The IRM Quarterly

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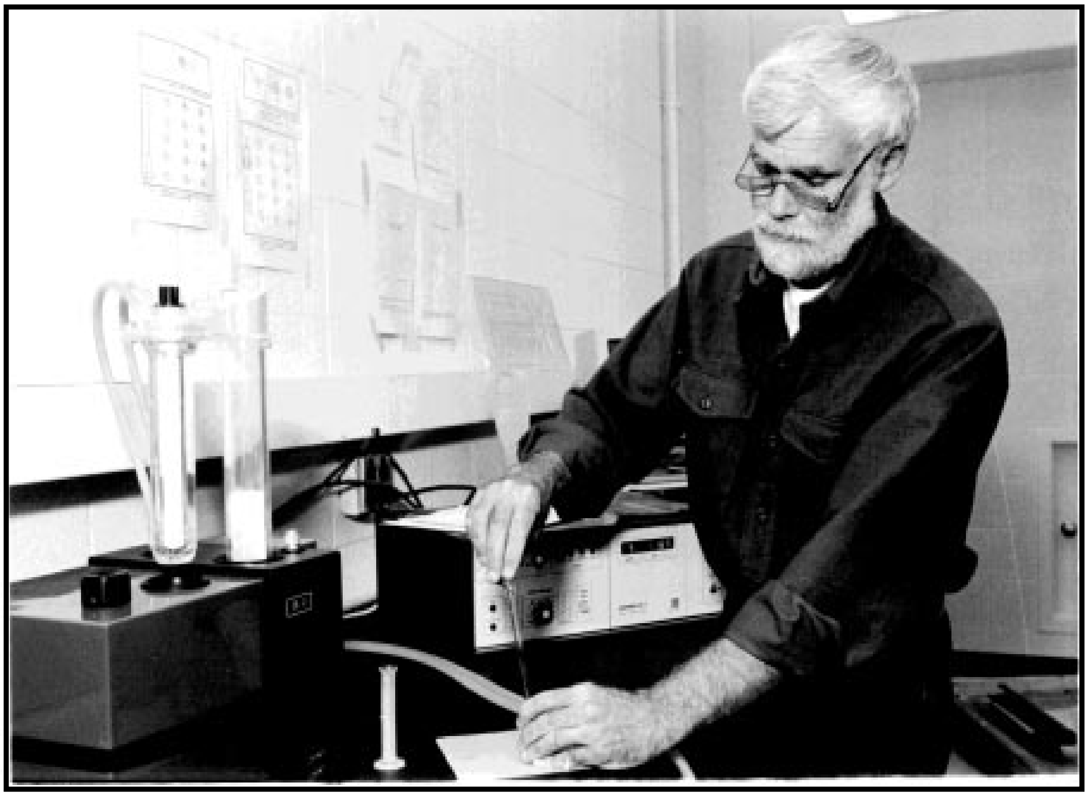


Photo: Dee De VanSlyke, Biomedical Graphics

Jim Marvin poses in front of the Kappabridge while loading a powdered sample for thermomagnetic analysis.

Kudos for the Kappabridge

Chris Hunt
IRM

This article is the second in a new series to explain the uses of—and how to use—some of the pieces of equipment that have added significantly to the capabilities of the IRM *during the last year. As was our aim with the previous series of articles, we hope both to remove some of the mystique that surrounds these latest arrivals, and to foster ideas for novel experiments afforded by their existence. This time, it's the Geofyzika Kappabridge susceptometer:*

THE KAPPABRIDGE

After Geofyzika's Jiří Pokorný and Jiří Wohlgemuth flew over from Brno, they set up and taught us to use our new Kappabridge in just one day. The primary use of this instrument is to measure low-field magnetic susceptibility as a function of either direction or high temperature.

Applications

The Kappabridge can be used in a wide range of studies. In its direction mode, the machine will yield anisotropy of magnetic susceptibility (AMS) data for use in magnetic fabric studies. Examples are determinations of streamflow or wind directions in sedimentary rocks, magma flow directions in igneous rocks, deformation in metamorphic rocks, or permeability/porosity/jointing in any rocks. In its temperature mode, the Kappabridge can easily determine or characterize mineral magnetic properties—such as Curie temperatures, Hopkinson peaks, and phase transitions—for use in mineral identification or in fundamental rock magnetism.

How?

The Kappabridge performs these feats by producing either susceptibility *vs.* direction data or curves of susceptibility *vs.* temperature.

When the instrument is used in its directional mode, the susceptibility of a sample is measured in 15 directions, and a susceptibility ellipsoid is calculated from the data. The degree and type of anisotropy can then be determined from the ellipsoid parameters.

When the machine is run in its temperature-sweep mode, Curie temperatures can be determined because the susceptibility drops to zero above the Curie point. Under appropriate conditions, Hopkinson susceptibility peaks also appear just below the Curie temperature.

Principles of Operation

Magnetic susceptibility is a measure of the magnetic response of a material to a small applied magnetic field. The Kappabridge has a coil which produces such a field (magnitude 300 A m^{-1} [~4 Oe], frequency 920 Hz). This coil also serves as a sensor because it is tied into an LRC bridge circuit. A comparison is made of the electronic characteristics of the circuit with and without the specimen in the coil, and the magnetic susceptibility of the sample is then calculated from the change. The temperature of the system is controlled up to 700°C and back by a heater with a water-cooled jacket. The manufacturer claims a sensitivity of about 4×10^{-8} SI for a typical 10-cm^3 AMS sample, and about 1×10^{-7} SI for a typical 0.25-cm^3 thermal sample.

