the loess-paleosol section at Luochuan were determined. The results suggested that the winter monsoon weakened during marine oxygen-isotope stages 5, 3, and l, and was strongest during stages 4 and 2. However, the records displayed second-order variations, which were lacking in the magnetic susceptibility record, that implied changes in atmospheric conditions affecting dust transport and deposition.

Paleointensity

Kent, D. V., and D. A. Schneider
Correlation of paleointensity variation records in the Brunhes/Matuyama polarity transition interval, *Earth Planet. Sci. Lett.*, *129*, 135–144, 1995.
The twin ^{10}Be peaks reported in some deep-sea sediment records have been attributed to the increased production of this cosmogenic isotope during the double paleointensity dips that occurred at the Brunhes/Matuyama transition. Because the main features of the ^{10}Be profiles were unaffected by the remanence lock-in process (variability in which process could lead to misinterpretations), they were useful for correlation as a proxy of geomagnetic dipole intensity variation.

Tanaka, H., M. Kono, and W. Uchimura
Some global features of palaeointensity in geological time, *Geophys. J. Int.*, *120*, 97–102, 1995.
A global paleointensity database was constructed from all published data for volcanic rocks older than 0.03 Ma. Analysis showed that the Earth's dipole moment exhibited long-term variations over the past 300 Ma, with a broad minimum at 120–180 Ma. However, this Mesozoic dipole low could not be completely established.

Weeks, R. J., *et al.*
Normalised natural remanent magnetisation intensity during the last 240,000 years in piston cores from the central North Atlantic Ocean: geomagnetic field intensity or environmental signal?, *Phys. Earth Planet. Inter.*, *87*, 213–229, 1995.
In North Atlantic sediment cores, normalization of the NRM intensity canceled the effect of climatically induced variations in magnetic mineral content and grain size, and a reliable record of relative paleointensity was obtained. The record yielded by IRM normalization was more consistent with previous sedimentary and volcanic results, than was the record yielded by ARM normalization.

Physics

Mishra, S. K., Z. Zhang, and S. Satpathy
Verwey transition in magnetite: mean-field solution of the three-band model, *J. Appl. Phys.*, *76*, 6700–6702, 1994.
The nature of the magnetite (Fe_3O_4) Verwey transition within a three-band spinless model Hamiltonian was studied as a function of the ratio of the intersite Coulomb repulsion U_1 and the bandwidth W. It was found that the electrons exhibited a Verwey-like order above the critical value of $U_1/W \approx 0.25$. The model predicted a transition from the metallic to the semiconducting state, with the band gap increasing linearly with U_1 beyond the transition point.

Reversals

Johnson, H. P., *et al.*
Geomagnetic polarity reversal rate for the Phanerozoic, *Geophys. Res. Lett.*, *22*, 231–234, 1995.
The Global Paleomagnetic Database was used to estimate relative reversal frequency for the last 570 Ma, and the results showed the expected long intervals of low reversal rate during the Cretaceous Normal and Permo-Carboniferous Reversed Superchrons, a new long period of low reversal rate in the Ordovician, and an additional short period of low reversals at the Jurassic/Triassic boundary.

Quidelleur, X., J. Holt, and J.-P. Valet
Confounding influence of magnetic fabric on sedimentary records of a field reversal, *Nature*, *374*, 246–249, 1995.
Predictions were confirmed that sedimentary paleomagnetic records, which purport to show a preferred longitudinal reversal path, might have been modified by artifacts linked to the acquisition of magnetization: the declinations of the remanence recorded at two sites during the Upper Olduvai reversal were similar to the directions of the maximum axes of the ellipsoids of magnetic anisotropy.

Rock Magnetism

Halgedahl, S. L., and R. D. Jarrard
Low-temperature behavior of single-domain through multidomain magnetite, *Earth Planet. Sci. Lett.*, *130*, 127–139, 1995.
An investigation was made of the low-temperature behavior of synthetic and natural magnetites that span single- and multi-domain behavior. Low-temperature behavior was characterized across a broad range of grain size (and thus domain state), and the physical mechanism by which low-temperature demagnetization occurs in magnetite particles containing domain walls was investigated.

