**The IRM Quarterly**

**Paths through the exchange jungle**

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**Introduction**

A common experience of rock-magnetic pioneers, who first started to measure low-temperature magnetic properties of natural samples, was that everything turned out to be different from what they expected. This happened to an extent which actually led to today’s attitude to expect only the unexpected at low temperature. Of course, the origin of this troubling situation has been recognized by now. Natural samples happen to be wild mixtures, especially of iron-minerals. And of these, even the well known ones, like magnetite, come in a rich variety of different blends leading to a wide scale of exchange-coupling strengths. This is of little interest at higher temperatures, where only the strongest magnets survive, but when temperature falls, all the previously well hidden beasts creep out of the cold, start to order, and show their ugly faces in our measurements. So if you put a rock in the MPMS and, after downloading the data the next day, wonder whether Mike has been playing a joke on you: Welcome to the exchange jungle!

Our previous work on natural hematite-ilmenite bearing rocks has led into the centre of this dark and dangerous territory (Fig. 1). There we have seen many mysterious effects that we couldn’t understand, and which were equally likely to be either regular properties of the underlying hematite-ilmenite solid solution, or wild occurrences of some unidentified admixtures. Bold, as real scientists are meant to be, we set out to the IRM to explore this unwieldy thicket, armed with some old maps (by Ishikawa et al. 1985), some new ideas (e.g. Robinson et al., 2004; Harrison, 2006), and a beautiful set of synthesized crystals from Ben Burton to complement our natural samples. All sample compositions were carefully estimated by XRD measurements, performed by T. Boffa Ballaran (Burton et al., in press).

We tried our best to exhaust (in every sense) the IRM helium reserves in the weeks we were working down between 5 and 60 K to probe the holes and clusters of the exchange networks shown in Fig. 2. A central idea of our measurements was to probe and extend the phase diagram of Ishikawa et al. (1985) in the light of magnetic influences of these random exchange forests, which originate either by replacing random pairs of Fe$^{2+}$ and Ti$^{4+}$ ions in the ordered ilmenite lattice by two Fe$^{3+}$ ions (ordered Ilm$X$ phase), or by randomly replacing two Fe$^{3+}$ ions in the hematite lattice by a pair of Fe$^{2+}$ and Ti$^{4+}$ ions (disordered Ilm$X$ phase).

**Curie temperatures**

A first topic was to investigate high- and low-temperature $M_s(T)$ curves of our synthetic samples in comparison to a volume-corrected version of the original Ishikawa and Akimoto (1957) phase diagram giving Curie temperature as a function of composition. The result in Fig. 3 indicates that some of our samples with low ilmenite content also contain small amounts of magnetite. Otherwise, the results coincide nicely with Ishikawa’s data and even indicate an interesting preference of the higher $T_C$ of the two Ishikawa and Akimoto (1957) data sets.

(cont’d. on p. 12...)
Visiting Fellows’ Reports

Mapping pedogenic grain size of the Chinese red-clay sediments using ac magnetic susceptibility and thermal fluctuation tomography

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During October 1-10, 2008, I came to IRM to perform detailed rock magnetic studies for some of the red-clay sediments from the Chinese Loess Plateau (CLP). The red-clay sequence on the central CLP has an age range of ~2.6–8 Ma. Thus the red-clay sequence arguably is one of few continuous terrestrial archives for studying forcing mechanisms of the Pliocene climate. Understanding forcing mechanisms of the Pliocene climate change is important because climate modelers have estimated ~2–4 ºC warming by the end of this century in response to increasing CO₂ inputs to the atmosphere [1]. The estimated future temperature is similar to that in the early Pliocene (~3–5 Ma) [2].

However, compared with the overlying loess-paleosol sequence, the enhancement mechanisms of magnetic susceptibility, the most widely used East Asian summer monsoon intensity proxy [3], have been rarely explored. I used my Visiting Fellowship to map pedogenic grain size of some red-clay and loess/paleosol samples using ac magnetic susceptibility [4, 5] and thermal fluctuation tomography [6]. The pedogenic strongly-magnetic grains are mainly maghemite because fine-grained magnetite has a high surface-to-volume ratio and thus is easily oxidized to maghemite. Results (Fig. 1) from both methods show that the pedogenic grain size of the red-clay and the loess/paleosol samples are almost indistinguishable, confirming my previous work [7]. These results thus suggest that red-clay magnetic susceptibility can be used to estimate paleo-rainfall intensity, as is the case in the overlying loess-paleosol sequence [8].