Kappabridge continued on page 5…

Visiting Fellows' Reports

In May, Joe Stoner arrived from Montreal, and Jim Channell flew up from Gainesville to pull all-nighters at the MicroMag. John Geissman made a two-part trip from Albuquerque—one in February and one in August—to bring us some tasty salsa, and also to work in the lab. Back in April, Weixin Xu came over from Ann Arbor to look at various rocks. Then in June, David Dunlop, Özden Özdemir, and Song Xu made their annual pilgrimage from Toronto. Below are summaries of the work done by these Fellows while at the *IRM*.

[Editor's note: Because of space limitations, I drastically cut most summaries, so you won't read about numerous experimental or project details, how good Minneapolis coffee houses or Weiwei Sun's dumplings are, or how our visitors thank us for our help. We gratefully acknowledge the latter, but it's getting so embarrassing that I may have to start expunging that stuff as a rule anyway.]

Joe Stoner
Université de Québec à Montréal
Jim Channell
University of Florida

Magnetic Studies of Marine Sediments from the Deep Labrador Sea

On our visit to the *IRM*, we had sediment samples from two long piston cores taken from the Labrador Sea. Initial high-resolution rock-magnetic analysis done at the University of Florida indicated that the magnetic properties of these cores are highly sensitive to sediment transport changes which are related to changing climatic conditions.

Magnetic properties of the first core, taken from the Greenland rise off southwest Greenland, are characterized by increases in magnetic grain size and concentration which appear to reflect changes from marine-based to land-based deglaciations of the Greenland ice sheet. Of special interest in this core is a high-coercivity layer at depth. The magnetic properties of this layer are similar to those of the surficial mixed layer above the Fe-reduction zone, and may indicate a relict oxic zone. [Ed.: See Joe's abstract, next page.]

At the *IRM*, the deglaciations were characterized by slight changes in grain size within the PSD zone. However, the samples from the high-coercivity and surficial layers show a unique grain-size trend characterized by higher H_{cr}/H_c values for given M_{rs}/M_s values. Their MPMS results are also different: they show very little remanence lost from either SP material or at the Verwey transition. Is this behavior related to oxidation of detrital and/or biogenic magnetite prior to passing through the zone of Fe reduction?

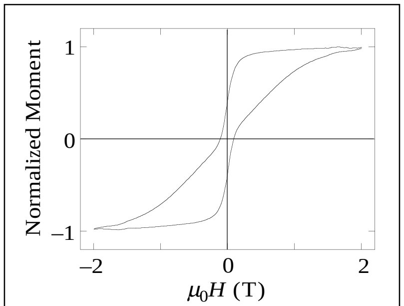
The magnetic properties of the second core, taken from the Labrador rise off Newfoundland, are strongly influenced by Heinrich events. (Heinrich events are sudden, possibly catastrophic surges of the Laurentide ice sheet which released massive amounts of ice and simultaneously deposited ice-rafted debris all across the North Atlantic. These events are characterized magnetically by much larger grain sizes.)

By measuring many loops on the MicroMag, we obtained a high-resolution record of the critical intervals and a low-resolution record of the background sediment as well. The hysteresis parameters from all the samples fell in the PSD–MD fields, but all MD samples were from Heinrich-event (or Heinrich-event-like) layers. The Heinrich-event samples displayed consistent magnetic behavior both within and between events, indicating a strong homogeneity even at the scale of a MicroMag sample. The low-temperature remanence experiments indicated very little SP material and a pronounced Verwey transition within Heinrich samples. This result varied significantly from the background samples which had a larger initial remanence drop—presumably due to SP material—and a smaller remanence drop at the Verwey transition.

John Geissman
University of New Mexico

From Remagnetized Carbonates to Sandstone Dikes, and Much More

I returned to the *IRM* after a 16-year absence to measure hysteresis loops of a wide variety of samples on the MicroMag, and the frequency and temperature dependences of susceptibility on the LakeShore. A brief description of four of my many rock-magnetic endeavors follows.