Roberts, A. P., Y.-L. Cui, and K. L. Verosub
Wasp-waisted hysteresis loops: mineral magnetic characteristics and discrimination of components in mixed magnetic systems, *J. Geophys. Res. B*, in press, 1995.
Modeling provided several conditions for, and constraints on, wasp-waisted hysteresis loops. A method was outlined for determining the magnetic components that could give rise to wasp-waisted hysteresis loops. This method relied both on high- and low-temperature magnetic measurements that were used to identify the dominant remanence-bearing minerals and on mineral-magnetic techniques that were used to discriminate between different magnetic domain states.

Sahu, S., and B. M. Moskowitz
Thermal dependence of magnetocrystalline anisotropy and magnetostriction constants of single crystal $Fe_{2.4}Ti_{0.61}O_4$, *Geophys. Res. Lett.*, *22*, 449–452, 1995.
Results of measurements of the temperature dependence of the magnetocrystalline anisotropy and magnetostriction constants of $Fe_{2.4}Ti_{0.61}O_4$ showed that the magnetoelastic contribution to magnetocrystalline anisotropy dominated the anisotropy constant at elevated temperature and that the effects of stress could not be neglected in theories of thermoremanence and micromagnetic models for intermediate titanomagnetites commonly found in oceanic basalts.

Shcherbakov, V. P., B. E. Lamash, and N. K. Sycheva
Monte-Carlo modelling of thermoremanence acquisition in interacting single-domain grains, *Phys. Earth Planet. Inter.*, *87*, 197–211, 1995.
Numerical modeling of TRM acquisition was performed using the Monte Carlo method to simulate the role of thermofluctuations. The results corresponded well to mean-field theory, which could be described in terms of a disordered system for interacting single-domain grains. Interactions became important when the magnetic fraction exceeded 0.5% volume, and they were responsible for strong increases in the blocking temperatures and the TRM saturation field, and reduction of the susceptibility.

Ye, J., and R. T. Merrill
Residual stress and domain structure, *J. Geophys. Res. B*, in press, 1995.
Calculations showed that as residual stress increased, the number of domains in Ti-rich titanomagnetite first increased and then decreased, and that large residual stress also caused laminar domain structures. The presence of a large macrostress and possible systematic errors in the observational estimates of the number of domains explained the current discrepancy between domain observations and theory.

Secular Variation

Løvlie, R., K. L. Ellingsen, and S.-E. Lauritzen
Palaeomagnetic cave stratigraphy of sediments from Hellemofjord, northern Norway, *Geophys. J. Int.*, *120*, 499–515, 1995.
Subglacial-deposited sediments from deep karst caves carried records of paleosecular variation (PSV) defining a clockwise rotation of the vector with time. The almost-closed PSV loop might represent discrete periods of sedimentation during subglacial events. Correlation with the PSV loop records from the nearby lacustrine sediments tentatively suggests that these sediments accumulated during the final Weichselian glacial retreat.

Lund, S. P.
A comparison of Holocene paleomagnetic secular variation records from North America, *J. Geophys. Res. B*, in press, 1995.
An analysis of Holocene records of North American paleosecular variation (PSV) indicated that distinctive field features could often be traced for more than 4000 km. Independent age determinations corroborated these correlations while also suggesting that westward (or eastward) drift was not significant. On the other hand, northward drift might have been a significant process between 1500–5500 B.P. Circularity (vector looping) was a preferred means of defining coherent space-time vector variations.

Quidelleur, X., *et al.*
Long-term geometry of the geomagnetic field for the last five million years: an updated secular variation database, *Geophys. Res. Lett.*, *21*, 1639–1642, 1994.
A re-examination of the updated Lee (1983) data base revealed no unambiguous maxima in the longitude distribution of VGPs. The shape of the common site longitude distribution had a pronounced (and robust) minimum close to the common site longitude and secondary maxima about 120° away from it. These features were related to predictions and to previous results.