I also measured high-temperature magnetic susceptibility, Mössbauer spectra, high-temperature hysteresis loops for selected samples (including extracts and residues) during my stay at IRM.

I thank the entire IRM family, especially Thelma, Mike, Amy, Subir, and Peter, for the scientific expertise provided, the stimulating discussions (most are instructions), and the hospitality. I thank my advisor John King for encouraging and supporting me to go to IRM.

References

Magnetic characterization of synthetic Martian basalt

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The strong intensity of the Martian magnetic anomalies mapped by the Mars Global Surveyor (MGS) has led to considerable interest in the magnetization of the Martian crust. A growing body of work seeks to explain the patterns of magnetization, as well as a magnetic mineral assemblage capable of producing a magnetization inferred to be several orders of magnitude stronger than typical terrestrial basalt. Titanomagnetite, chromite, and pyrrhotite have all been observed as remanence carriers in the Martian Shergotty-Nakhla-Chassigny (SNC) meteorites. While most rock magnetic studies have focused on the magnetic mineralogy of the geologically youthful SNC meteorites, the magnetic anomalies are largely limited to the more ancient southern highlands (e.g. Connerney et al., 1999); most meteorites may therefore be atypical of the magnetized crust. In contrast, this study takes an experimental approach, synthesizing basalts of expected Martian composition.

This study builds upon work by Brachfeld and Hammer (2006) and Hammer (2006). We systematically evaluate the effects of major element composition, oxygen fugacity (fO2), and cooling rate on phase chemistry and magnetic mineralogy, grain size, and intensity of remanent magnetization. Two basic starting compositions are used for the sample synthesis. The first is Fe-rich, Al-poor and is patterned after SNC basaltic meteorites (Johnson et al., 1991). It is similar in composition to that used in Brachfeld and Hammer (2006), but includes small amounts of Mn and Cr in light of the possibility that chromite (Weiss et al., 2002) or Fe-Cr-Ti spinels (Yu and Gee, 2005) may play a role in the stable magnetization of the Martian crust.

The second composition has a much lower Fe/Al ratio and is based on satellite thermal emission spectrometer observations of the southern highlands that suggest a more terrestrial-like composition (Hamilton et al., 2001). fO2 is varied between the iron-wüstite (IW) and quartz-fayalite-magnetite (QFM) buffers. Samples are cooled from liquidus temperatures at constant cooling rates ranging from 231°C hr⁻¹ to 5.7°C hr⁻¹. An exponentially varying cooling rate was also applied to simulate the natural cooling path of a conductively-cooling lava flow.

Work at the IRM was designed to evaluate magnetic grain size and composition with the particular goal of characterizing the smallest grains in more reduced samples for which microprobe data cannot be obtained. Curie temperature (Tc) estimates were carried out on the high-temperature vibrating sample magnetometer (VSM); magnetic hysteresis was measured as a function of temperature from 10 to 300K on the low-temperature VSM; field-cooled (FC) and zero-field-cooled (ZFC) isothermal remanent magnetization (IRM) was measured on warming from 10K to 300K on the Quantum Designs MPMS; and frequency-dependence of susceptibility was measured on warming from 20K on the Lakeshore MPMS. These experiments were complemented by remanence experiments carried out at the University of Hawai‘i Paleomagnetic Laboratory.

Oxide grain size and abundance is predominantly controlled by oxygen fugacity, with secondary effects of cooling rate and composition. Room temperature hysteresis data (Fig. 1) illustrate that samples at high fO2, slow cooling rate, and high Fe-content typically have a larger average magnetic grain size. Likewise, the addition of Cr results in a considerable increase in grain size, most likely because the highly-compatible Cr stabilizes the oxides at a higher temperature in the crystallization sequence.