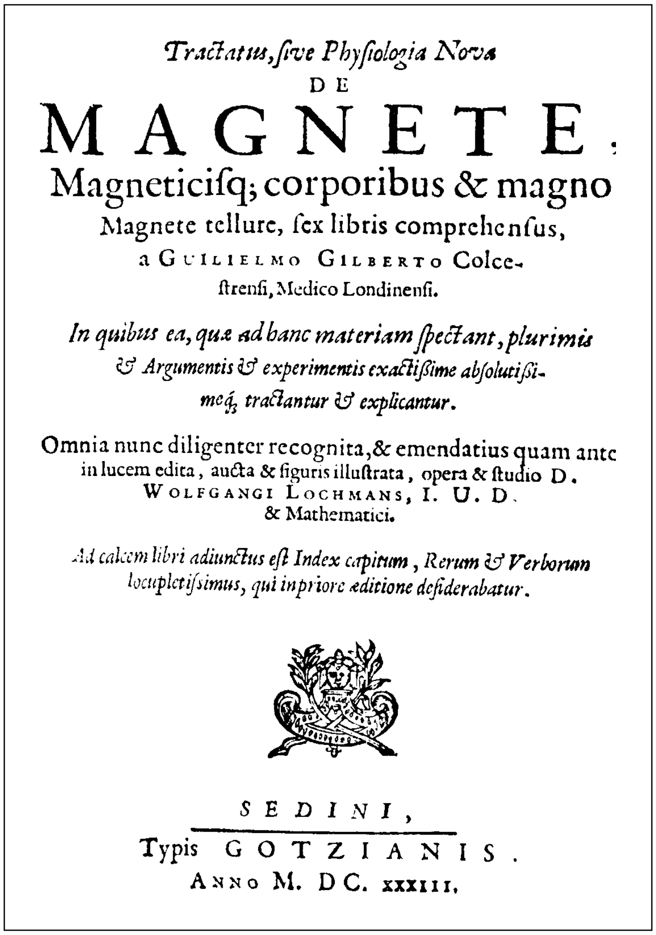
Pikes Peak Granite

In an attempt to test the hypothesis that nonconformities between Proterozoic crystalline rocks and late-Paleozoic strata in the Rockies served as channelways for something responsible for late-Paleozoic hematite-borne chemical remagnetization, I concentrated my work on three sites in the Proterozoic Pikes Peak granite. At one site, my collegues and I interpreted the magnetite-borne magnetization to be a TRM. The magnetization at the other sites was dominated by hematite and was of late-Paleozoic affinity. Yet megascopically, all specimens appeared identical! For the first site, *IRM* hysteresis loops are indicative of coarse magnetite; for the other sites, K-feldspar and biotite crystals yield hysteresis data indicative of an abundant, high-coercivity phase (see figure), which we interpret to be hematite.

As part of a larger project to determine the origin of faults responsible for extension of upper crustal rocks in metamorphic core complexes (MCC), we have been attempting to demonstrate that MCC rocks carry pre- and syn-kinematic magnetizations which could be useful in deciphering their structural history. We wanted to obtain sufficient hysteresis data from the rock types present at the South Mountains MCC in Arizona to adequately characterize the magnetization signal. Overall, the data obtained at the *IRM* are consistent with previous demagnetization data: for those magnetite-dominated rocks that responded well to demagnetization, the hysteresis results suggest dominance by PSD particles.

In a study of hematite-cemented "sandstone dikes" in Jurassic sandstones and siltstones, we thought that we might be able to test the age of hematite magnetization acquisi-

VF Reports continued on page 6…


Tractatus, ſive Phyſiologia Nova
DE
MAGNETE,
Magneticiſq; corporibus & magno
Magnete tellure, ſex libris comprehenſus,
a GUILIELMO GILBERTO Colce-
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In quibus ea, quæ ad hanc materiam ſpectant, plurimis
& Argumentis & experimentis exactiſſime abſolutiſſi-
meq; tractantur & explicantur.
Omnia nunc diligenter recognita, & emendatius quam ante
in lucem edita, aucta & figuris illuſtrata, opera & ſtudio D.
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& Mathematici.
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SEDINI,
Typis GOTZIANIS.
ANNO M. DC. XXXIII.

Title page from Gilbert's De Magnete, *third edition, 1633.*

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 2200 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

Anomalies

Arkani-Hamed, J., R. A. Langel, and M. Purucker
Scalar magnetic anomaly maps of Earth derived from POGO and MAGSAT data, *J. Geophys. Res., in press*, 1994.
Two scalar magnetic anomaly maps of the Earth were derived from a comparison of the common features of a new POGO scalar magnetic anomaly map and two new MAGSAT anomaly maps. The derivations used two selection criteria with different levels of stringency which suppressed the noncrustal components of the original maps by different amounts.

Florio, G., *et al.*
Anisotropic magnetic susceptibility in the continental lower crust and its implications for the shape of magnetic anomalies, *Geophys. Res. Lett., 20*, 2623–2626, 1993.
Magnetic anisotropy measurements on samples from the lower continental crust were made to test the hypothesis that anisotropy may distort magnetic anomalies. Yet, when the measurements were compared with an abnormal magnetic anomaly model, these anomalies could not be related easily to anisotropic magnetic susceptibility of the source rocks. Thus, such shapes were most likely caused by a strong remanence in subsequently rotated source bodies.

Climate Change

Peck, J. A., *et al.*
A rock-magnetic record from Lake Baikal, Siberia: evidence for Late Quaternary climate change, *Earth Planet. Sci. Lett., 122*, 221–238, 1994.
Rock-magnetic measurements of sediment from Lake Baikal showed variations related to Late Quaternary climate change. Using a conceptual model based upon the well-dated last glacial-interglacial transition, variations in magnetic concentration and mineralogy were related to glacial cycles. Variations in magnetic concentration and mineralogy of these sediments correlated to the SPECMAP marine oxygen-isotope record.

Stoner, J. S.
High-resolution rock-magnetic study of a Late Pleistocene core from the Labrador Sea, *Can. J. Earth Sci., 31*, 104–114, 1994.
Results of a high-resolution rock-magnetic study of a Late Pleistocene core from the Labrador Sea revealed that grain-size coarsening at glacial-interglacial transitions was due to increased detrital deposition related to ice retreat and the associated melt-water flux from southern Greenland. A high-coercivity layer appeared to be related to a lack of reduction diagenesis that preserved single-domain material.

Tarduno, J. A.
Temporal trends of magnetic dissolution in the pelagic realm: gauging paleoproductivity?, *Earth Planet. Sci. Lett., 123*, 39–48, 1994.
Magnetic hysteresis data from the western equatorial Pacific suggested that the preservation of magnetic remanence in pelagic carbonates was controlled by paleoproductivity. Hysteresis excursions were linked to greater magnetic dissolution associated with increased glacial organic carbon supply. Changes in the redox boundary were coupled to glacial terminations and resulted in anomalous magnetic features.

Data Manipulation

Tauxe, L., and G. S. Watson
The fold test: an eigen analysis approach, *Earth Planet. Sci. Lett., 122*, 331–341, 1994.
In an illustration of a new fold test, beds underwent rotation about both a vertical and a horizontal axis—a situation likely to occur in nature. When rotated back to horizontal around what would be the observed strike, the data exhibited a peak in concentration at about 60% unfolding, similar to published data sets. Thus, the origin of remanence in many cases may not have been syn-folding, but merely an artifact of structural complications.