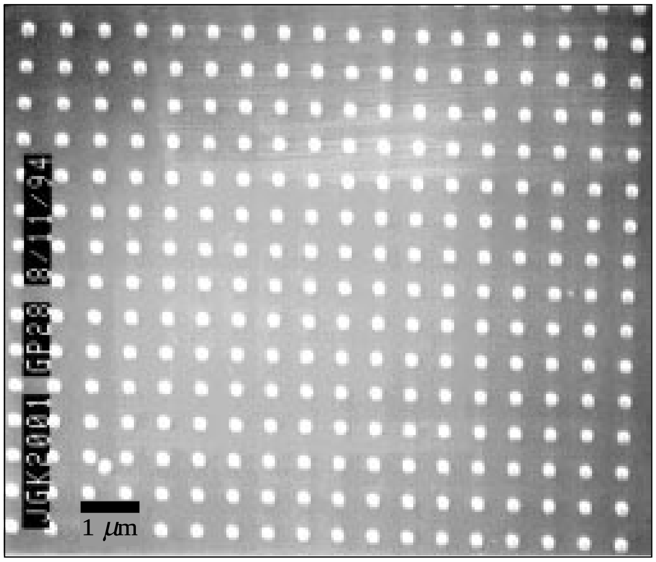
Yamazaki, T., and N. Ioka
Long-term secular variation of the geomagnetic field during the last 200 kyr recorded in sediment cores from the western equatorial Pacific, *Earth Planet. Sci. Lett.*, *128*, 527–544, 1994.
The inclination record of cores from the western equatorial Pacific showed long-term cyclic changes of several degrees in amplitude. The intervals of the variation were 40–50 ka, which was longer than the core's memory and was close to the Milankovitch frequency associated with the change in obliquity of Earth's rotational axis. Thus, orbital forcing could have been a cause of the long-term secular variation. ■

…VF Reports *continued from page 2*

James G. King
Edinburgh University

Magnetic Properties of Magnetite Produced by the Electron-Beam Lithography Method

SEM image of a nano-engineered array of cubic 0.2×0.2×0.2-μm magnetite particles.



Micromagnetic simulations predict that, in a transition from truly single domain to more than one domain, magnetite particles should pass through a lower energy state—the so-called vortex state—but this still has to be confirmed experimentally. Attempts at observing such predicted magnetic properties using artificially produced magnetic powders have been hampered by particle clustering, lack of controlled orientation, and lack of accurate knowledge of the individual constituent particles.

In an attempt to overcome these shortcomings, we produced oriented particles of different size, aspect ratio, and inter-particle spacing (see Figure). These particles were produced using the Electron-Beam Lithography lift-off techniques that are often employed in nanolithography engineering. Since we couldn't produce stoichiometric magnetite directly—it requires higher temperatures than the flowing temperature of the organic resist used in electron beam lithography—we had to produce iron and later change it to Fe_3O_4 by annealing it in an appropriate environment.

So, my main reason for visiting the *IRM* was to measure the magnetic properties of these particles. Below is a brief summary of the equipment used, the questions to be answered, and some comments on the results.

(i) MPMS: Does the magnetite produced by conversion of Fe to Fe_3O_4 show a Verwey transition at the appropriate temperature for stoichiometric magnetite? Result: It did.

(ii) Mössbauer: Was the Fe_3O_4 which was produced from Fe stoichiometric? Result: There wasn't enough material in the film, so the Mössbauer signal was just noise. Producing the film using enriched ^{57}Fe might work.

(iii) AGFM (MicroMag): Are the hysteresis loops typical for Stoner-Wohlfarth coherent rotation? Result: No. This is as expected from micromagnetic calculations which show a non-coherent mode of atomic moment reversal. The AGFM (MicroMag) was also used to measure some randomly oriented octahedral particles of magnetite, produced at a substrate temperature of 300°C, as a function of film thickness and particle size.

(iv) MFM: Are there any visible domains in these arrays of particles? Result: None observed. The reason for this is not known, but it may be due to the fact that the particles are not single crystals. Attempting to produce highly oriented or single crystals seems appropriate.

Archana Pawse
Michigan Technological University

ESR Spectra and Magnetic Properties of Guatemalan Volcanic Ash

My research project investigates the use of Electron Spin Resonance (ESR) spectroscopy and magnetic properties for the identification of volcanic ash. These properties are sensitive to the chemical composition, mineralogy, and grain size of the ash. We expect that each volcano has a distinct ESR spectrum, and hence it can be used as a fingerprint of that particular volcano.

We had conducted ESR and hysteresis studies on 9 different volcanic ash deposits and 19 samples of ash erupted in October, 1974, from Mt. Fuego, Guatemala, obtained at increasing distances from the volcano. The results indicated that ESR spectra and some magnetic properties (coercivity of remanence and saturation magnetization) are uniform in distal ash and suggested that they had potential for use in identifying ash.