Electron microprobe analyses of the largest oxide grains (QFM samples) show most samples are characterized by titanomagnetics with significant Mg-, Al-, and (often) Cr-substitution. Terrestrial-type samples show relatively more Cr and Al enrichment, consistent with their bulk composition (lower Fe/Al ratio). Tc estimates and thermal demagnetization of a thermal remanence are consistent with the microprobe analyses. Under more reduced conditions, meteorite-type samples show depressed blocking temperatures consistent with more impurity-substitution and/or with a finer grain size. By contrast, terrestrial samples show elevated blocking temperatures under reducing conditions, consistent with oxides closer to pure magnetite. The FC-ZFC IRM data for all QFM meteorite-type samples (e.g. Fig. 2a) are characterized by a large decrease in magnetization at ~50-60K, and the magnitude of the
drop increases with decreasing cooling rate. The temperature of this transition ($T_{crit}$) is similar to that observed in Brachfeld and Hammer (2006), where it was interpreted as a magnetic isotropic point in titanomagnetite. By contrast, several of the IW samples (e.g. Fig. 2b) display a continuous decrease in intensity from 10 to ~60K, followed by a second rapid decrease to zero at ~140K, possibly an ordering temperature for a high-Cr phase.

While $fO_2$ and bulk composition appear to exert the primary controls on oxide composition, there again appears to be a more subtle effect related to cooling rate. Meteorite-type samples generated at QFM show evidence for elevated $T_c$ under slower cooling conditions, which is again consistent with less impurity substitution. This is supported by low-temperature measurements of the frequency-dependence of susceptibility (Fig. 3). These samples display a frequency-dependence between ~$T_{crit}$ and ~120-140K, over which interval susceptibility increases sharply on warming. The high-$T_c$ (~470°C) samples display a relatively large increase in susceptibility at or above $T_{crit}$ while the lower-$T_c$ (~330-340°C) samples show a smaller increase at $T_{crit}$; these patterns are similar to variations with composition observed in titanomagnetite (Moskowitz et al., 1998; Carter-Stiglitz et al., 2006).

When combined with the remanence measurements, data collected at the IRM allow us to characterize potential candidates for the source of the magnetic anomalies, as well as to place constraints on conditions likely to produce an intense and stable remanence in rapidly cooled materials of potential Martian composition.

Huge thanks to everyone at the IRM for all their help during my visit.

References

Connerney, J.E.P., M.H. Acuña, P.J. Wasilewski, N.F. Ness, H. Rème, C. Mazelle, D. Vignes, R.P. Lin, and

Effects of reheating on magnetic properties of ilmenite-hematite from the Ecstall pluton
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The Ecstall pluton, near Prince Rupert, British Columbia may hold one of the keys to understanding discordant paleomagnetic directions from the Western-most terranes of North America. The purpose of my visit to the IRM was to study the magnetic properties of ilmenite-hematite from the Ecstall pluton, and how these properties were affected by subsequent reheating from an adjacent pluton. The effects on ilmenite-hematite textures and mineralogy may provide insight into the timing of remanence acquisition in different parts of the Ecstall, which may lead to clearer tectonic interpretations. Before arriving at the IRM we had some single grain hysteresis measurements, as well as some TEM work indicating a second magnetic phase in samples within 13 km from the thermal boundary. Our goal was to identify that phase, its location within ilmenite-hematite grains, and relation to reheating using remanence vs. temperature, magnetic force microscopy (MFM), and hysteresis measurements.

Using the MPMS we measured remanence vs. temperature for single grains weighing approximately 0.02 to 0.06 mg. The grains were placed on a cut glass slide inside a gelcap for measurement in the MPMS for the typical RT SIRM cooling and warming, and FC and ZFC SIRM warming cycles. The second magnetic phase was identified as magnetite by the Verwey transition at ~110 K (figure 1). The Morin transition was absent, probably suppressed by the Ti content of the hematite. Other interesting features are high remanence below ~40 K, and a slight increase in remanence on warming near the expected Morin transition temperature in some samples. By measuring different grains from the same location, we noticed variability in the amount of magnetite, but no samples >~13 km from the thermal boundary showed evidence of magnetite.

Using the AGM we measured hysteresis loops and first order reversal curves (FORC’s) for at least one grain from every location. Each grain was measured in three orthogonal positions to get a sense of anisotropy, but as hematite has very weak cleavage it was difficult to orient grains crystallographically. We did not see distinct anisotropy. To look for exchange magnetism, a phenomenon seen before in natural ilmenite-hematite, we measured hysteresis at low temperatures. It was difficult keeping the AGM probe...
In general, hysteresis properties change in two ways as the thermal boundary is approached. Variable amounts of wasp-waistedness is seen from the addition of magnetite in samples <~13 km from the thermal boundary, and an apparent increase in coercivity of hematite in samples <~8 km from the thermal boundary (figure 2).

