The IRM Quarterly

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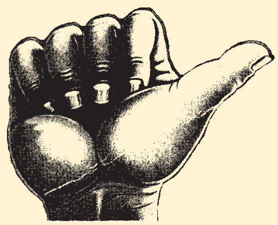
Inside...

The Updated Hitchhiker's Guide to IRM



Brian Carter-Stiglitz

Institute for Rock Magnetism, Dep't of Geology and Geophysics, University of Minnesota

Figure 1--The Weisman Gallery, a free modern art museum on campus.

What follows is a distillation of a lot of information that visitors to the lab may find helpful. Some of it relates to working in the lab, and some of it addresses the generic concerns of a traveler staying in the Twin Cities.

Places to Stay

Brekke's
805 E River Parkway
Minneapolis, MN 55414
Mr. & Mrs. Sherwood Brekke
(612) 922-0430

The Radisson
615 Washington Ave. SE
Minneapolis, MN 55414
(612) 379-8888
http://www.radisson.com/

Days Inn Minneapolis
2407 University Ave SE
Minneapolis, MN 55414
(612) 623-3999
http://www.daysinn.com/

Wales House
1115 5th St. SE
Minneapolis, MN 55414
(612) 331-3931
waleshouse@aol.com
http://www.waleshouse.com/

There are a few lodging options close to the University. The Days Inn is a fifteen-minute walk and offers rooms for about seventy dollars per night. But be sure to ask for the University discount or you'll pay ninety. The Radisson offers more upscale accommodations at around one hundred dollars a night. Wales House is a ten-bedroom house that has been used as an "inn" for the last thirteen years. It is steps from the University and offers rooms for $49/night (shared bath) to $59/night (private bath). Wales House tends to book quickly, so if you are interested in this one make your reservation in advance. For the more budget minded, Brekke's Rooming House cannot be beat. Single rooms are as low as $13/night. But expect to get what you pay for. You may be able to find some other options on the University's website: http://www.housing.umn.edu/offcampus/temp.htm.

Getting Here, Around, and Away

Most visitors fly into Minneapolis and Saint Paul International Airport. Getting to the city from the airport is easy. A train (the "light rail") connects downtown to airport. The fare is a couple of dollars. If you are going to make a bus connection, make sure to keep your ticket because it includes a bus transfer. If you ride the bus first and pay in cash, make sure to ask the driver for a light-rail transfer. You will want to look at the bus and train schedule ahead of time to see how frequent they will be running when you arrive. The schedules and a trip planner can be found at www.metrotransit.com. If you prefer, taxis are always available. A taxi is the best way to get to your hotel if you are arriving when the trains and buses are running infrequently, e.g., Sundays.

The best option for getting around once you are here will depend on where you are staying. Most visiting fellows stay within walking distance, and find that walking back and forth to the lab works with the occasional bus ride if a trip off-campus is necessary. If you rent or bring a car beware: parking at the University is a bit of a nightmare and expect a 10-15 minute walk between your car and the lab. Parking options can be explored www.umn.edu/pts. If you are situated too far to walk to the lab, commuting by bus may be the best option. (It is for all of the IRM staff, who bus or bike to work.)

guide, continued on page 4

Visiting Fellows' Reports

Magnetic Properties of the Balabanli Volcanic Units in Biga Peninsula (Turkey)

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My M.Sc. thesis is to determine the vertical and horizontal rotations in Biga Peninsula in Western Turkey. For this aim we have sampled Miocene age (Borsi et al., 1972) ignimbrites and andesites from 40 sites for paleomagnetic analysis in order to quantify rotations (Fig.1). In Istanbul University's paleomagnetism laboratory natural remanences have been measured using a Molspin fluxgate spinner magnetometer. Samples were then brought to the IRM for magnetic analysis.

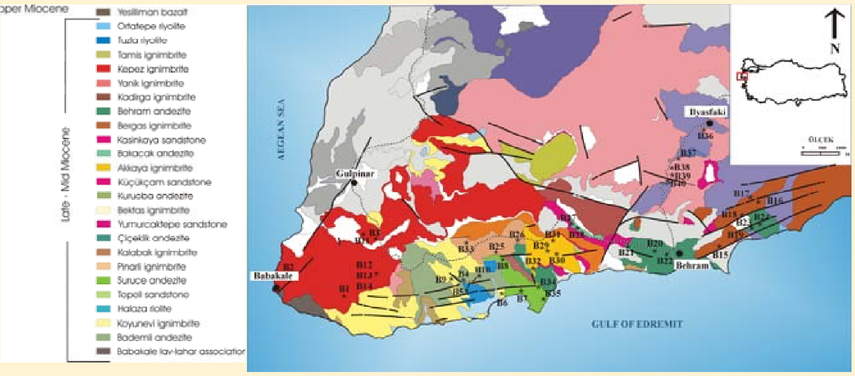

Figure 1--Geological map and the stratigraphy of the studied area (modified from Karacik, Z., 1995) and the locations of the sites.

I have divided my samples into 10 categories representing each one of the geological formations so that the magnetic analysis of those samples would tell if the samples were reliable for paleomagnetic study.