The purpose of my visit to the *IRM* was to obtain more information about the magnetic properties of ash by conducting measurements of magnetic susceptibility as a function of temperature on these samples.

I conducted high-temperature AC susceptibility measurements on the Kappabridge, low-temperature SIRM and DC susceptibility measurements on the MPMS, and hysteresis measurements on the MicroMag. High-temperature susceptibility measurements on the 19 Mt. Fuego samples show a Hopkinson effect and a Curie temperature of 305°C. The variation of susceptibility with temperature was reversible. The Curie temperature is compatible with high-titanium titanomagnetite. Above the Curie point, the susceptibility shows an inverse dependence on temperature. This indicates the presence of some paramagnetic components in the ash.

I also conducted high-temperature measurements on glass separates and on heavy mineral separates of two samples of volcanic ash. The susceptibility measurements of heavy separates were similar to that of ash.

The low-temperature SIRM measurements do not show a Verwey transition for magnetite. The room-temperature remanence was attributed to titanomagnetite. There is no ilmenite in the ash, since no transition was apparent at the Néel temperature. The inverse susceptibility versus temperature measurement shows deviation from paramagnetism, which indicates the presence of some ferrimagnetic minerals. The variation of SIRM demagnetization behavior and of susceptibility with both high and low temperature is similar for all the samples of ash regardless of the distance of the sample from the volcano.

I conducted hysteresis measurements on the Mt. Fuego samples using the MicroMag. Comparison of these magnetic parameters with the hysteresis data obtained on the VSM at Michigan Technological University showed differences in the values of the parameters, but similar trends were observed. I also conducted MicroMag measurements on glass separates of ash samples obtained from the May, 1980, Mt. St. Helens eruption in southwest Washington. These samples had a very low coercivity.

Further analysis of the data will give more information regarding the composition of the ash. I am presently working on this analysis.

Darcy Van Patten
University of Washington

Granulometry in Zero-Age Basalt using Optical and Magnetic Analyses

Many of the magnetic properties of rocks are strongly dependent on the grain size of the magnetic minerals. Paul Johnson and I have been working on developing a rock-magnetic technique that can be used to estimate the size distribution of the magnetic minerals in submarine basalts. The technique is based on a combination of hysteresis-loop parameters and optical measurements of the larger end of the particle-size distribution. Our strategy is two-fold: First, we will perfect the technique on a series of cores taken from unaltered zero-age pillow basalts from the 1993 eruption on the Juan de Fuca Ridge. Then, we propose to extend the measurements to basalt samples of increasing age (0–0.8 Ma), which were dredged from the East Pacific Rise. In doing samples of increasing age, we hope to see how the relationship between optical grain size and magnetic grain size varies as the grains are oxidized.

We have 8 pillow fragments of various sizes recovered from the new Juan de Fuca Ridge flow, all with the same whole-rock chemistry, but with a wide range of remanence intensities and magnetic properties. We plan to determine optical grain size using standard reflected light studies of polished thin sections, with the grain size being quantitatively determined using a newly available computer-based technique.

In March, I visited the *IRM* to measure approximately 40 hysteresis loops using the VSM as the first step in developing our technique. The hysteresis parameters obtained indicate that although all of the new-flow samples have characteristics of single-domain and pseudo-single-domain particles, there is a large range of particle sizes. We are hoping that some of the variation in intensities and susceptibility can be explained in terms of grain size and abundance. I also used both the VSM and the Kappabridge to measure Curie temperatures on four samples. These Curie temperatures confirm that the new-flow rocks are unoxidized. Analysis of the new rock-magnetic data is still underway, and the corresponding optical grain-size measurements should be completed by the end of summer. ■

…Education *continued from page 1*

sessions. It can be said, therefore, that the educational effort was truly two-way, as befits the "college of scholars" model.