Crustal Magnetization/VRM

Bina, M.-M., and M. Prévot
Thermally activated magnetic viscosity in natural multidomain titanomagnetite, *Geophys. J. Int., 117*, 495–510, 1994.
Experimental magnetic viscosity and hysteresis data from submarine basalts were found to be compatible with the theory of thermal fluctuations, assuming that Bloch-wall pinning is due to several kinds of energy barriers. This indicated that the proportionality between magnetic viscosity and irreversible susceptibility required particular distributions of energy barriers, and that it could not be considered as a general characteristic of thermally activated magnetic viscosity.

Kelso, P. R., and S. K. Banerjee
Elevated temperature viscous remanent magnetization of natural and synthetic multidomain magnetite, *Earth Planet. Sci. Lett., 122*, 43–56, 1994.
Natural granulites had a nearly linear increase in VRM acquisition rate with temperature, whereas artificial glass-ceramic magnetites displayed variable rates. Elevated temperature VRM acquisition by deep crustal granulites, if extrapolated over the Brunhés chron, would produce a magnetization of several A m^{-1}, which is of the order required by models for the source of long-wavelength magnetic anomalies.

Prévot, M., and M.-M. Bina
Origin of magnetic viscosity and estimate of long-term induced magnetization in coarse-grained submarine basalts, *Geophys. Res. Lett.*, *20*, 2483–2486, 1993.
The viscous induced magnetization (VIM) of submarine basalts which contain multidomain (MD) titanium-rich titanomagnetite was found to be due to thermal fluctuations, not diffusion. Experiments above room temperature showed that a linear log(t) extrapolation of laboratory measurements at room temperature yielded an underestimate of the Brunhés VIM.

Toft, P. B., *et al.*
Demagnetization by hydration in deep-crustal rocks in the Grenville province of Quebec, Canada: implications for magnetic anomalies of continental collision zones, *Geology*, *21*, 999–1002, 1993.
Hydration reactions in deep-crustal rocks from the Grenville province of the Canadian Shield offered an explanation for the weak induced magnetization of continent-continent collision zones: troctolite hydrated to gneiss over 1-2 m in the field, and the order-of-magnitude change in magnetic susceptibility between the two corresponded to decomposition of magnetic oxides in the troctolite.

Geology

Cañón-Tapia, E., G. P. L. Walker, and E. Herrero-Bervera
Magnetic fabric and flow direction in basaltic pahoehoe lava of Xitle volcano, Mexico, *J. Volcanol. Geotherm. Res.*, *in press*, 1994.
Lava flows were drilled to study the variation of anisotropy of magnetic susceptibility within their cooling boundaries. Results show that, on steeper slopes, the mean maximum susceptibility paralleled the flow direction, while on shallower slopes, the mean intermediate susceptibility followed the flow direction. However, it was proposed that the maximum susceptibility always pointed in the direction of local movement.

Sorrell, W. H.
Origin of superparamagnetism in core-mantle grains, *Mon. Not. R. Astr. Soc.*, *268*, 40–48, 1994.
During heating by cosmic ray impacts, impurity Fe atoms in H_2O ice mantles of interstellar dust grains rapidly oxidized to uniformly disperse single-domain magnetite particles. These particles behaved like an assembly of superparamagnets, greatly enhancing alignment of core-mantle grains in dense clouds. Superparamagnetism alone, however, could not explain the polarized far-infrared emission observed from cold dust in Orion clouds.

Models

Cortini, M., and C. C. Barton
Chaos in geomagnetic reversal records: a comparison between Earth's magnetic field data and model disk-dynamo data, *J. Geophys. Res.*, *in press*, 1994.
The duration-frequency distribution of geomagnetic polarity time intervals resembled those generated by random processes, although many models suggest that a field reversal could be the outcome of deterministic dynamics. The latter are parts of an extremely complex system, nonlinearly interacting among themselves over a wide range of time scales. Nevertheless, the reversal sequence could not be predicted with Nonlinear Forecasting.

Paleointensity

Tauxe, L., and N. J. Shackleton
Relative palaeointensity records from the Ontong-Java Plateau, *Geophys. J. Int.*, *117*, 769–782, 1994.
Spectral analysis of a relative paleointensity record suggested periodic behavior of the Earth's field with a dominant period of between 30 ka and 40 ka. This dominant period did not correspond to orbital changes, so "tuning" the paleointensity record to that of astronomical precession appears inconsistent with existing isotopic age constraints derived from the SPECMAP time-scale. The data suggested that the Earth's orbit has not played a detectable role in the modulation of the magnetic field.

Yang, S., J. Shaw, and T. Rolph
Archaeointensity studies of Peruvian pottery from 1200 B.C. to 1800 A.D., *J. Geomagn. Geoelectr.*, *45*, 1193–1207, 1993.
Using the Thellier method, archaeointensities were determined from about 60 ceramic samples from Peru, with ages ranging from 1200 B.C. to 1800 A.D. Mineral magnetic properties were used to estimate magnetic mineralogy and to successfully select samples suitable for archaeointensity measurements. Finally, a secular variation curve covering the past 3000 years was obtained for Peru.

Paleomagnetism

Herrero-Bervera, E., *et al.*
Age and correlation of a paleomagnetic episode in the western U.S. by $^{40}Ar/^{39}Ar$ dating and tephrochronology: the Jamaica, Blake, or a new polarity episode?, *J. Geophys. Res.*, *in press*, 1994.
Characteristics of paleomagnetic records which were carefully dated and correlated indicated virtually identical paleofield variation, particularly with regard to the geometry of a Normal-to-Normal geomagnetic polarity episode. This paleofield behavior resembled the Blake episode, but appeared to be 10,000 to 70,000 years too old. If the episode were in fact not the Blake, then paleomagnetic polarity episodes of different ages might have had similar transition paths, which implies that a common mechanism was involved.