During my stay at the IRM I used a VSM to obtain hysteresis loops for 40 sites. We used a 1.25 T maximum magnetic field and measured the hysteresis parameters, Ms, Mr, Bc and Bcr. These parameters are plotted on a Day Plot (Day et al., 1977) and the results show that most of the samples are pseudo-single domain, with a couple of multi domain samples (Fig. 2).

To obtain the Curie temperatures for 12 geological formations, I used the Kappa Bridge susceptometer. The samples were heated to 700 ºC and cooled back to room temperature. Some samples contained a single dominant magnetic phase that was partially destroyed by heating above the Curie point, while others contained two phases, one of which (probably maghemite) was destroyed by heating to 300 ºC to 400 ºC.

We calculated the first derivatives of the thermomagnetic curves. The Curie temperatures range from 547 °C to 618 °C. The samples with T_C>580ºC are probably partially-oxidized or partially-maghemitized magnetites. The ones with T_C>600 ºC might be labelled as "strongly maghemitized" and those with 580 ºC <T_C<600 ºC as "partially maghemitized". Also the T_C near 547ºC could be labelled as "(titano)magnetite" (Table 1).

Table 1

Sample	Location	Curie Temperatures [ºC]
B11.2.3	Kepez ignimbrite	575.2 (magnetite)
B14.9.a	Kepez ignimbrite	576.8 (magnetite)
B15.8	Kadirga ignimbrite	613.6 (strongly maghemitized)
B17.3.k	Kadirga ignimbrite	570.9 (magnetite)
B32.7	Bektas ignimbrite	547.06 (titanomagnetite)
B32.7	Bektas ignimbrite	618.4 (strongly maghemitized)
B33.8	Kalabak ignimbrite	572.2 (magnetite)
B37.4	Yanik ignimbrite	579.45 (magnetite)
B6.12	Koyunevi ignimbrite	578.55 (magnetite)
B7.4.a	Suruce andezite	585.7(partially maghemitized)

Low temperature measurements were made on 12 samples. Room temperature saturation isothermal remanence was measured using a MPMS. In the RTSIRM cooling experiment, the broad temperature range where the remanence decreases includes both the Verwey transition and the isotropic point. Both of these are involved in loss of remanence on cooling and recovery on rewarming. There are probably a range of compositions in each sample, so there is not a single isotropic point or Verwey temperature, but a range of them from around 130 K (isotropic point for pure magnetite) down to around 60 K. As we can see from the first graphic (fig. 3), the remanence at first increased with cooling, reaching a broad peak at 212 K, and then decreased gradually with cooling to the isotropic temperature. At the isotropic temperature 75-80% of the room temperature SIRM was demagnetized for B14 (Kepez ignimbrite). Warming above 55K resulted in an increase in SIRM, followed

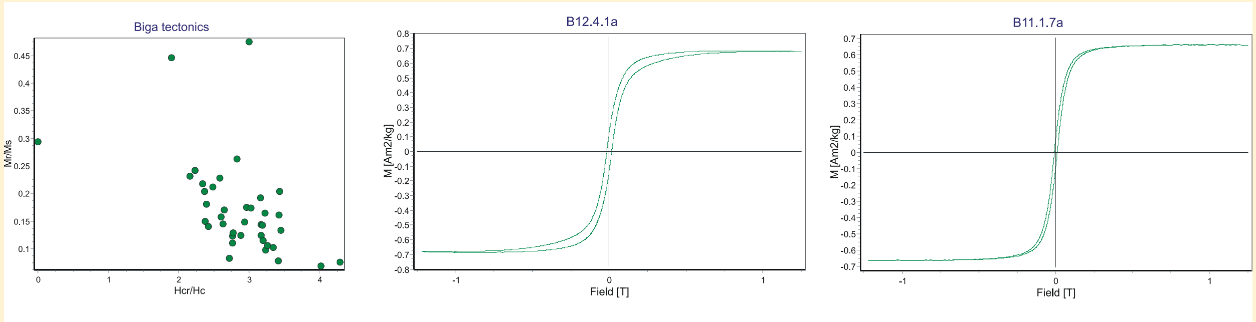

Figure 2--Two representative hysteresis loops from the Balabanlý Volcanic rocks and the Day Plot.

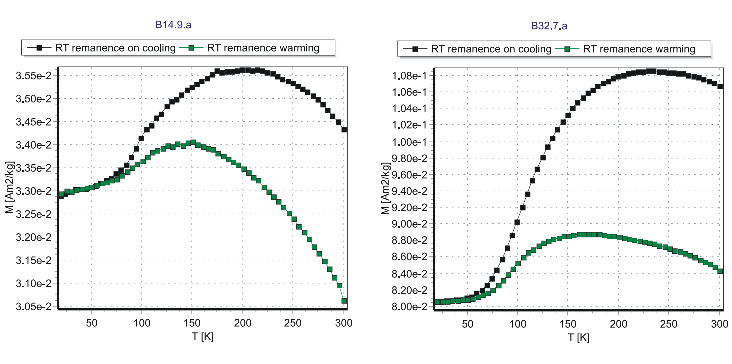

Figure 3--Two representative RTSIRM curves.

by a broad maximum around 140 K, and then a smaller, more gradual decrease between 140-300 K. At room temperature, 78% of the original SIRM was recovered. In the second graphic, the remanence at first increased with cooling, reaching a broad peak at 234 K, and then decreased gradually with cooling to the isotropic temperature. At isotropic temperature 75-80% of the room temperature SIRM was demagnetized for B32 (Bektaþ ignimbrite). Warming above 52 K resulted in an increase in SIRM, followed by a broad maximum around 165 K, and then a smaller, more gradual decrease between 165-300 K. At room temperature, 78% of the original SIRM was recovered.