FORC analyses also show both changes in hysteresis properties. The magnetite appears as a separate peak at lower coercivity than the main hematite peak. The center of the hematite peak moves to higher coercivity as the thermal boundary is approached (figure 3). The hematite peak is offset from the $H_a = 0$ axis indicating interaction between different domains of hematite. The magnitude of this offset increases as the thermal boundary is approached. The shape of the hematite peak goes from sharp to broad as the thermal boundary is approached.

Hysteresis properties and remanence vs. temperature curves from single grain samples from the Ecstall pluton are affected by reheating. As the thermal boundary is approached, first there is growth of magnetite at <~13 km, and then an increase in coercivity of hematite at <~8 km. The amount of magnetite varies between grains from the same location, and this is the main cause of variability in both remanence vs. temperature curves, and hysteresis loops. These results indicate that paleomagnetic directions from reheated portions of the Ecstall may be due to growth of magnetite in ilmenite-hematite during reheating, and should therefore be compared with different APW directions than those from portions unaffected by reheating. The magnetite in these samples is not clearly observed in standard thermal or AF demagnetization of whole rock samples, nor is it visible in reflected light, or SEM. This illustrates that rock magnetic, and even single crystal, experiments are sometimes essential for paleomagnetic studies.

I would like to thank everyone at the IRM, especially Mike Jackson, Peat Solheid, and Amy Chen. I’d also like to thank Gary Scott for tirelessly helping me collect data.

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**Figure 2.** Representative hysteresis loops from a) > 13 km, b) 13-8 km, and c) < 8 km from the thermal boundary. D) Offset hysteresis loop at 20 K from > 13 km from the thermal boundary.

**Figure 3.** Single grain FORC diagrams for a) 15 km, b) 13 km, c) 8 km, and d) 4 km from the thermal boundary. Evidence of magnetite in b), and c). Coercivity increases, and peak broaden progressively from a-d.)
Current Articles

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 taken 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 subjected to Procrustean culling 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 10,000 references, is available free of charge.

Your contributions both to the list and to the Abstracts section of the IRM Quarterly are always welcome.

Articles for this issue compiled by Julie Bowles

Anisotropy


Archeology


Bio(geo)magnetism


Staniland, S., B. Ward, A. Harrison, G. van der Laan, and N.
Environmental Magnetism


Extraterrestrial Magnetism


Geomagnetism and Geodynamics


Magnetic Field Records and Paleointensity Methods


Shcherbakova, V.V., B.Z. Asanidze, V.P. Shcherbakov, and G.V. Zhidkov, Geomorphic field paleointensity in the cretaceous from Upper Cretaceous rocks of Georgia, Izvestiya-Physics of the Solid Earth, 43 (11), 951-959, 2007.


Magnetic Microscopy and Spectroscopy


Westphalen, A., M.S. Lee, A. Remhof, and H. Zabel, Invited Article: Vector and Bragg Magneto-optical Kerr effect for

**Magnetic Remanence and Remanence Acquisition Processes**


**Magnetostратigraphy and Geochronology**

Ashley, G.M., Orbital rhythms, monsoons, and playa lake response, Olduvai Basin, equatorial East Africa (ca. 1.85-1.74 Ma), Geology, 35 (12), 1091-1094, 2007.

**Mineral and Rock Magnetism**


**Mineral Physics and Chemistry**


Modeling and Analysis Software


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**2008 International Conference on Rock Magnetism**


June 2-8, 2008, Beautiful Cargèse, France

Registration deadline extended to Feb. 29

See www.irm.umn.edu/Cargese/ for details.

**IRM staff evolves**

Welcome to Julie Bowles, who moved intrepidly from Hawai‘i to Minneapolis in December to become “the new Brian” at IRM. Julie will take on a number of important duties, including working with visiting scientists, updating our web site, and editing the Quarterly.

**IRM’s Amy Chen wins best student paper at Fall AGU!**

Congratulations to Amy Chen on her award-winning contribution:

Monoclinic c-axis selection at the Verwey transition: new insights from off-axis electron holography and the delta-ratio magnetosome detection method.