Van der Voo, R.
True polar wander during the middle Paleozoic?, *Earth Planet. Sci. Lett.*, *122*, 239–243, 1994.
The apparent polar wander paths in the Late Ordovician-Late Devonian interval for Laurentia, Baltica, and Gondwana were nearly identical and could be superpositioned without causing continental overlaps. Thus, in spite of the lack of information about the oceanic elements, true polar wander might have occurred with a cumulative magnitude of about 75° during a 75-Ma interval.

Paleosecular Variation

Lund, S. P., and L. Keigwin
Measurement of the degree of smoothing in sediment paleomagnetic secular variation records: an example from Late Quaternary deep-sea sediments of the Bermuda Rise, western North Atlantic Ocean, *Earth Planet. Sci. Lett.*, *122*, 317–330, 1994.
Smoothing of paleosecular variation (PSV) records by a depositional/post-depositional remanence (DRM/pDRM) acquisition process was investigated by comparing PSV records from both North America and Great Britain with muted records from Bermuda Rise cores. Results suggested that DRM/pDRM reduced the Bermuda Rise signal by 50%, a result which was reproduced by a mathematical model which ran the PSV signal through a low-pass filter.

Physics

Castro, J., J. Rivas, and H. J. Blythe
On the annealing of magnetic relaxations in magnetite at high temperatures I: a new look at the room-temperature relaxation, *J. Magn. Magn. Mater.*, *131*, 311–320, 1994.
Analysis of the annealing behavior of the magnetic after-effect in vacancy-doped magnetite ($Fe_{3-d}O_4$) revealed that at least two relaxation processes occurred which were attributable to the presence of unstable single vacancies and their complexes. In the final annealing steps, only octahedrally coordinated single vacancies were left, and these migrated with activation parameters. The main annealing process was thus the movement of vacancies to grain boundaries.

Vincent, E., *et al.*
Low temperature dynamics of small γ-Fe_2O_3 particles, *J. Phys. I*, *4*, 273–282, 1994.
In a study of the response of a system of small (~4-nm) ferrimagnetic particles at low temperature (< 12 K) to a field reversal, the reversal of the particle magnetic moments through the anisotropy barriers was shown to be governed by thermally activated dynamics down to 0.6 K, with no evidence for quantum effects.

Wanamaker, B. J., and B. M. Moskowitz
Effect of nonstoichiometry on the magnetic and electrical properties of synthetic single crystal $Fe_{2.4}Ti_{0.6}O_4$, *Geophys. Res. Lett.*, *21*, 983–986, 1994.
Various magnetic and electrical parameters were measured on a synthetic single crystal of titanomagnetite, both as grown and after it was annealed at different oxygen fugacities. The data indicated that long-range ordering was a function of nonstoichiometry, with higher cation vacancy concentrations producing a more random cation distribution. This effect may explain the differences among cation distribution models for titanomagnetite.

Reversals

Vizan, H., *et al.*
Late Palaeozoic-Mesozoic geomagnetic reversal paths and core-mantle boundary, *Geophys. J. Int.*, *117*, 819–826, 1994.
An analysis of transitional virtual geomagnetic poles (VGPs) from the Late Paleozoic-Mesozoic showed them to be located in preferred areas which coincided with present-day zones of fast seismic velocity at the core-mantle boundary (CMB), as observed for Late Cenozoic transitional VGP paths. The similar geometries of the polarity transitions might therefore have been impressed by sources of the CMB which have persisted through the Mesozoic to the present.

Rock Magnetism

Dunlop, D. J., A. J. Newell, and R. J. Enkin
Transdomain thermoremanent magnetization, *J. Geophys. Res., in press*, 1994.
Transdomain thermoremanent magnetization, produced when thermally activated transitions between different domain structures become blocked during cooling, was investigated. Results from running a one-dimensional micromagnetic model suggested that only the lowest energy state at blocking was significantly populated. This was a consequence of the Boltzmann statistics of equilibrium states and was unaffected by the details of transitions between states.

Hendriksen, P. V., *et al.*
Ultrafine maghemite particles I. Studies of induced magnetic texture, *J. Phys. Condens. Matt.*, *6*, 3081–3090, 1994.
A sample with an oriented magnetic texture was prepared by freezing a ferrofluid containing maghemite particles in a magnetic field. The degree of alignment of the easy directions was examined for varying strengths of the freezing field, and the results were successfully compared with the predictions of a simple model which assumed that the intrinsic magnetic anisotropy in the particles was uniaxial and that the particles were non-interacting.

Hendriksen, P. V., *et al.*
Ultrafine maghemite particles II. The spin-canting effect revisited, *J. Phys. Condens. Matt.*, *6*, 3091–3100, 1994.
Incomplete alignment of the spins in ultrafine maghemite particles subjected to large applied fields was shown to stem from a canting of individual spins, not from incomplete alignment of the net particle magnetization due to large magnetic anisotropy.

Ye, J., A. J. Newell, and R. T. Merrill
A re-evaluation of magnetocrystalline anisotropy and magnetostriction constants, *Geophys. Res. Lett.*, *21*, 25–28, 1994.
If the effect of magnetostriction is taken into account in magnetocrystalline anisotropy theory, the “zero strain” anisotropy constant K_1 must be replaced by a “zero stress” anisotropy constant K_1', which differs from K_1 by a term involving magnetostriction constants and elastic constants. Because K_1' also appears in the dynamic behavior of ferromagnets driven by an applied field, ferromagnetic resonance experiments should give a direct measurement of K_1. ■

…*Kappabridge* continued from page 1

For more information on the thermal capabilities of the instrument, see F. Hrouda, “A technique for the measurement of thermal changes of magnetic susceptibility of weakly magnetic rocks by the CS-2 apparatus and KLY-2 Kappabridge,” *Geophys. J. Int., in press*, 1994.