If we correlate these results with the samples' Curie temperatures B14 has a Curie temperature (576 ^{o}C) showing that the sample contains magnetite, and B32 has two curie temperatures (547 ^{o}C and 618 ^{o}C) showing that the sample contains titanomagnetite and is strongly maghemitized.

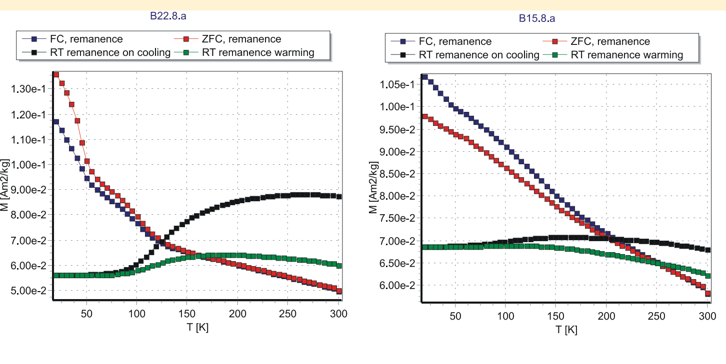

Figure 4--Two representative FC, ZFC, and RTSIRM curves.

Another experiment, ZFC and FC, was made using a MPMS. In the first graphic (fig.4), there is a clear transition at 55 K, but it is not the Verwey transition (which is visible near 120K in sample B22.8). Magnetite often exhibits anomalous behaviour (in remanence and/or susceptibility) near 50 K that is not yet well understood. In the same graphic it is noticable that ZFC curve is greater than FC curve, indicating multi-domain material. The data also suggest that the sample might be oxidized or might contain a small amount of Ti. If we look at the Curie temperature of this sample, we can say that this sample contains partially oxidized magnetite (562 ^{o}C). It can also be considered as that this sample could have a superficial maghemite layer because of the behavior below and at the Verwey transition around 102K.

In the second figure FC curve is greater than ZFC curve. This could indicate that the sample has a finer grain-size than those that show the opposite behavior. B15's Curie temperature is 613.6 ^{o}C, indicating maghemite. As a result this sample should be treated by alternative field demagnetization for the paleomagnetic purposes. Also this sample might have a chemical remanent magnetization.

In addition to the rock magnetic studies mentioned above, we have done XRD experiments to further constrain the magnetic mineral contents in our samples. XRD was done at Süleyman Demirel University, Isparta, Turkey. The results demonstrate the presence of magnetite and maghemite in our samples.

We are reporting that according to hysteresis parameters and the Day plot results 32 of our samples are PSD. Curie temperatures show that the samples have magnetite and maghemite. RTSIRM and ZFC-FC curves show that the magnetic remanence of most of our samples are stable and the ones that are oxidized should be considered as non stable samples for a paleomagnetic study. And finally, XRD results are consistent the theory that the main magnetic mineral in our samples is magnetite. These results will be correlated with the paleomagnetic data and the tectonics of the area.

I would like to thank to the IRM staff, particularly Mike, Peat, Brian and Ramon for educational discussions and their help with the measurements.

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Conference Report: Spring AGU 2007

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The faithful retention of changes in the Earth's magnetism by natural materials has given rise to a hundred years of fruitful inquiry involving such topics as internal planetary dynamics, geomagnetic polarity reversals, and plate tectonics. Over the last twenty years or so, the magnetism of numerous geological archives has also turned out to be an effective means of tracking climatic and environmental change—even the magnetism of dust on tree leaves can be exploited to monitor pollution. All of these endeavours benefit from the rapid, nondestructive nature of magnetic measurements, but they all ultimately demand a thorough understanding of the fundamental magnetic properties of the minerals that provide this geophysical cornucopia. At the recent Joint Assembly of the American Geophysical Union (Acapulco 22-25 May 2007), a special session (GP33A Magnetic Microstructures and Interactions: Implications for Paleomagnetism) was devoted to assessing the many rapid advances in mineral magnetism that are currently taking place.

Richard Harrison (Cambridge) described investigations concerning the role of crystallographic twinning in magnetite (Fe3O4). He captivated the audience with the remarkable movies in which he and his colleagues have succeeded in imaging the real-time interplay of twin domain walls and magnetic domain walls as magnetite changes from cubic to monclinic symmetry on cooling through the Verwey transition at 120K. Magnetite is the most important magnetic mineral relevant to the topics mentioned above, and this type of experiment is crucial to a proper understanding of its mineral physics.