Workshops

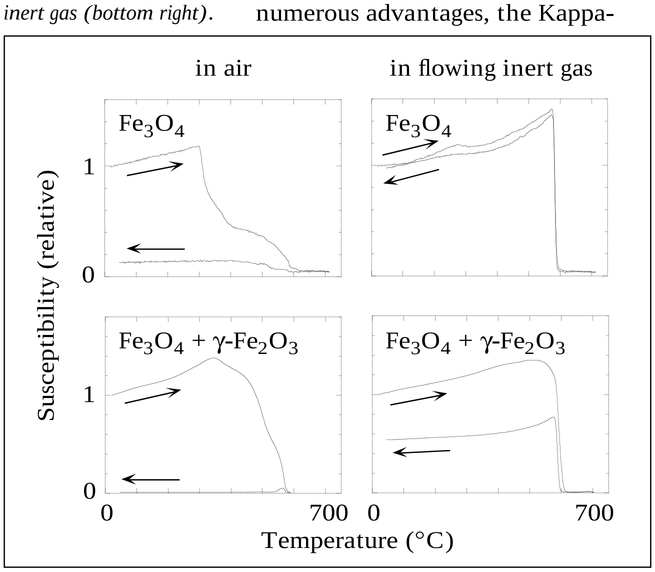
We have also held three training workshops for grad-students and more senior scholars at our facilities in Minneapolis: (1) Environmental Magnetism (1991) [in conjunction with the Paleorecords of Global Change Research Training Group], (2) Applications of Rock Magnetism to Quaternary Studies (1993) [as part of the biennial meeting of the American Quaternary Association], and (3) Applications of Rock Magnetism to Archaeology (1995) [as part of the annual meeting of the Society for American Archaeology].

I hope that this short piece will both inform the general reader and encourage the student reader. For the latter, we are always here to discuss a potential project (on the phone or via e-mail), and maybe to measure a few preliminary samples to enable a hopeful researcher to write a competitive proposal for a Visiting Fellowship to the *IRM*. ■

Kappabridge Has Gas!

Peat Solheid
Jim Marvin
IRM

Low-field susceptibility as a function of temperature for (1) magnetite in air (top left) and in flowing inert gas (top right), and (2) a mixture of magnetite and maghemite in air (bottom left) and in flowing inert gas (bottom right).



It is well known that our Kappabridge has proved to be of invaluable service in its ability to measure susceptibility as a function of temperature up to 750°C. And its high sensitivity enables us to detect very low concentrations of magnetic material. Furthermore, it has allowed both *IRM*ers and *IRM* users to measure Curie temperatures, the Hopkinson effect, and even the inversion of maghemite. However, despite its numerous advantages, the Kappabridge has had one drawback: the sample test-tube that fits inside the furnace is open to the air at the top, resulting in uncontrolled conditions at the surface of the sample, *i.e.*, the sample is free to oxidize if it wishes.

What this has often meant is that what goes in as fine-grained magnetite or maghemite comes out as bright red hematite (large grains generally don't have enough surface area to oxidize appreciably). Other materials, such as loess or ocean sediments, have so much organic matter in them that, in spite of the air, they make magnetite under reducing conditions created by the breakdown of the organics. We have seen these problems manifest themselves to varying degrees in nearly all samples in the form of irreversible susceptibility *vs.* temperature curves.

Although such changes can be instructive in many cases, they are uncontrolled dynamic processes. Thus, there has been pressure from many *IRM* users to better control the atmosphere in the test tube. This prompted us to modify the apparatus in order to bathe the sample in a flowing inert gas, which would nearly eliminate oxidation, in principle. Dramatic results were obtained with a flow of 100 ml min^{-1}. We have tested this bathing technique on fine-grained (1-μm) magnetite which completely oxidized to low-susceptibility hematite when measured in air, but which had a reversible susceptibility curve when measured in the inert gas (see Figure). A mixture, containing 50% magnetite and 50% maghemite that had comparable susceptibilities, was also measured both in air and in the inert gas (see Figure). The results demonstrate how the maghemite inverted to hematite—which is a temperature-dependent crystallographic change, not an oxidation process—and the magnetite remained intact. Similarly clear-cut results were obtained for a pyrrhotite sample.

For simple, one- or two-member systems, the flowing inert gas seems to have solved our oxidation problem. For more complicated, real-world specimens, there are many more mineral components in the mixture. The interpretation of resulting susceptibility data may still be difficult, but at least there will be one fewer variable to worry about. ■

RAC Supports Changes at the *IRM*

On April 22, the *IRM*'s Review and Advisory Committee (RAC) held its semi-annual meeting in Minneapolis to look over our facilities and to talk with staff and students. RAC members David Dunlop (University of Toronto), Dennis Kent (Columbia University), John King (University of Rhode Island), and Dan Dahlberg (University of Minnesota) contributed a great deal—and also enjoyed a delectable lunch at our favorite Vietnamese restaurant. Sue Halgedahl (University of Utah) sent her comments long distance, and Bob Butler (University of Arizona) passed along the suggestions that resulted from a poll of recent *IRM* users. Bill Seyfried (Head of the School of Earth Sciences, University of Minnesota), the *IRM* staff, and most *IRM* grad students and post-docs were also on hand to provide valuable input.

