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One Move to Rule The Mall: Big Changes in Store for the IRM

Lab Space, Summer School and Conference Schedules Affected

A model of the new Tate Hall, view is from the East, looking at the back of the building, the IRM will be located on the second floor in the south wing (to the left in the picture), with plenty of natural light coming in.

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A new home for the IRM

After 25 years in Shepherd Labs, the IRM is preparing for a new beginning: the approaching move to the newly renovated Tate Hall at the University of Minnesota!

In the summer of 2017 the IRM will be united with the rest of the Earth Science Department and the Limnological Research Center (which hosts LacCore), as all will migrate together from various locations on campus to occupy the newly renovated Tate Hall on the University's historic central mall.

Tate Hall, previously occupied by the Department of Physics, is currently undergoing a complete renovation, which started in the summer of 2015: the exterior of the building will be the only remaining vestige of the original 1927 building whereas the interiors, back, and central atrium will be completely re-built and expanded, adding considerable volume and functionality. Most importantly, the lab spaces are being designed by us in collaboration with the architects, therefore the renovations will be custom fit, providing us with the functionality we need. The "New Tate" will thus host the quasi-entirety of the research in earth sciences conducted at the U of M (the only exceptions being the Minnesota Geological Survey and the sedimentological and environmental research group at the St. Anthony Falls Laboratory), and will therefore foster increased communication and exchange between laboratories.

What does this mean for the IRM?

The move is anticipated to take place in June 2017, and we at the IRM have started planning to make the

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Visiting Fellow Report

Rock magnetic effects induced in diabase and basalt by >20 GPa experimental spherical shock waves

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Hypervelocity impacts represent a major mechanism for the evolution of the solid matter in our solar system. Impact shock waves can modify both the bulk magnetic properties and the remanent magnetization of rocks [1]. Understanding the physical mechanisms associated with shock-induced changes in magnetic properties is important for interpreting the paleomagnetic records of returned lunar rocks, meteorites, and cratered planetary surfaces. One way to experimentally test the effects of shock on rock magnetic properties is to conduct experiments where explosively generated shock waves travel through a spherical sample [2]. This approach is advantageous because: (1) resulting shock durations are similar to natural impacts, (2) target rocks are not contaminated by impactor material, and (3) a wide range of pressures and temperatures may be investigated in a single shock experiment. Following ref. [2], the spherical shock experiments were conducted at the Zababakhin All-Russian Scientific Research Institute for Technical Physics (RFNC-VNIITF; Snezhinsk, Russia) on spheres 49 mm (og-1) and 50 mm (og-2) in diameter, respectively. The spheres were prepared from (titano)magnetite containing block samples of a basaltic lava flow (sample og-1) and diabase dike (sample og-2) from the Osler Volcanic Group of the late Mesoproterozoic North American Midcontinent Rift [3]. Our goal for the IRM visit was to characterize magnetic changes induced in these rocks by pressures >20 GPa. One motivating aspect for this work is that correlative lithologies are found within the nearby Slate Islands impact structure [4].

The equatorial plane of og-2 is shown in Fig. 1. Consistent with prior spherical shock experiments on the Saratov ordinary chondrite [2], both the shocked flow and dike samples exhibited concentric zonation: a central void space (observed only in og-1) was surrounded by an inner layer of impact melt (Zone I, most shocked), a middle partially melted layer (Zone II), and an outer layer of unmelted rock with solid-state shock features (Zones III and IV, least shocked). These zones are petrographically different. Like Zone IV, Zone III is characterized by an intact texture, but the plagioclase grains have been transformed into diaplectic glass.

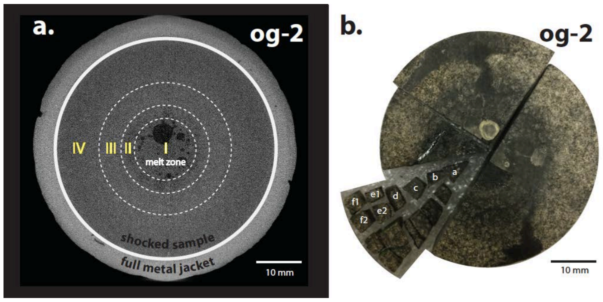

Figure 1. (a) Microtomographic image of the cutting (equatorial) plane of og-2 sample (spatial resolution: 33 µm; image acquired using a XT H 450 micro-focus X-ray and CT tomography system by Nikon Metrology in Leuven, Belgium; the image comes from 3D reconstruction from 2400 angle scans per sample); (b) A photograph of the equatorial slice of the og-2 sample with the subspecimens labeled.