Alexsey Smirnov (Yale) tackled the long-standing problem of how the (very widespread) microscopic subdivision of iron-titanium oxide grains in igneous rocks affects the way in which they acquire magnetic remanence as they cool from the molten state. The evolution of such phase splitting may continue to quite low temperatures, leading to potentially important differences between "pure" thermoremance and thermo-chemical remance. This, in turn, threatens to compromise attempts to determine the strength of the geomagnetic field in the geological past, a subject that is currently receiving a great deal of attention as geomagnetists and paleomagnetists try to work out how the field fluctuates in time and space, how it reverses, and whether or not there is a connection between reversal rate and dipole moment.

Ramon Egli (Munich) presented his quantitative model of magnetostatic interactions (another long-standing problem) and emphasized its application to the interpretation of first-order reversal curves (FORC's). This relatively new technique is now being widely used to assess the magnetic ingredients of the many different types of natural materials (lava flows, sediments, atmospheric aerosols) employed in paleomagnetism and environmental magnetism. It appears that current practise may lead to erroneous conclusions, so it is vital that we get the physics right. The theoretical underpinning of the FORC protocol was also addressed by Michael Winklhofer (Munich) using micromagnetic calculations, another relatively new development that promises to realize William Fuller Brown's 1960's dream of obtaining complete magnetic configurations from ab initio calculations. It turns out that FORC diagrams can take on many forms, and proper interpretation may prove rather tricky. The inclusion of second-order reversal curve (SORC) data may be the way forward.

An entirely different approach was described by David Krasa (Edinburgh) who is employing lithographic techniques to fabricate well-characterized arrays of magnetite nanoparticles. These offer unprecedented control over the physical properties of appropriate sampes, and thus promise to provide much-needed experimental verification of micromagnetic calculations.

The session was rounded off by Gunter Kletetchka's analysis of the possible structural control of magnetism by microscopic lamellar intergrowths in rhombohedral titanohematite crystals. He and his colleagues at NASA argue that the high coercivities and strong magnetic moments produced could play a significant role in the intense crustal magnetic anomalies observed on Mars.

So there you have it: a magnetic renaissance ranging from nanodots to planets.

guide, from page 1

Places to Eat

There are a lot of good restaurants around the campus. And the choices present a nice range of prices and cuisines. The IRM stand-by continues to be Bona, a Vietnamese restaurant on Washington Avenue (see map). The menu is somewhat schizophrenic, consisting of two distinct cuisines: standard Americanized Chinese food, and traditional Vietnamese dishes. Most of us prefer the latter. Try the Vietnamese salads (with rice noodles) or the Pho. The place is always packed, but the service is quick and the prices cannot be beat. E.g., a small Pho is around six dollars. Just a few doors down is Hong Kong Noodles. Order one of the specials written on the chalkboard next to the entrance for a traditional Chinese dish. On the other side of Washington Ave. are some other options including the fast-food Chipotle, and the Lotus (another Vietnamese restaurant). Closer to campus on Washington Avenue are a couple of "bar-food" restaurants, including Big Ten and Sally's. The coffee shop, Espresso Expose, has sandwiches and soup for five dollars.

A few other options can be found if you follow Washington Avenue across the river. In particular, Town Hall Brewery serves beer brewed on the spot and food worthy of the brew. Town Hall has a nice patio and a couple of pool tables, so it is a nice place to go after a day in the lab. For a taste of Americana try the hot-dog joint, the Wienery.

Dinkytown also has several nice places to eat. Café 421 serves great salads, sandwiches, pasta, and more hearty meals like pork tenderloin. It is moderately priced; expect to spend around ten dollars, plus tip, for a plate. Café 421 also has a good wine list. The restaurant's owner, Georgia, is a gregarious Greek, so be on the lookout for the Greek-inspired specials and desserts. Also in Dinkytown is the Loring Pasta Bar. The Loring features amazing interior design and excellent food. It also has the best wine list within walking distance of campus. If you are a student, bring your I.D. for a 30% discount. Another option is

Annie's Parlor, which serves good burgers, fries, and shakes. For a traditional American breakfast do not miss Al's Breakfast, a Dinkytown landmark. The building is actually a converted alley, so the seating is limited to a bar that runs most of the length of the restaurant. And since it is usually full, waiting customers line up behind seated diners. The line moves fast, so even if it runs out the door, you will not have to wait long. If a party of two is waiting and two non-contiguous places open up, a cook or waitperson will ask everyone to move over a place or two. The pancakes and eggs benedict cannot be beat. I ate breakfast at Al's the day that I defended my thesis, because I knew that I would leave with a big smile on my face. Try it.

There are a couple of dining options on campus. Closest in proximity to the lab are the vending machines in the basement. IRM staff members have been known to lunch out of the vending machines, choosing cheeseburgers, sandwich wedges, etc. Nolte Hall has a small cafeteria that is nearly as quick as the vending machines. But for a quick sandwich you would be better off choosing D'Amico and Sons on the first floor of the Alumni Center. They serve great soups, sandwiches and pasta salads with an Italian theme. The desserts are superb. The half-a-sandwich and soup meal for seven dollars is a good deal.