Nitty Gritty

A sample for AMS measurements can be in any of the standard shapes (minicores, cubes, or boxes of roughly 10 cm^3). The sample is manually lowered into the sensor in each of the 15 directions. Internal data-manipulating software can be used to correct for the empty sample holder, re-measure bad points [it’s easy to get lost during 15 sets of 3-D specimen gymnastics!], and determine AMS parameters relative to the sample, the sample site, or the bedding at the sample site.

Samples for Curie-temperature measurements consist of small rock chips, soil, or powder. A typical 100-mg specimen is simply placed in a small test tube [see cover photo]. The temperature sensor goes in the tube next, and the whole thing fits into a bracket which automatically moves in and out of the bridge coil to measure the susceptibility. Internal data-manipulating software can then be used to correct for the empty furnace. (In one such case, we successfully extracted a good Curie temperature from a signal that was less than one-tenth that of the empty diamagnetic furnace.)

Total preparation time for either technique is about five minutes per sample. Once the sample is ready, an AMS determination takes about 10 minutes, and a temperature sweep about 90. Data files are in standard ASCII format, and can be made compatible with any IBM or Mac program for further data-massaging or plotting.

Pluses and Minuses

The Kappabridge is an impressive device, and can, with minimum effort, provide detailed AMS data or susceptibility information at high temperature; its drawback is the uncontrolled redox conditions in the furnace during a run. For example, pure magnetic minerals oxidize, while complicated samples reduce or oxidize or both, depending on their chemistry. But Jim Marvin has plans afoot to make a simple modification to provide a controlled atmosphere—perhaps a test-tube cork with a couple of hoses running to an argon tank. We’ll keep you posted. ■

…*VF Reports* continued from page 2

tion relative to dike injection. Despite the fact that we observed no difference in magnetization directions, we did find unusual magnetic properties: although demagnetization was nearly complete either by 450°C or by 100 mT, IRM acquisition began to saturate only at 1.0 T. Bulk hysteresis data I obtained at the *IRM* show coercivities between about 100 and 3200 mT, and M_{rs}/M_s ratios between 0.35 and 0.55. All of the hysteresis curves are "wasp-waisted," some dramatically. We conclude, then, that the characteristic magnetization in these rocks is likely carried by a low-coercivity fraction of the magnetic mineralogy, possibly titanomaghemite.

We have also studied the thermal demagnetization of "juvenile" fragments in pyroclastic volcanic deposits in order to define the emplacement temperature. Although some juvenile fragments responded well to thermal demagnetization, many yielded uninterpretable results. We guessed that these materials were dominated by SP grains. Measurements made at the *IRM* are consistent with this hypothesis: MicroMag data show no hysteresis, and LakeShore data show a decrease in susceptibility with frequency.

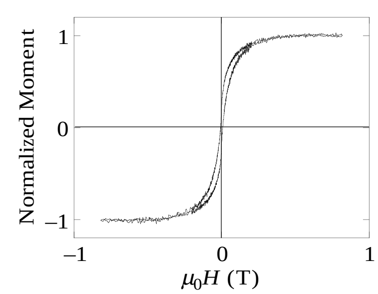
Weixin Xu
University of Michigan

Rock-Magnetic Studies of Oceanic Pillow Basalts, Remagnetized Carbonates, and Gabbros

The main objective of my visit to the *IRM* was to quantify the saturation magnetization of natural titanomaghemite in oceanic pillow basalts. Prior to the visit, we made SEM and TEM observations on a suite of pillow basalt samples dredged from the Atlantic Ocean. Electron diffraction patterns indicated that the major magnetic mineral in the oldest sample was titanomaghemite with a primitive cubic superlattice.

At the *IRM*, I measured Curie temperatures, hysteresis properties, and low-temperature saturation magnetization for the basalt samples. Curie temperature measurements confirmed the progressive maghemitization with increasing age. Hysteresis results indicated an increase in coercivities (H_{cr}, H_c) at a low degree of maghemitization, and a decrease in coercivities at a high degree of maghemitization. These results are similar to those of earlier studies. Such behavior can be explained by crystal structural data: in the early stages of maghemitization, vacancies are randomly distributed, resulting in high stress; in later stages, vacancies become ordered, thus decreasing the stress.

I also measured some carbonate and gabbro samples during my visit. Hysteresis measurements of remagnetized carbonates indicate that some remagnetized carbonates have wasp-wasted (or constricted) hysteresis loops [see figure], and some have normal loops. Hysteresis measurements of gabbro show that the needle-shaped magnetite found in its plagioclase has a very high coercivity (H_{cr} ~100 mT), and is likely to be the carrier of the primary natural remanent magnetization in gabbro.



Remagnetized Carbonate

David Dunlop
Özden Özdemir
Song Xu
University of Toronto–Erindale

Studies of Remanences in Magnetite and Goethite

David's main project was to test the thermal and AF demagnetization behavior of viscous remanent magnetization (VRM) in multidomain (MD) magnetites. Although there was little dependence on initial state in stepwise thermal demagnetization, a long demagnetization tail extended far above the VRM temperature of 350°C, essentially to T_c. This concurs with predictions from the just-published theory of multidomain partial TRM [Ed.: See abstracts by Dunlop and Xu, 1994, and Xu and Dunlop, 1994, in the last issue], and differs strikingly from the behavior of VRM in single-domain grains.

