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The Third Summer School for Rock Magnetism Held at the IRM



Group photo from the field trip to Taylor's Falls and the Stillwater historical boom site.

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All good things always come in threes, and so do the Summer Schools at the IRM: Students of eleven different nationalities (studying at sixteen institutions from eight countries) just departed Minnesota after attending the third Summer School on Rock Magnetism.

The Summer School is a biennial event held at the IRM since 2011: each year it has been a great success, and to ensure that all students leave with a good hands-on experience, we once again capped the school at twenty students on a first-arrived first-served basis.

As for the previous Summer School, we were able to provide some limited Scholarship Support thanks to the National Science Foundation and the American Geophysical Union, which were assigned based on the student's CVs and application letters.

For most students the Summer School is a first course entirely dedicated to rock magnetism and the first opportunity to perform measurements and interpret data gathered on a variety of rock-magnetic instruments.

Having the students work in groups of five on projects that are (broadly) based on the students' interests and fields of study has proven to be a winning strategy to add relevance to course. This year's students' interests ranged from sedimentary magnetism, to environmental magnetism, stratigraphy, paleomagnetism and paleointensity (all with more in-depth interest in specific rock-magnetic properties), which allowed creating four specific projects which stimulated those curiosities. The four projects selected for the students to work on were: A) Ocean Sediment Magnetization; B) Magnetic properties of Serpentinites; C) Archeomagnetism; and D) the Magnetic Properties of the Tiva Canyon Tuff.

Group A studied ocean sediment grabbed from different localities within the Gulf of San Jorge, Argentina. Because the gulf has no major river input, sediment provenance is dominated by eolian dust derived from Patagonia and sediment transported from the northward Western Malvinas Current. Goal of the study was to determine whether it is possible to use magnetic properties to distinguish the sediment sources, providing insight into the transport mechanisms and the depositional processes. A variety of magnetic granulometry and char-

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pg. 13...*

Response Article

A new basis for the SI system of units? A micromagnetist's perspective

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In a recent issue of the IRM Quarterly, a star-studded list of rock magnetists put together some proposals for changing the SI system of units and the way we use them (Stacey et al., 2014). The first proposal is to change the units by which the magnetization M is measured. This would involve replacing the official SI convention

$$B = \mu_0 (H + M), \quad (1)$$

called the Sommerfeld system, by the Kennelly system

$$B = \mu_0 H + M, \quad (2)$$

and creating a new unit for M called the Néel in honor of Louis Néel. This new unit would be the tesla in all but name. The second proposal is to always plot hysteresis loops with H on the x axis and B or M on the y axis; measures of coercivity should be in units of A/m, the same as H . They claim that their proposal is "a minimalist resolution of the disruption to magnetism studies that has resulted from introduction of the SI system."

The occasion for this proposal is a pending revision of the SI system of units that will replace the standard kilogram in Paris by a new standard that is not based on a physical artifact. Among the consequences is that the permeability of free space, μ_0 , will no longer be defined as $4\pi \times 10^{-7} \text{ Hm}^{-1}$. Instead, it will be a measured parameter. The units system will be determined by seven fundamental constants that will be defined by their current values. Stacey et al. (2014) are disappointed that the CODATA committee won't use the opportunity to choose an entirely new and more logical set of values for these constants. Instead, the new system "will still be a patched up arrangement loaded with historical compromises."

There are good reasons for compromises, however. As long as present values of physical constants are consistent with past values, old publications can easily be compared with new. Any change to the units, even a small one, would need to be communicated to the scientific community. Textbooks would need to be rewritten, and if scientists wanted to use data from older publications, they would need to convert them to the new units. We need to carefully weigh the pros and cons.

What are the disruptions that they hope to fix with

their proposal? First, in the Sommerfeld system, the permeability of a material is a non-intuitive number, being commonly of the order of magnitude of μ_0 . In addition, they believe that the units for H are awkward, providing a "stumbling block to recognition that H is a primary field and has contributed to attempts to write it out of magnetism altogether ..." They are concerned particularly that electromagnetism textbooks, and some committees on units, want to remove any mention of H . They are also concerned that the wrong units are used for M , disguising its true nature. And finally, they find confusion reigning in the labeling of axes for hysteresis loops.

In this response, I will attempt to determine whether the above concerns are justified and whether the proposed changes address them. We can immediately see that they will have no effect on the perceived relation between B and H because only the units of M will change. Nevertheless, I will discuss this issue and the treatment of magnetic fields in textbooks with a view to making my own recommendations at the end.