Small coffee shops that serve espresso drinks surround the campus; just wander around any of the surrounding neighborhoods and you are bound to run into one. Though the subject is hotly debated, I prefer the coffee from Espresso Royal, with locations in Stadium Village and Dinkytown. But the other options all serve palatable coffee and pastries.

What to Pack

Do not forget your samples.

OK, we get it: It is cold in Minnesota. All of our visitors tell us this. The good news for visitors is that, as any Minnesotan will tell you, it is not the temperature but the length of winter that really hurts. Having said that, if you come during winter, a hat, gloves, and a winter coat are necessities.

Diversions

EVEN OUR MOST DEVOTED VISITING FELLOWS find the need to occasionally stray from the confines of Shepherd Labs. If you find yourself in a similar position, the Twin Cities offer a range of recreational activities. Downtown Minneapolis (specifically the pedestrian street, Nicollet Mall) is a nice place to do some shopping and also hosts most of the Cities' nightlife. Uptown (south of Downtown) is also a nightlife hotspot, with lots of good restaurants and bars. Of course, the Mall of America is a popular place to do shopping, and since the light rail stops there it is easy to get there.

The Cities also have some fine museums. The Weisman modern art museum is on campus and is free. The Walker modern art museum is world renowned, and a new wing has recently been added. The Walker has a beautiful sculpture garden and a nice high-end restaurant on its second floor. The Minneapolis Institute of Arts is equally fine. Saint Paul boasts the Natural History Museum and a great Science Museum. There are some great architectural treasures in the Cities as well, including Saint Paul's Cathedral (Saint Paul), the Basilica of Saint Mary (Minenapolis) and the State Capitol (Saint Paul). The State Capitol was built by Cass Gilbert, the native Minnesotan who also designed the U.S. Supreme Court's building and many of the University's buildings. There is also the Mill City Museum, a striking deconstructed grain mill, and the Guthrie Theater in Minneapolis. Both are on the river, abutting the Stone Arch Bridge. If you find yourself looking up at the Guthrie, walk across the Stone Arch Bridge and have a drink at one of the nice bars and restaurants on Main Street.

The Cities also has a fine collection of parks if you would like to get out and enjoy nature in the city. The Mississippi River has walking and bicycling paths that follow it on either bank. Minnehaha park is also a beautiful park, whose highlight is its falls. If you visit Minnehaha park between April and October be sure to eat at Sea Salt to drink some good Minnesotan beer and eat some of the best seafood to be had in the state, most of which is not Minnesotan. Como park in Saint Paul is also worth a visit. If you visit in the middle of winter, you may need a trip to the Como Conservatory to warm up your disposition. The Conservatory is a set of greenhouses featuring a sunken garden and a palm garden. It is well worth its price, as it is free. The Como Park also has a small zoo with an entertaining monkey house. The park itself is large, so it is a good place to do some walking.

If you are a sports fan the Cities is well equipped with professional baseball, basketball, football, and hockey teams. Another baseball option is the minor league team the Saint Paul Saints. The Saints are known for their non-baseball distractions, including great sausages, excellent beer, and antics like a massage-giving nun, a pig, and a karaoke singer.

Working at IRM

OF COURSE, OUR VISITING FELLOWS are most interested in getting their samples measured. This section describes the various instruments available at IRM, typical experiments, sample preparation, and the IRM internal database, where all of the data generated at IRM are stored.

Instruments

2G MAGNETOMETERS

2G Enterprises' rock magnetometers are specifically designed to measure the weak remanent magnetization of geologic samples. They employ DC superconducting quantum interference device sensors (SQUID). The SQUIDs measure the current induced in three orthogonal super-conducting pick-up coils. As of the writing of this piece, IRM has placed an order for a new 2G magnetometer.

The new magnetometer will be a horizontal system with a U-channel core handler and an inline AF demagnetizer.

The U-channel handler will also be adapted to handle discrete samples, allowing the automation of traditional rock magnetic measurements on single specimens. In particular, this will allow the automated measurement of isothermal remanent magnetization (IRM) acquisition and demagnetization curves; anhysteretic remanent magnetization (ARM) acquisition and demagnetization curves; and the anisotropy of ARM. The first two measurement automations will greatly increase the efficiency of the data collection necessary to perform magnetic component analysis. 2G makes a narrow coil geometry with a high spatial resolution and a long coil geometry with a uniform response zone. The former is ideal for measuring U-channels because the narrow coils maximize the sampling resolution. And the latter is ideal for single specimens, because the entire specimen will be in a uniform response zone. At IRM, our user base will demand both capabilities, so we have compromised with an intermediate geometry. The magnetometer will have a sensitivity of ~10^{-12} Am^2. We also have an older radio frequency 2G magnetometer with a wide bore, and a large uniform response zone. The sensitivity of this magnetometer is ~10^{-9} Am^2. A shielded room, in which both magnetometers will be housed, will be built in Fall 2007. The residual field in the room should be less than ~200 nT.