**IRM Visiting Fellowship Application Deadline April 30**

The IRM is accepting proposals for work to be carried out between July and December. Fellows have access to all IRM instruments for up to 10 days and are eligible for reimbursement of travel expenses (up to $750; lodging and meals excluded).

Topics for research are open to any field of study involving fine particle magnetism, but preference will be given to projects relating magnetism to geological or environmental studies, or to fundamental physical studies that are of potential relevance to the geosciences.

See www.irm.umn.edu/visiting/fellows.htm for more information, or e-mail Mike Jackson (irm@umn.edu) for an application.
An abundant feature of natural hematite-ilmenite solid solution members is high remanence and coercivity at low temperatures due to a spin-glass (SG) phase. Although spin-glass properties are remarkable and easily detected, and therefore important for interpreting LT measurements of natural samples, they cannot be explained by micromagnetics or even molecular-field theory. One has to go all the way back to the Heisenberg exchange Hamiltonian to interpret spin-glass behavior in terms of frustrated weak exchange links, which only order at low temperatures. In spite of extensive theoretical work, a detailed understanding is still missing. This jungle has not been civilized. An interesting and unsolved problem is to delimit the SG region in the phase diagram especially for ilmenite-poor compositions. The rapid loss of low-temperature IRM close to the SG transition in Fig. 4 corresponds well to the known parts of the phase diagram, but also allows new conclusions concerning the ilmenite-poor solutions. These are also well supported by low-temperature susceptibility (Fig.5) whose out-of-phase component peaks near the SG threshold. Also hysteresis parameters change dramatically across the SG transition as indicated in Fig. 6. An interesting effect is seen in Ilm51, where freezing through the SG transition apparently fixed some remanence strongly enough to shift the 1.5 T hysteresis loop upwards. This shift is different from exchange bias (e.g. McEnroe et al., 2007) which moves the hysteresis loop in the field direction without upward or downward shift.

Amplitude dependence of magnetic susceptibility

In order to take into account all aspects of the SG behavior, we also measured viscosity of IRM, (thereby under Mike’s suspicious eyes introducing a VSM automation based on AutoIt 3.0), and amplitude dependence of susceptibility. For the latter we expected, based on SG literature, to see amplitude dependence from the SG transition downwards. We better should have expected...
Figure 4: IRM warming done at the IRM, using LT VSM and MPMS to find SG transition.

Figure 5: In-phase (blue) and out-of-phase (green) magnetic susceptibility as a function of temperature for several ilmenite-hematite solid solutions. Only the lowest measured frequency is shown.

Figure 6: Hysteresis loops through the spin-glass transition document a rapid loss of coercivity. Loop shape appears to be mainly related to composition. Ilm51 loops at low temperature are upward shifted.

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the unexpected. In Fig. 7 the amplitude-dependent susceptibility of Ilm68 sets in with a beautifully square-root-like phase transition at about 50 K, well above the SG boundary, and in the “wrong” direction. We now think it is probably related to unlocking of clusters in the holes between the ferrimagnetically ordered, percolating exchange network (Fig. 2), and may be a feature of the FM’-FM boundary region in the phase diagram.

**Hunting the Griffiths phase**

An other puzzle of the phase diagram is the transition from ferrimagnetic to antiferromagnetic behavior, occurring with increasing ilmenite content near Ilm87. It might be related to a percolation threshold where the average size of connected clusters in the exchange network (Fig. 2) drops below infinity. On the ilmenite-rich side, the remaining double-layer interaction enforces AF ordering as soon as it freezes in somewhere below 57 K (ilmenite ordering). Why does the AF order occur below 57 K for smaller X and not above? There are more interacting Fe ions if X is smaller, why don’t they increase the Néel-temperature (Tₙ)? We think that this has to do with the difference in exchange coupling between Fe²⁺ and Fe³⁺ ions. By adding Fe³⁺ to the ilmenite lattice adjacent-layer interactions are increased, but the effective double-layer interactions are probably weakened, even though Fe²⁺-Fe³⁺ and Fe³⁺-Fe³⁺ interactions are stronger than the original Fe²⁺-Fe²⁺ interaction. This is due to the fact that an Fe³⁺ ion in a Ti layer has strong AF coupling to both adjacent Fe layers, leading essentially to a strong local FM coupling of these initially AF-coupled sites in the Fe layers. This effect outweighs the increase of double-layer AF coupling resulting from replacing the same number of Fe²⁺ by Fe³⁺ ions in the ilmenite Fe layers. Apparently the resulting decrease of AF-ordering temperature goes along with increasing size and number of FM-clusters which can have correlated spins, leading to the “supparamagnetic” behavior characterizing the PM’ region of the phase diagram. A typical expression is the peak in out-of-phase susceptibility above Tₙ for Ilm90 in Fig. 5.