In other projects, David also thermally demagnetized orthogonal pTRMs in MD magnetites. The unblocking temperature spectra overlapped considerably, and neither component was totally erased until close to T_c. This paleomagnetically undesirable characteristic is in striking contrast to Thellier's law for single-domain grains, in which the pTRMs behave independently, and each demagnetizes over its original blocking-temperature interval.

On the Kappabridge, the samples had the expected Hopkinson peaks just below 580°C, as well as some spurious lower-temperature peaks due to oxidation. The MPMS was used to measure both unannealed and annealed versions of the samples. During heating of a SIRM produced at 10 K, the Verwey transition was clearly seen, but the amount of remanence change, the memory, and the width of the transition varied in a regular way with grain size and state of stress (as determined by annealing). It is hoped that these data can be used as the basis of a method for calibrating both grain size and stress state in magnetite.

Özden's main experiments, which used a small water-cooled furnace and Helmholtz coils located inside a 6-layer mu-metal shield, showed that readily measurable and repeatable TRMs could be induced in goethite single crystals. TRMs were induced parallel and perpendicular to the crystallographic c-axis [001] (which is also the antiferromagnetic spin axis). The relatively strong TRM was extremely stable: it could not be significantly demagnetized by the 100-mT maximum AF field. Thermal demagnetization showed a sharp decrease in the 90°C–120°C range, and the remanence disappeared at the Néel point, 120°C.

Özden's other experiments were AF demagnetization of CRM and TRM in synthetic and natural magnetites ranging from submicron to PSD size, both before and after low-temperature demagnetization. The AF coercivity spectra became progressively harder as the magnetites partially oxidized to maghemite, indicating that the memory of initial remanence in a cycle across the Verwey transition is governed by internal stress at the magnetite-maghemite interface.

Song's first experiments were AF demagnetizations of partial TRMs in MD magnetites using the SRM, AF demagnetizer, and Özden's furnace. The purpose was again to test existing theories, and to see if there were any indications of transdomain processes during pTRM acquisition. From plots of the data, all the pTRM AF-demagnetization curves largely followed what the existing theory

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What's with these Wasp-Waisted Loops?

Last spring, Sue Beske-Diehl of Michigan Technological University directed traffic on the information superhighway to coordinate an e-mail discussion about the origin of wasp-waisted hysteresis loops. [Ed.: She reports that Phil Schmidt quotes Dave Clark as saying that "wasp-waisted loop" is not politically correct; hence we must use the term "constricted loop." She then admits to having been unaware that wasps were sensitive about their waists!] Twelve people sent in contributions which Sue organized and summarized to include: 1) a description of constricted hysteresis loops, 2) reasons for constricted hysteresis loops, 3) rock types that have constricted hysteresis loops, and 4) current research on constricted hysteresis loops. A copy of the summary can be obtained through Sue at Department of Geological Engineering, Geology, and Geophysics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931-1295, or via e-mail: sbeske-d@mtu.edu. ■

Calibration Continuation

Since the last issue, in which the results of an inter-laboratory calibration exercise were reported, Ian Snowball, the trial coordinator, received several requests for the trial sample from many countries, including Japan, Mexico, and Canada. Thus, it appears that there is indeed impetus to standardize, and not just for χ and SIRM. Ian says he has some lake mud which contains SD

Calibration continued on page 8…

Meetings Update

Santa Fe 2

Santa Fe, June 1994

Subir Banerjee
IRM

In 1992, a very successful *IRM*/NSF-sponsored conference on the "Effects of Chemical Change on Magnetization" took place in Santa Fe at St. John's College. By popular demand, there was a reprise this year on June 23–26, when more than 50 graduate students, post-docs, and faculty members converged to discuss "Remagnetization and Environmental Magnetism." Some called it an "anti-AGU" meeting: there were no parallel sessions, there were no time limits on questions, and the morning and evening jogs and walks at 7000-foot elevations kept the debates cool and manageable.

The Remagnetization sessions dealt with secondary magnetizations in hard rocks and sediments which yield: 1) paleomagnetic paleogeography (for testing geodynamic models of, say, Paleozoic mantle convection); and 2) high-resolution dipolar reversal tracks and relative paleointensity time series. The Environmental Magnetism discussions provided ways to recognize the useful magnetic parameters that provide accurate proxies to global climate change records, both on the continent (loess profiles) and in the oceans (sediment records).

If there is something unique about these Santa Fe conferences, it is the intense yet respectful dialogues that take place between those who unscramble the paleomagnetic records from "real" rocks and the aficionados of theoretical and experimental rock magnetism who are fond of studying "synthetic" rocks and minerals with supercomputers, SQUID magnetometers, and atomic/magnetic force microscopes.

A full report of the conference will appear soon in *Eos*, and a more detailed booklet is in the offing.

AMQUA

Minneapolis, June 1994

Linda Shane
Limnological Research Center, University of Minnesota

The 13th biennial meeting of the American Quaternary Association (AMQUA) was hosted by several University of Minnesota departments in Minneapolis on June 19–22. AMQUA is a highly interdisciplinary organization of scientists who research all aspects of the Quaternary including geology, climatology, oceanography, ecology, anthropology, archaeology, sedimentology, and geochemistry. Approximately 370 registrants heard 23 talks and saw 140 posters focused on various aspects of the theme "Data and Models in Quaternary Research." In addition, there were 12 field trips and workshops presented before and after the meeting, including a short course by the *IRM* on methodologies in environmental magnetism.

There were many highlights. On a global and time-extensive scale: William Ruddiman (University of Virginia) spoke about the possible role of the Cenozoic uplift of the Rockies and the Tibetan Plateau in triggering glaciations. On a landscape and decadal-to-100-year scale: James Clark (Duke University) spoke about the modeling of disturbance history, and Dorothy Peteet (NASA/GISS) spoke about abrupt short-term climate fluctuations during the last deglaciation.