VIBRATING SAMPLE MAGNETOMETERS

IRM has three vibrating sample magnetometers (VSM). A VSM is an instrument particularly suited to measuring the magnetization of a sample in an applied field. The instrument works by vibrating a sample next to a set of pick-up coils. The vibrating sample creates a time-varying magnetic flux in the coils, generating a current that is proportional to the sample's magnetization. The applied magnetic field is generated by a water-cooled electromagnet. (This type of magnet is the same as one made by wrapping wire around a nail and hooking the wire up to a battery.) On either side of the sample are two pick-up coils that are oppositely wound. This means that the changing flux produced by the sweeping magnet generates currents of equal magnitude but opposite sign in each of the two pick-up coils. So, the magnet is invisible to the pick-up coils. Accordingly, VSMs measure only the magnetic field produced by the sample and not that produced by the magnet.

IRM's oldest VSM operates at room temperature only, has a sensitivity of ~10^{-8} Am^2, and a maximum field of 1.45 T. On this instrument, it takes about 12 minutes to measure a hysteresis loop and remanent coercivity. The pole gap (the space in which your sample must fit) is a little less than an inch. Our two other VSMs were made by Princeton Measurements Corporation. These highly reliable instruments are lab workhorses; IRM users measure over 15,000 loops each year on these instruments. At room temperature the VSMs' sensitivity is 0.5 nAm^2, and the maximum field is 1.8 T. The pole gap on the Princeton VSMs can be adjusted to fit the particular sample, but the size of the gap affects the maximum field and sensitivity; the narrowest gap being the best for both parameters.

One of the Princeton VSMs can be equipped with a cryostat and the other may be equipped with a furnace. The cryostat allows measurement from ~10 K to 473 K and the furnace allows measurement between room temperature and 800 ^{o}C. Any measurement that can be performed at room temperature can also be made at variable temperature, including DC demagnetization of IRM, hysteresis loops, and saturation magnetization as a function of temperature. The high temperature VSM is used most frequently to measure Curie temperatures derived from saturation magnetization. And the low-temperature setup is most often used to measure loops and DC demagnetization curves as a function of temperature. Note that when the cryostat is installed, the VSM's sensitivity drops to ~2 nAm^2. If you would like to use the low temperature VSM it is important to have a good reason to do so and a good measurement plan, because the low temperature VSM is both very time consuming and expensive to operate. (It costs about $200/day.) Of course, the instrument is available for use, but be sure to formulate a question to be answered or a hypothesis to be tested before you begin your measurements. The low temperature VSM is not really appropriately used as an exploratory instrument.

The low temperature VSM can be switched from a VSM to an alternating gradient magnetometer (AGM). The AGM has a much higher sensitivity of around 10 pAm^2, but the sample size is much more limited than the VSM. The exact sample size depends on the particular AGM probe used, and is either 50 or 100 mg for the probes available at IRM. Often this means that the VSM is a better option for measuring weak samples, because much larger samples can be used. The AGM may also be used with the cryostat in place. For some samples, this is the only possible way to measure at low temperature. Operating the AGM at low temperature is very time consuming, because the flow conditions must be constantly adjusted during measurement. The AGM's sensitivity is also a function of temperature: 10-50 K, 5 nAm^2; 51-100 K, 1 nAm^2; and 101-473 K, 50 pAm^2.

The Princeton VSMs or AGM can also be used to perform more exotic measurements. For example, we employ the Princetons to measure first-order reversal curves. When used at variable temperature the instruments may also be used to perform thermal fluctuation tomography, which yields the joint grain-size, shape distribution for the iron oxides in a sample (see the *IRM Quarterly* vol. 14 no. 3). Finally, it is worth noting that the Princeton VSMs can be used to measure the anisotropy of high-field susceptibility. These exciting measurement do present some complications. Thus, if you are interested in making them be sure to discuss it with IRM staff before you arrive.

QUANTUM DESIGNS MAGNETIC PROPERTIES MEASUREMENT SYSTEM

The two Magnetic Properties Measurement Systems (MPMS) at IRM are also workhorses that are in constant use. The MPMSs are highly versatile machines that can be used to measure an induced magnetization (applied fields up to 5 T), remanent magnetization, and susceptibility, all as a function of temperature (1.7-400 K). The sensitivity of the MPMS is ~10^{-10} Am^2, and the field may be zeroed to within 0.5 μT. Note, however, that the field control and the measurement is only in one direction, vertical. So the horizontal field is not controlled, and the full vector magnetization is not measured.

The MPMS is typically used to detect low temperature phase transitions, magnetic transitions, and blocking temperatures. The first two phenomena are exploited to define the mineralogy of the magnetic minerals in a sample, and the last is exploited to define the grain size of the magnetic minerals. A typical visiting fellow will measure field cooled (FC) and zero-field cooled (ZFC) low-temperature saturation IRM (SIRM) on warming, and room temperature SIRM (RTSIRM) low-temperature demagnetization curves. The FC and ZFC measurements are performed by measuring a remanence on warming (typically from 10-300 K) after two initial pretreatments: 1. the FC remanences are measured after cooling in a 2.5 T field, and the ZFC remanences are measured after cooling in a zero field. For the ZFC remanences a saturating field is applied at 10 K and then turned off just prior to measurement on warming. For the RTSIRM curves, the sample is magnetized at room temperature, i.e., a saturating field (2.5 T) is applied and then zeroed. The RTSIRM is then measured on cooling and warming. These experiments, measured altogether, take about 8 hours. Because of the time requirement, visitors do not typically perform this entire measurement during the day, but instead measure a RTSIRM cooling curve followed by a ZFC-remanence warming curve. This experiment typically takes about 3 hours. So, one plan is to measure 2-3 of these each day, and then launch the longer 8-hour ZFC/FC and RTSIRM cooling and warming sequence before leaving for the evening.