Previous investigations of impact metamorphism [5] and our optical microscopy investigations result in peak shock pressure estimates on the outside boundaries of zones I, II and III as ~70 GPa, ~50 GPa and ~30 GPa, respectively. Based on the extensive melting in the center, we estimate that shock-induced heating reached temperatures of ~1300-1400°C in Zone I. Dendrite-like ferromagnetic grains were nucleated from the melt in Zone 1 and were imaged using the magnetic force microscope during our visit at the IRM (Fig. 2).

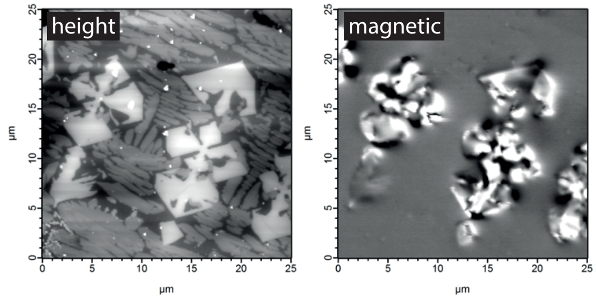

Figure 2. Magnetic Force Microscope (MFM) images from the melt zone (Zone I) of og-2. (a) topography; (b) magnetism.

From our demagnetization of experimentally shocked samples, we interpret Zones I, II and III to have acquired thermoremanent magnetization (TRM) from shock heating. Zone IV appears to lack a TRM overprint and may have experienced shock demagnetization of the primary (pre-shock) magnetization, but not substantial remagnetization. Shocked samples have higher remanent coercivities than unshocked samples of the same parent rocks that were revealed through hysteresis experiments (Fig. 3a) and demonstrate more SD-like behavior with increasing shock degree (Fig. 3b,c). Coercivity changes may be related to domain wall pinning in multidomain ferromagnetic grains along with the subdivision of grains through mechanical fracturing (abundant fractures with the Fe-Ti oxide grains were observed in the shocked samples through electron and magnetic force microscopy).

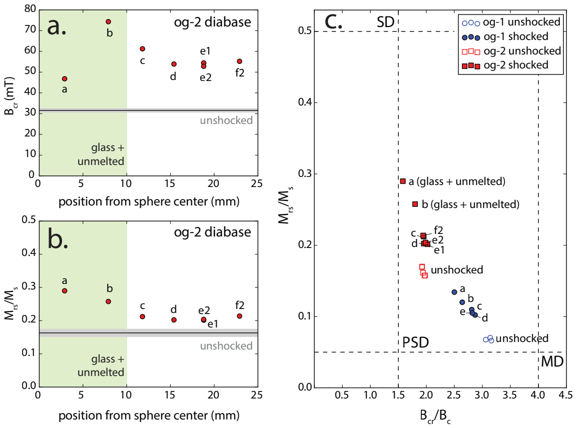

Figure 3. Summary of hysteresis parameters associated with unshocked and shocked specimens.

Target rocks within some impact craters and shock stage >S3 meteorites have experienced shock pressures >20 GPa. Rock magnetic experiments on the spherical shocked basalt and diabase quantify the shock-induced magnetic effects at these pressures, which include coercivity changes, shock demagnetization and thermal remagnetization. These results build on our existing understanding of the magnetic effects of shock to help guide future interpretations of the remanent magnetization and bulk magnetic properties of highly shocked materials from planetary surfaces.

Acknowledgements

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Using sediment magnetic properties to determine the onset of human settlement at Australian archaeological sites

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Mineral magnetic analyses were carried out at the Institute for Rock Magnetism (IRM) to understand if magnetic enhancement within a sandstone rockshelter in interior Australia was associated with cultural horizons. A key concern regarding rockshelter studies is that the proposed ages for the earliest archaeological sites are based on luminescence dating of sediments, rather than directly of cultural materials, leaving the association between the sediments and evidence of human activity questionable. Magnetic analyses show that magnetically enhanced sediments is likely a result of anthropogenic burning of hearth fires, which burn hotter and for a longer time than natural wild fires. Susceptibility and frequency dependence of susceptibility (χfd) signatures provide an important tool to resolve that human occupation starts at 2.2 m depth within a stratigraphic section. Anhysteretic remanent magnetization (ARM) and saturation isothermal remanent magnetizations (SIRM) where used to examine the amount of SD and PSD material in the samples. Hysteresis loops provided the average magnetic domain state (SP, SD, PSD, MD) and concentration. Finally low temperature tests were used to understand temperature dependent magnetic transitions.