Deep in the jungle you watch out for mystic or mysterious beasts, imagined ones, like unicorns, or existing ones, like orangutans (Fig. 8). Ben Burton pointed out to us such a creature described in a theoretical article by Griffiths (1969). Griffiths argues that in diluted Ising ferromagnets the critical temperature of the undiluted FM is still of significance because the partition function becomes non-analytic there, even though FM ordering is suppressed or occurs at lower temperature. In vague analogy, this Griffiths phase (as the beast it is now called) may be related to exchange-cluster formation in ilmenite-rich solutions above the AF-ordering temperature, if we interpret additional Fe³⁺-ions as diluting the pure ilmenite AF phase. It would be extremely fascinating to find some clear experimental evidence which can be linked to the Griffiths phase. Therefore we often designed our measurements to continue way above the ordering temperature of the mixture to be able to detect any trace of this mystic creature. Although sometimes we thought we saw its shadow sidle through the trees, we haven’t yet a proof of the existence of the Griffiths phase in our samples.

**From paths to streets**

Figure 8: The orangutan is a once mystical creature which finally was proved to exist. The photograph was taken in Munich, Bavaria. Its fluffy fur resembles the well-known Oachkatlzschwoaf (squirrel tail).
We extensively explored a jungle at the IRM, thanks to all the instruments, the measurement time, and the excellent help provided by the staff. Yet, we only could trample a few paths towards the understanding of the complex behavior of exchange-coupled networks. Our task now is to build a street, a more systematic approach to theoretically formulate the physical properties found in terms of exchange coupling, using either mean-field theory, or where necessary, more complicated spin-glass theories like the TAP approach. Only then can we head for the final aim to correlate the strange effects found in natural samples, like huge LT exchange bias in hematite-ilmenite exsolution lamellae, with our theories in order to tame the monsters which creep out of our harmless rocks when temperature falls (Fig. 9).

Acknowledgements

We hope that the above account made it clear that our expedition would not have been possible without the support of many wise people who lived for a long time in the exchange jungle. B. Burton, T. Boffa Ballaran, and P. Robinson were central members of our home base, who prepared or characterized the samples and helped to identify new species found. Though life in the jungle was tough, we experienced wonderful hospitality from the native tribe “irm”. We first tried to barter firewater for liquid helium, but then found that the wonderful fountain “nsf” provides a free flow to all guests of the tribe. Thank You.

References


Simon (“Si”) Foner
b. 13 August 1925, Pittsburgh, PA
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Winner of the American Physical Society’s Keithley Award in 1999, Foner invented the vibrating sample magnetometer (VSM) as a staff physicist at MIT in the 1950s. In 1961 he was a founding staff member of the MIT high-field laboratory (which in 1967 was renamed the Francis Bitter National Magnet Laboratory). In 1977 Foner became chief scientist at FBNML, and he later served for two years (1988–89) as associate director of the lab. In the 1980s he began developing high-quality superconducting wire for high-field applications and was responsible for the measurement and understanding of many materials in superconductivity and magnetism. He and his colleagues at the FBNML were pioneers in pulsed high-field magnet technology; his advances underpin much of the current technology in that area. In the mid-1980s Foner built magnets that generated millisecond-length fields in the 60–70 T range.

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The IRM Quarterly is published four times a year by the staff of the IRM. If you or someone you know would like to be on our mailing list, if you have something you would like to contribute (e.g., titles plus abstracts of papers in press), or if you have any suggestions to improve the newsletter, please notify the editors:

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The IRM staff consists of Subir Banerjee, Professor/Director; Bruce Moskowitz, Professor/Associate Director; Joshua Feinberg, Assistant Professor/Associate Director; Jim Marvin, Emeritus Scientist; Mike Jackson, Peat Solheid, and Julie Bowles, Staff Scientists.

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