The MPMS also measures susceptibility as a function of frequency, applied field, and temperature. But since another instrument (the Lakeshore magnetometer) also measures susceptibility as a function of all of these variables, we typically suggest that the visitor use the Lakeshore for susceptibility and the MPMS for remanence.

LAKESHORE SUSCEPTOMETER

The Lakeshore magnetometer measures susceptibility as a function of frequency, applied field, and temperature. The frequency dependence of susceptibility is often indicative of superparamagnetic material. For more details on this measurement the reader is directed to the *IRM Quarterly* vol. 10 no. 4, vol. 12 no. 1, and vol. 13 no. 4. The field dependence often gives clues as to the precise mineralogy, e.g., titanomagnetites and pyrrhotite have strong field dependences. Typically, visitors will make a preliminary measurement to determine whether there is any field dependence. If there is not, then one need only measure susceptibility as a function of frequency. Usually, visitors choose to measure susceptibility at five frequencies from 20-300 K. This measurement takes around twelve hours to complete.

MÖSSBAUER SPECTROSCOPY

Mössbauer spectroscopy is based on the recoil-free, resonant emission of gamma rays from nuclei in a crystal lattice (the Mössbauer Effect). Essentially, a nucleus within a crystal lattice absorbs a gamma ray from an external source, and if the nucleus emits a gamma ray at the same energy as the original gamma ray (hence the recoil-free requirement) then the emitted gamma ray can be absorbed by another nucleus in the lattice. As such the whole crystal lattice resonates. Whereas X-ray diffraction probes a crystal's electron structure, Mössbauer spectroscopy probes a crystal's nuclear structure. In Mössbauer spectroscopy, the gamma ray source is moved back and forth, producing a Doppler shift. Accordingly, the sample is exposed to gamma rays of slightly different energies, some of which are absorbed courtesy of the Mössbauer Effect. Whether or not the gamma rays are absorbed depends, in part, on the magnetic exchange between atoms within the crystal.

Accordingly, Mössbauer spectroscopy can be used to determine whether an iron oxide is magnetically ordered or blocked (when spectra are obtained over a range of temperatures), and what mineral the iron is in, e.g., magnetite versus hematite, Fe^{2}+ versus Fe^{3+}. A very useful feature of Mössbauer spectroscopy is that each iron atom produces an equal response, whether it be in hematite, magnetite, or a paramagnetic mineral. So, while the large magnetic moment of a small amount of magnetite may hide the small magnetic moment of a much larger amount of hematite in, say, a hysteresis loop; Mössbauer spectroscopy "sees" each mineral with equal efficacy. The limit to Mössbauer spectroscopy is that it is only sensitive to minerals with concentrations >2% by mass.

IRM has two Mössbauer spectrometers. One operates between room temperature and 77 K in zero field. The other operates between room temperature and 4.2 K and can measure in an applied field up to 6 T. The low temperature measurements are particularly suited for determining blocking and Curie temperatures. It can take between a few hours to a few days to obtain a spectrum for a sample. If you are interested in conducting Mössbauer measurements during your visit, make sure to talk with IRM staff about your plans well in advance of your visit.

MAGNETIC FORCE MICROSCOPY

IRM also has a magnetic force microscope (MFM). An MFM scans a sample by passing a microscopic magnetic lever over the samples surface. The attraction and repulsion of the magnetic lever is detected and is a function of the stray magnetic fields produced by the sample. So, the domain structure of a sample can be observed. Sample preparation is the key to getting good domain images with the MFM: The sample must be meticulously polished and be strain-free. The sample size is also limited; it must fit within a circle with a diameter of 1.2 cm, and must have a thickness less than ~0.5 cm. If you are interested in using the MFM during your visit, make sure that you talk with IRM staff well before you arrive.

AND THE REST

The rest of IRM's battery of instruments includes the following. Our AGICO Kappa bridge susceptometer measures susceptibility at a single frequency and applied field. It has a furnace attachment, so measurements can be made from room temperature up to 750 °C. Anisotropy of magnetic susceptibility can also be measured on this instrument. Another susceptometer, the Roly-Poly built by James Marvin, also measures the anisotropy of susceptibility and is useful when the samples are too strong for the AGICO. Another machine is our Schoenstedt spinner magnetometer, which is useful for measuring remanences that are beyond the 2Gs' dynamic ranges. IRM also has several demagnetizers, including two stand-alone AF demagnetizers (maximum field of 200 mT) with ARM-imparting capabilities, and a thermal demagnetizer. We also have a small thermal remanent magnetization furnace.