The study site is a Pleistocene sandstone rockshelter, Gledswood Shelter 1 (GS1) located in northern Australia. Six adjoining 1 x 1 m test pits were excavated to bedrock (depth of ca 2.6 m) within the overhang. Seven stratigraphic units (SU) were defined as well as a distinct archaeological level at which stone artifacts appear. Initial radiocarbon dates dated the site to about 28,000 years ago (Wallis et al. 2009), but recalibration using OxCal v.4.2 (Bronk Ramsey 2009) against SHCal13

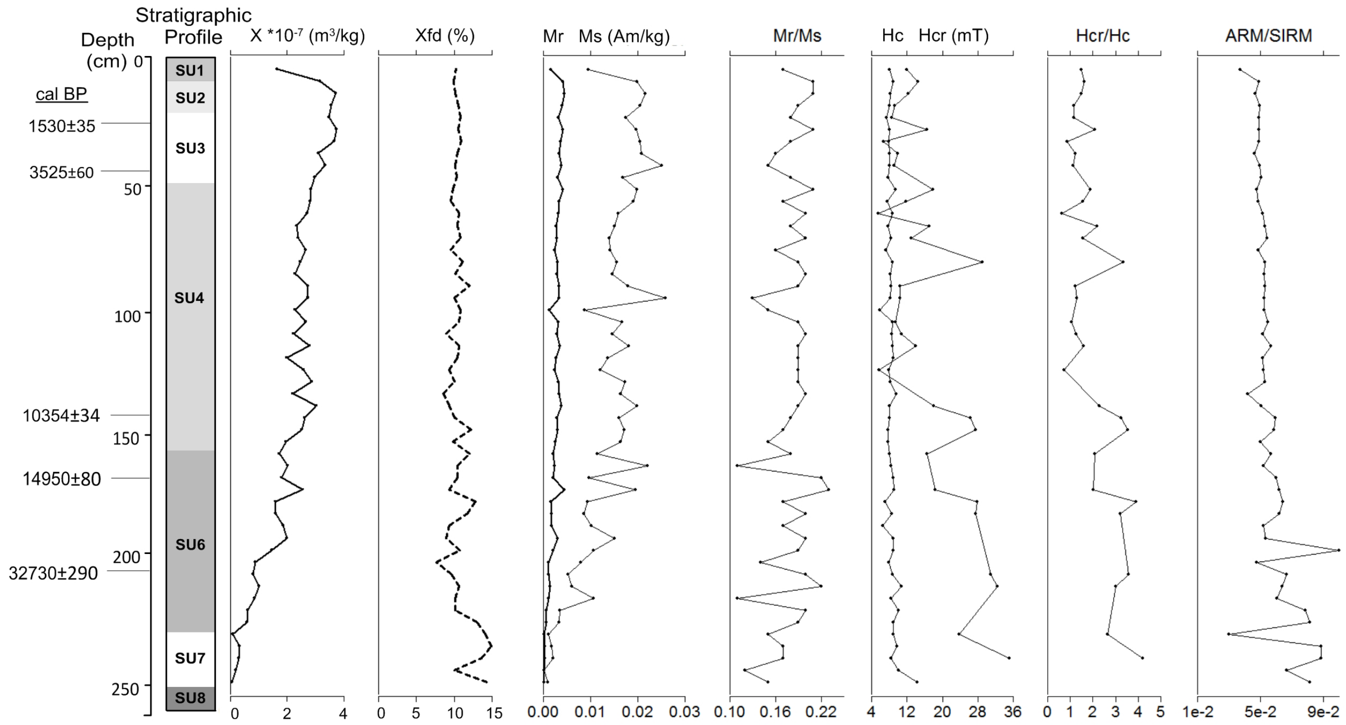

Figure 1. Profile of low-field magnetic susceptibility and frequency dependence of susceptibility with selected sediment magnetic parameters for Square C1.