1. Neglecting H

It is true that textbooks on electromagnetism tend to downplay the importance of H and its electrostatic counterpart D . For example, Jackson (1975) calls B and E the "fundamental fields" while H and D are "derived fields". The latter are "introduced as a matter of convenience in order to take into account in an average way the contributions to ρ [the charge density] and J [the current density] of the atomic charges and currents." Not mentioned at all in this account is the role of electron spin.

As Stacey et al. (2014) point out, other textbooks go even further. For example, Giancoli (2008) manages to discuss Maxwell's equations, along with diamagnetism, paramagnetism and ferromagnetism, without ever mentioning H . To be fair, some books on magnetism (Spaldin, 2011) and solid state physics (Ashcroft and Mermin, 1976) use H exclusively.

An exclusive use of B or H may be convenient, and is only harmful if it is associated with a distortion of the physics. The distortion that tends to accompany a preference for the B -field is an over-emphasis on current loops. An example is the categorical statement in Griffiths (1999) (p.258): "Magnetism is not due to magnetic monopoles, but rather to moving electric charges; magnetic dipoles are tiny current loops." He calls the approach where the magnetization is represented by magnetic charges the "Gilbert model", and says "My advice is to use the Gilbert model, if you like, to get an intuitive 'feel' for a problem, but never to rely on it for quantitative results." That would certainly come as a surprise to the micromagnetic community, which uses nothing else. And for good reason. It is far easier to calculate magnetic fields using charges than current loops, makes more sense when you're relating them to electron spins, and gives the same answer if done correctly.

Stacey et al. (2014) also mention a paper by Crangle and Gibbs (1994) that reports the results of a discussion on units at a joint Magnetism and Magnetic Materials-Intermag conference in 1994. Given the context, I find

it astonishing that the paper has the following statement: "The H -field is rarely used alone. It only arises when calculating the magnetic effect of an electric current or in similar cases." (Such as in the study of ferromagnets?)

Crangle and Gibbs think they are proposing to get rid of the H -field. In its place, they want to use $B_0 = \mu_0 H$. They describe this field as "the free-space field that would remain if the medium were taken away." Which is nonsense. B_0 is just H in different units, and it changes if you take a magnet away.

2. Will the real field please stand up?

The distortions of physics that I discussed above are not what Stacey et al. (2014) have in mind. They think that H is the primary (causative) field and B a "materially dependent consequence". To support this claim, they advance the following "irrefutable argument": in measurements of the phenomenon of hysteresis, B "lags" H . It's not clear what they mean by this. Hysteresis is often described as a lag between cause and effect, but a magnetic hysteresis loop occurs because there are multiple choices of magnetic state for a given field and energy barriers between them. However, they also say that "the principle of causality disallows any effect that precedes its cause", which indicates that they must be talking about a temporal lag.

For a temporal lag to really establish cause and effect between H and B , it should be an intrinsic effect, not the result of magnetic viscosity (which, of course, varies greatly and depends on many factors besides magnetism). And it should be local - not due to the time it takes a change in magnetic field to propagate. But no such time lag is predicted by Maxwell's equations.

The debate over which field is primary has been going on a long time. In an extensive discussion of the issue, Roche (2000) identifies three major traditions. William Thomson (Lord Kelvin) accorded equal status to H and B ; Michael Faraday and James Clerk Maxwell asserted that H is the cause of B ; and Hendrik Lorentz interpreted B as the average of the microscopic fields and considered H an artifact. (However, both Maxwell and Lorentz showed some ambivalence in their positions.) Although the authors of textbooks on electromagnetism tend to favor Lorentz, no one seems to have come up with a definitive way of establishing which view is correct.

There seems to be general agreement that, on the scale of particles with charges and spins, there is only one magnetic field because all the sources are point sources in a vacuum. The split into two fields occurs when the sources are represented by a continuous distribution. To establish the relationship between microscopic and macroscopic scales, the point sources must be averaged over some region. This can be done in more than one way (Brown, 1962; Jackson, 1975; Roche, 2000), and depending on the approach, the two fields can be considered an expression of the non-uniqueness of the result of averaging or one can be made to seem primary and the other derived.

It is instructive to compare the B - H debate with that on mass. Two kinds of mass are recognized, inertial (re-

sistance to acceleration) and gravitational (response to a gravitational field). Their relationship is formalized by the equivalence principle, which states that they are the same thing (up to a point, at least). There are strong and weak versions of this principle and an intermediate version used in general relativity, and all of them have been tested with a variety of experiments (Will, 1993). There are also competing theories in which they are non-equivalent. But the two masses are measured in the same units and are generally represented by the same symbol.