IRM has a rock saw and a wafering saw should you need to cut samples. And we have various polishers should you need to prepare a sample for the MFM. Note that we strongly suggest that sample preparation (like cutting and polishing) be performed before arriving at IRM, as this will maximize the use of your time here. If you are interested in characterizing the *bulk* grain-size of sediments or powders, then our laser-diffractometer grain-size analyzer may be of use. Finally, we have a magnetic separator which can extract the magnetic particles from a powder or sediment.

Sample Preparation

Most of our sample preparation techniques have remained unchanged since the *IRM Quarterly* article on the topic was written nearly a decade ago. (We will let our readers judge whether this indicates IRM's propensity to "get it right the first time" or our obstinate resistance to change.) Thus, the reader is directed to the *IRM Quarterly* vol. 6 no. 4 for the details of sample preparation. Sample preparation for the low-temperature VSM was not, however, discussed in the previous article. Generally, there are a few ways to mount such samples. They all utilize plastic sample holders of identical shape and size as those used in the high-temperature VSM: "cylindrical ceramic holder[s], or on a 'semicylinder' side-mount holder[s] (the latter holds [samples] more securely, but approximately halves the allowable volume). The ideal size is thus about 2.5 x 5 x 5 mm (. . . or a mass of roughly 150 mg)." *IRM Quarterly* vol. 6 no. 4. For the low-temperature measurements the sample is affixed to the sample holder with a dab of vacuum grease rather than high-temperature cement. For powders, two options are possible. The powder may be mixed with grease and applied to the end- or side-mount sample holder. Or one half of a poly-carbonate capsule (a non-gelatin capsule that does not dissolve in water) can be filled with powder and slid onto an end-mount holder and secured with tape. At any rate, expect to measure ~150 mg of sample.

Database

One of the more exciting developments at IRM over the last few years has been the creation of an internal database. For a few years now, all of the data measured at IRM havebeen archived in a searchable, interactive database. This has not only changed the way that data are stored, but it has dramatically changed how we interact with the data. Now, data are uploaded to the database pretty much as they are measured. This means that all of the data are processed automatically by our database software. Sophisticated data plots can be generated on the fly. So, IRM visitors can, e.g., make Day plots with all of their data instantly with the click of a button. What this means for our visitors is that the time spent handling data in spreadsheets, normalizing and converting units is eliminated, as is the time spent generating plots. So visitors get to show IRM staff and faculty *all of their data* as it is being measured, rather than simply measuring a bunch of data that does not see the light of day until the visitor returns home and has the time to process all of the data. So, IRM staff and faculty can help analyze visitors' data during the visit in a way that was not possible before the database was developed. A second benefit to the visitor is that they no longer have to deal with hundreds of text files generated by the various instruments' control software. Instead, visitors leave IRM with a single Microsoft Excel file that contains all of the measurements made at IRM. The excel file is created with the click of button.

The first step to entering data into the database is uploading information about your specimens to the database. This is done by filling out an Excel spreadsheet. We suggest that visitors try to do this before they arrive. You can download a copy of the spreadsheet template on IRM's website. The following columns must be input. "Specimen_ID" is the name of the particular specimen. The name must be unique, and should describe the actual physical object that will be measured. "Specimen_azimuth" and "Specimen_plunge" give the specimen's orientation should it be oriented. If it is not oriented, enter 0 and 90 respectively. If your samples are oriented ask IRM staff for the details of our default orientation scheme. Specimen mass and volume are self explanatory and should be entered if you have them. If you plan on preparing your specimens at IRM, you can leave these blank. If measuring a specimen's mass is impossible, use 1000 g as the mass. Using 1000 g, makes it obvious that a nominal mass has been used and since all of our data are in SI units the data will be unaffected by mass normalization. "Specimen-coordinate" is the height of the specimen within a section or core, and should be entered if it is available. This parameter will allow you to quickly generate depth plots of your data. The default specimen-sample hierarchy is a typical paleomagnetic scheme. A sample is the largest oriented piece of material, and a specimen is the sub-sample of the sample that is actually measured. So a an entire rock core is a sample and the ~1 inch piece cut from the core is a specimen. As another example, if you have bagged sediment, the bag of sediment is a sample and the gel-cap filled with the sediment is a specimen. I would use a naming scheme like Sample_1 for the bagged sediment, and Sample_1_gelcap for the gel-cap specimen. Accordingly, "Sample_ID" is the name of the sample from which the specimen was derived. "Site_ID" defines the next level up in the hierarchy. Perhaps it is the name of a lava flow, or a stratagraphic level in a section.

"Locality_ID" defines the general location of the site, and "Expedition_ID" defines the field trip when the samples were taken. If your samples do not fit easily within this scheme, you can use the fields however you wish. Just realize that the way you define these parameters will affect how you can interact with your data once it is in the database. For example, you can generate a Day plot for all specimens from a particular sample, site, locality, or expedition.

Enjoy your stay. But this is Minnesota, so if you didn't like it, pretend like you did.

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 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.). 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 Current Articles section of the IRM Quarterly are always welcome.

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