Following the recommendations of the RAC members, we agreed to make a number of substantial changes regarding visitors and Visiting Fellows. Our explosive growth (there were 364 visitor-days during the last 12 months—and nobody here can recall which day we had off!) had resulted in scheduling problems. To remedy the situation, we decided to alter the requirements for visitors. So, effective immediately, the following will hold:

Visiting Fellowship Applications

An application for a Visiting Fellowship will consist of an *IRM* Cover Sheet (which asks for vital statistics and a concise project summary), up to 3 pages of text, any necessary tables and figures, and an *IRM* Equipment Form (which asks for time estimates on requested machines). The "official" forms are available from the *IRM* office. Faxed and e-mailed applications will no longer be accepted. [This applies to applications being sent for the June 9 deadline, too!]

Visit Scheduling

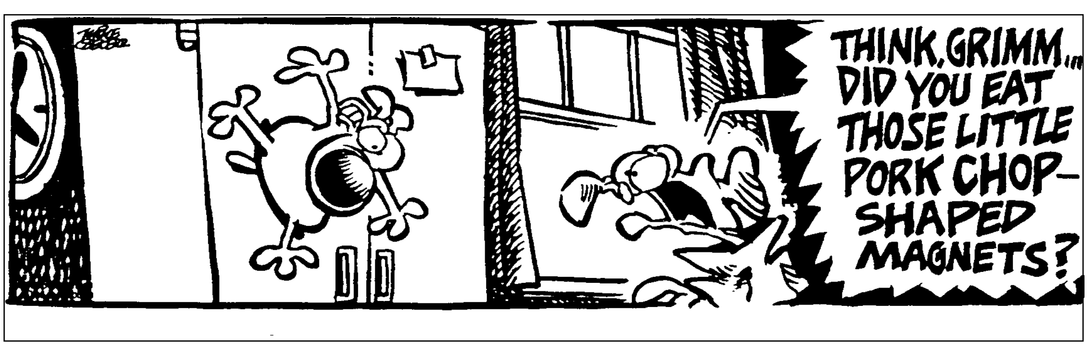
Visiting Fellowship visits will now be limited to around 10 days, scheduled through the Lab Manager, Chris Hunt. Informal visits will still be limited to 3 days, and will still be arranged through the Lab Manager. One week per month will be reserved for *IRM* staff, post-docs, and students to work or to do maintenance and repair.

These few changes, which will result in a leaner—but certainly not meaner—visitor program, will enable us to better meet the needs of all of our users. And, these new guidelines notwithstanding, the *IRM* will remain an open, anti-bureaucratic environment in which we can all thrive. ▬

IRM Goes on the Web

Bernie Housen
IRM

Check out the *IRM*'s new page on the World Wide Web by pointing your favorite browser (Netscape will work best) at: http://www.geo.umn/docs/irm.html. On this page you will find general information about the *IRM*, and some of the latest news on *IRM* happenings. In the near future you will be able to obtain the *IRM* brochure, information about our equipment, Visiting Fellowship information and applications, and copies of this newsletter, too. Please be patient; not everything works as of this writing. Additional functions will be added as construction proceeds. We would like your input on other possible features, especially links to other resources that would be of interest to the rock-magnetic community. So, the next time you surf the net, drop by our place. ▬



☛ June 9 Application Deadline is Nigh!

Visiting Fellowship Applications for short stays this fall and winter are due almost immediately. Details about how to apply are in *Eos* (April 18 and May 9 issues) and in *GSA Today* (May issue). Be sure to include both the new Cover Sheet and the modified Equipment Form as part of your proposal; ask the Lab Manager for more information or for copies of the new forms. ▬

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, Professor/Director; Bruce Moskowitz, Assistant Professor/Associate Director; Jim Marvin, Senior Scientist; and Chris Hunt, Senior Scientist/Laboratory Manager.

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