An exhaustive volume of abstracts was published, and some of the posters and papers presented will be published in *Journal of Paleolimnology*.

MMM-Intermag

Albuquerque, June 1994

Sherry Foss
IRM/Magnetic Microscopy Center, University of Minnesota

The Sixth Joint Magnetism and Magnetic Materials (MMM)-Intermag Conference, sponsored by the American Institute of Physics and the Magnetics Society of the IEEE, was held in Albuquerque on June 20–23. Hundreds of talks and posters were presented on fundamental and applied magnetism (with emphasis on the latter); magnetic media, and recording and head technology of various sorts were well represented. Along with traditional thin films, considerable attention was given to magneto-optic, particulate, and the newly emerging magnetic multilayer technologies. Indicative of its general importance, the basic properties and application issues of magnetic multilayer media were the subjects of tutorials designed for scientists and engineers who are not working in this area, but who are interested in developing a solid foundation in its technology. Investigations of interactions in systems of fine particles and spin glasses were plentiful, stimulated by ongoing progress in producing model systems of study and by growing concern for macroscopic quantum tunneling (MQT). As at the previous MMM conference, magnetic microscopy and imaging techniques attracted a large audience. A report of the conference proceedings will be divided between the *Journal of Applied Physics* and the *IEEE Transactions on Magnetics*. ■

New *IRM* Faces

Four newcomers have added greatly to the workings of the *IRM* recently. After serving as our able field guide (and knowledgeable tour director!) in the Chinese loess plateau last September, Jiamao Han from the Institute of Geology at the Chinese Academy of Sciences in Beijing spent four months in Minneapolis this spring and summer continuing his work on the magnetic characteristics of loess/paleosol sequences. He spent many hours at the new equipment, sharing with us his low-key charm. Following in his scientific footsteps is Rick Oches, our new post-doc who arrived this August from the University of Massachusetts to study loess from all over the world. Thanks to our renewed funding from the NSF and the Keck Foundation, we will welcome two more post-docs this fall. Physicist Taras Pokhil will come from the Russian Academy of Sciences in Moscow with MOKEs and MFMs on his mind. And a yet-to-be-appointed geologist will also arrive soon to study diagenesis in all of its manifestations. We're happy to have the wealth of fresh insights that these scientists bring. ▪

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predicts. However, there was a notable tail in almost every curve that extended to some high AF, which cannot be explained by the theory based on wall motion, but which may be attributable to transdomain processes. A combination of thermal and then AF demagnetization significantly reduced both low- and high-coercivity components. If the high-coercivity components are associated with transdomain processes, this result then shows that a remanence resulting from a transdomain process may not be as magnetically hard as expected.

For his second experiment, Song measured hysteresis loops at different temperatures on the VSM in order to obtain bulk coercivity H_c as a function of temperature in MD magnetites. Often, $H_c(T)$ is expressed as the saturation magnetization $M_s(T)$ to some power n, where n is believed to carry information about the type of defect-wall interaction and the type of anisotropy that controls the wall width in a given sample. Results show a variation of n with grain size which may reflect the fact that, with increasing grain size, the anisotropy that controls the wall width shifts from magnetostatic and/or magnetoelastic energies to the magnetocrystalline anisotropy energy. ▪

...Calibration continued from page 7

magnetite of bacterial origin with a narrow grain-size distribution [bacteria can probably exert better control over magnetite purity and grain size than humans!]. Standard measurements could include hysteresis parameters (saturation magnetization, saturation remanence, coercivity, and coercivity of remanence) as well as ARM and IRM acquisition and demagnetization curves. Look for Part 2 of the calibration exercise in an upcoming issue. ▪

The *Institute for Rock Magnetism* is dedicated to providing state-of-the-art facilities and technical expertise free of charge to any interested researcher who applies and is accepted as a Visiting Fellow. Short proposals are accepted semi-annually in spring and fall for work to be done in a 1–3-week period during the following half year. Shorter, less formal visits are arranged on an individual basis through the laboratory manager.

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

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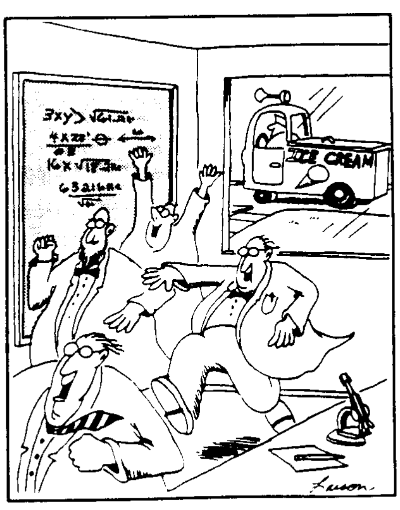
I R M
Institute for Rock Magnetism

The New Visiting Fellows

Funny how we receive fewer applications for trips to Minnesota during the winter....

But we did have several! For the period September 1994–February 1995, the Fellows, with their affiliations and research interests, are listed below in alphabetical order. [And and usual, watch for their reports in upcoming issues.]



A typical summer day at the IRM.

N.B. The proposal deadline for visits during March–August 1995 will be shortly after the AGU meeting in December. Look for announcements in the Fall issue, as well as in *Eos* and *GSA Today*.

Students

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

Maria Cioppa
Lehigh University
the effects of strain on hematite grain size

Richard Harrison
University of Cambridge
rock magnetism and minerology in the magnetite-spinel system

Harry Rowe
University of New Mexico
relative paleointensity from lake sediments

Post-PhD

Toshitsugu Yamazaki
California Institute of Technology
paleoclimate from pelagic clay ▪