(Hogg et al. 2013) have pushed this date back to about 38,000 years ago.

Low-field mass-normalized magnetic susceptibility readings (χ) were taken every 5 cm in the excavated samples at both low (460 Hz) and high (4600 Hz) frequencies for χfd%. At the Institute for Rock Magnetism, samples were then given an ARM using a 100 µT DC bias field with a 200 mT peak alternating field. SIRM were imparted using a 1 T impulse field. ARMs and SIRMs were measured using a 2G Enterprises cryogenic rock magnetometer within a magnetically shielded room whose background magnetic field is <200nT.

Hysteresis loops and backfield curves were measured for 30 samples using a Princeton Measurements Micro-Mag Vibrating Sample Magnetometer. The parameters used in this study include saturation magnetization (Ms), saturation remanent magnetization (Mr), and coercivity (Hc). The paramagnetic and ferromagnetic portions of the induced magnetization were also examined for each hysteresis loop using the high field slope (from 0.8 to 1.0 T) of a hysteresis loop. Backfield curves were used to calculate the impulse field, Hcr, needed to reverse half of a sample's magnetization (such that the total remanence is zero).

Samples were then cycled to low (20 K) temperatures to measure changes in their magnetic susceptibility or remanence. Low-temperature measurements were collected on 10 selected samples using a Quantum Designs MPMS-5S (magnetic properties measurement system). An initial field of 2.5 T was applied before samples were measured. Samples were then cooled from room temperature (300 K) to 20 K and the remanence was measured at 5 K increments in a zero field. The samples were given another remanence in a field of 2.5 T at 20 K, and warmed from 20 K up to 300 K, measuring remanence in a zero field at 5 K increments.

The χ data reveal a strong correlation with the stratigraphic units within the GS1 sedimentary sequence (Fig 1). As shown, the GS1 samples are weakly magnetic in the culturally sterile layers (the basal units of lower SU6, SU7 and SU8). Susceptibility values are highest in the upper portion of the sequence (in SU1, SU2 and SU3) and almost all samples within the shelter have a higher χfd% (9–12%), indicating they contain a greater percentage of SP grains, consistent with burned soil.

Hysteresis measurements show that both Ms and Mr generally increase through time (towards the surface) (see Fig 1). By contrast, the Mr/Ms ratio shows no trend with depth, indicating that the grain-size distribution of the magnetic mineral assemblage remains constant even when the concentration of magnetic minerals increases. Hcr and the ratio Hcr/Hc both generally decrease through time (towards the surface). This suggests that each sample may have a combination of both high and low coercivity minerals, yet the relative abundance of lower coercivity magnetic minerals (likely produced by fires during human occupation) increases through time with respect to naturally occurring high-coercivity minerals. This interpretation is also consistent with the progressive decrease through time in the ARM/SIRM ratios.

Fig 2a, 2c and 2e shows how a sample's low temperature SIRM (LTSIRM) and room temperature SIRM (RTSIRM) vary during thermal cycling between 20 K and room temperature. The LTSIRM warming curves (solid lines) show loss of remanence on warming over the whole temperature range. The RTSIRM cooling curves (dashed lines) are more useful in that they show inflection points near important mineral transformations. The Verwey transition is weakly expressed in all samples (Figure 2b, 2d and 2f), suggesting that pure stoichiometric magnetite is not the dominant magnetic mineral in the sample, but that it is present in trace concentrations in each sample throughout the stratigraphy. The Morin transition is present in the uppermost stratigraphic layers SU4-2, but not in lower SU6 or SU7.

Select samples were also examined for variations of susceptibility as a function of temperature and frequency. Fig 3 shows an example of low temperature, frequency dependence of magnetic susceptibility. The different frequencies showing an increasingly wide range of susceptibilities as the sample is warmed, suggests that the sample contains a population of SP-sized grains. The increase in both susceptibility and its frequency dependence on warming indicates a broad size distribution of SP-SD particles (Worm 1998), consistent with the LT-SIRM results.

There is a positive relationship between the onset of human occupation at GS1 as defined by the presence of stone artifacts and a change in the magnetic properties of the associated sediments. The stable and consistently higher χfd% in the sediment associated with human occupation is likely a by-product of human behavior involving pyrotechnology. While most natural soils show a progressive decrease in the abundance of SP grains with depth (Lindquist et al. 2011), the samples at GS1 show consistently elevated SP concentrations. This further indicates that the sediments are not an expression of natural environmental processes, but that human occupation played an important role in the formation of the magnetic assemblage.

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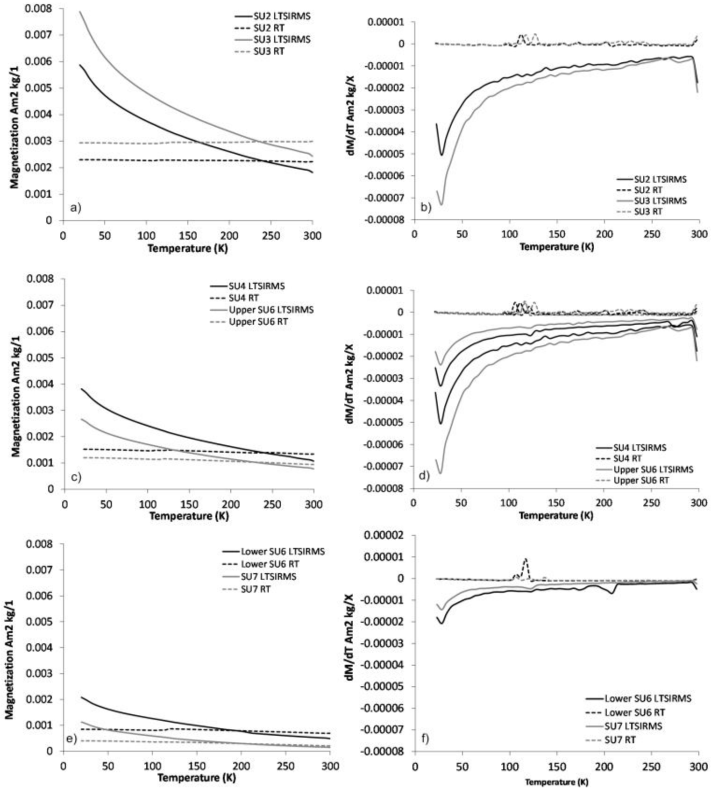

Figure 2. Room-temperature SIRM measured while cooling in zero field, and low-T SIRM (LTSIRMS) measured while warming in zero field (a, c, e). Both show only faint signs of the Verwey transition (Tv~120K) and no indication of the Morin transition (Tm~260K) (b, d, f).

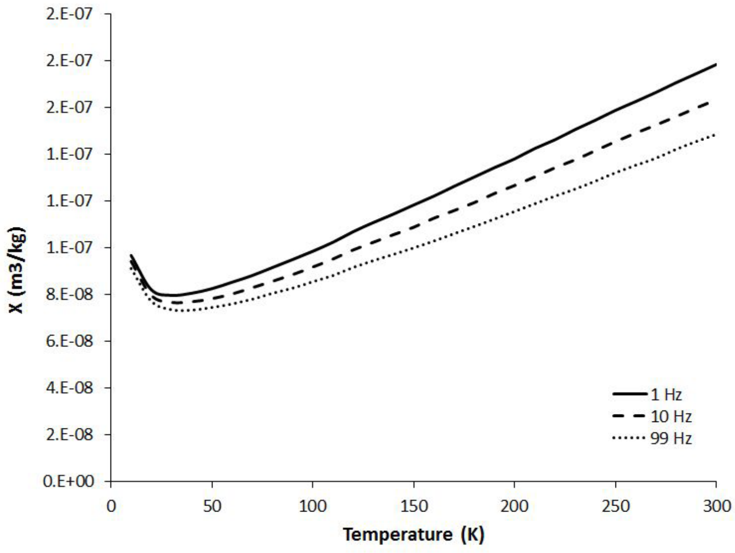

Figure 3. Low-temperature multiple frequency tests show susceptibility and frequency dependence increase with temperature, indicating a significant nanoparticle population. There is little or no indication of the Verwey transition.

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 ISI Web of Knowledge, 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 Current Articles section of the IRM Quarterly are always welcome.

Archeomagnetism

Geiling, J. M., and A. B. Marin-Arroyo (2015), Spatial distribution analysis of the Lower Magdalenian human burial in El Miron Cave (Cantabria, Spain), Journal of Archaeological Science, 60, 47-56.

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Environmental magnetism and Climate

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Gilbert: Natural Magnetism in Smithing.

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move as efficient as possible, meaning as little down instrument-time as we can manage. We are hoping to be able to complete the move, including instrument shutdown, transport and set-up, within a six-month period, going from complete functionality at the current location to complete functionality in Tate Hall.

The arrangement of the new lab has been entirely designed by us, and will feature an open floor plan located on the second floor of the building, that will span the whole distribution of instruments. At one end of the spectrum of the lab will be the low-field section (kappabridges, Magnon and zero-field rock magnetometers, including a new shielded room), whereas on the other end the high field instruments (Mossbauer, VSMs and MPMSs) will reside, including two separate sound- and vibration-proofed spaces for the helium liquefier plant and the AGM. Separating the two, the new IRM will feature a fully equipped clean sample preparation space, which will also host our magnetic imaging instrumentation (MFM, optical microscope for Bitter patterns analysis). Staff, faculty and visiting fellow offices will be located adjacent to the lab. A general-purpose rock-cutting, drilling, crushing and what-not room will be shared with the rest of the geology department and will be located in the basement of Tate Hall, while our specialized sample prep equipment will remain within the IRM domain. Not too shabby, uh?

Related changes: summer schools and conferences

In order to make the transition as smooth as possible, however, and with the IRM's community-based activities in mind, some peripheral switches need to occur. Specifically, it was decided by the IRM and the Review and Advisory Committee that it would be in the best interest to invert the scheduling of the Summer School for Rock Magnetism and Santa Fe conference. Therefore, this coming summer the IRM will host another summer school (June 1-10, 2016), whereas the next conference will be pushed back to the summer of 2017. Information on the summer school will be posted soon on our web site, and we anticipate opening registration in March. As in previous years, registration will be limited to 20 students.

The benefits of this change are primarily two-fold: on one hand it will allow us to run a summer school without conflicting with the lab relocation, with guaranteed functionality on all instruments; and on the other, with people being away for the conference in the (boreal) summer of 2017 anyways, the relative inconvenience of the lab move to the community would be reduced.

Regarding the conference itself, an additional long-term benefit is that Santa Fe will no longer occur in the same years as the Castle Meeting, leaving more freedom of choice for participants.

Having brought up the Santa Fe conference, and as mentioned in a previous Quarterly issue, it has been proposed for the next IRM conference to be held in Kiama,

Construction work on Tate Hall. The new IRM will be located on the second floor of the South Wing (pictured), whereas the center of the building will feature a brand new addition, as depicted in the model on the first page.

Australia. The Australian conference will be co-organized with the Canberra and Beijing groups and would have the same discussion-oriented format as in Santa Fe. Kiama is the type-locality where the reverse-polarity superchron was first identified and deserves a special place in the heart of every magnetist, and will therefore be a fantastic location for a conference and fieldtrip.
Additionally, having the meeting hosted in a place other than the United States it more easily allows participation of colleagues from Asia and the Pacific.
On the other hand, however, there are significant drawbacks, and for the exact same reasons as above for many American (from North and South) and European participants it may be much harder to attend the conference. Of particular interest to us is also student participation and whether research budgets of PIs would allow for their students to travel to Australia.

We are asking the community for input on holding a meeting in Kiama, and have put together a very short questionnaire that should take a couple of minutes to fill in. The questionnaire can be found at:

https://docs.google.com/forms/d/1UCCrXfsRh0CmLSKFilI1gLAt-AjY8fcguuO2aethO6Q/viewform?usp=send_form

We are looking forward to hearing your thoughts on the next IRM conference, and to the participation of your students in our 2016 Summer School!

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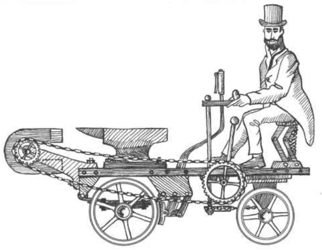

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The IRM Quarterly

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 10-day period during the following half year. Shorter, less formal visits are arranged on an individual basis through the Facilities Manager.

The *IRM* staff consists of **Subir Banerjee**, Professor/Founding Director; **Bruce Moskowitz**, Professor/Director; **Joshua Feinberg**, Assistant Professor/Associate Director; **Mike Jackson, Peat Sølheid** and **Dario Bilardello**, Staff Scientists.

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