Compared to the equivalence principle, the arguments over B and H seem mostly over semantics. Faraday and Maxwell believed that, even in a vacuum, there are two distinct fields H and B . However, no experiment in vacuum has ever distinguished between them (Roche, 2000), and to my knowledge there is no theoretical prediction that would allow us to separate them. Similarly, arguments about whether one of them is primary in a medium don't seem to have any experimental consequences. If I had been involved in the definition of the SI system, I would have advocated using the same units for H and B .

3. Is M a B ?

In their discussion of the units for M , Stacey et al. (2014) cite Whitworth and Stopes-Roe (1971), who experimentally measured the torque on a bar immersed in a permeable fluid and concluded that it was better predicted by $\mu_0 \mathbf{m} \times \mathbf{H}$ than by $\mathbf{m} \times \mathbf{B} = \mu_0 \mathbf{m} \times \mathbf{H}$, where μ_r is the relative permeability. The result is equivocal: experiments with magnets of different shapes can seem to support either system or neither (McCraig, 1973), so the physics has probably not been fully worked out. Nevertheless, Stacey et al. (2014) conclude that magnetization does not behave like a current loop, which in a discussion of Ampere's law they associate with \mathbf{H} , so it must act like \mathbf{B} and should have the same units as the latter.

We can hardly conclude from one experiment that \mathbf{M} always acts like a B -field. In general, it is an average over a mixture of magnetic spins and currents. Moreover, the magnetic fields have distinct characters. \mathbf{B} is solenoidal ($\nabla \cdot \mathbf{B} = 0$) but generally not irrotational ($\nabla \times \mathbf{B} = 0$) in a medium, while \mathbf{H} is the reverse. Equation 1 predicts that \mathbf{M} is a mixture of both, so it does not have the character of either.

4. Physics and units

How does the above discussion impact the proposals by Stacey et al. (2014)? Since the argument that M is like a B -field fails, it does not provide support for changing its units.

That leaves the perceived inconvenience of the SI units - the non-intuitive numerical values for the permeability μ . Stacey et al. (2014) don't seem to feel that defining a relative permeability $\mu_r = \mu / \mu_0$ is an adequate solution. How would their proposal change matters? In the SI system, the susceptibility χ is dimensionless and

$$\mu = \mu_0 (1 + \chi). \quad (3)$$

In their proposed system, χ would have units of Néel

mA^{-1} and

$$\mu = \mu_0 + \chi. \quad (4)$$

This does not seem likely to make the values for μ any more intuitive, but χ would be less intuitive.

If someone prefers to use the Kennelly system, they can do so without creating a new system of units. For decades, physicists and engineers have used a quantity called the magnetic polarization, usually represented by I or J and equal to $\mu_0 M$ (Chikazumi, 1964; O'Reilly, 1984). It is officially recognized by organizations such as the IEEE.

Units are just conventions and do not determine physical laws. When this is forgotten, confusion can result. Stacey et al. (2014) claim that the argument that either H or B can be considered primary "fails" because, in the pending revision to the fundamental constants, μ_0 will be a measurable parameter with a measurement uncertainty. That's a bit like saying that the speed of light in a vacuum used to be variable because it was measured, but now it is a constant because CODATA has defined it exactly. An uncertainty in μ_0 reflects nothing more than an uncertainty in the units. Physical units are either base units (which must be related to a measurable quantity) or derived from base units; and the definitions of the base units change over time. Indeed, in the CIPM recommendation for a redefinition of the kilogram, there is also one for the ampere (Mills et al., 2006). Instead of being defined in terms of the force between two parallel conductors, it would be equal to exactly $1 / (1.60217653 \times 10^{-19})$ elementary charges per second.

5. Representing hysteresis loops

Stacey et al. (2014) are concerned that magnetic hysteresis loops are presented with a great variety of units, with both H and B represented on the horizontal axis. They prefer H , of course, because they believe it is the independent variable. They also think that loops should plot H against B because, in those units, the area of a loop is equal to the energy loss per cycle.

Unless we are designing an AC transformer, I'm not sure why we should care about energy loss. Paleomagnetists don't, and neither do most people studying magnetism. Hysteresis loops are plotted with a variety of units because they have a variety of purposes. If someone is plotting a magnetic moment in Bohr magnetons, chances are that they are measuring an atomic or molecular magnet; if they measure magnetization in $\text{Am}^2\text{kg}^{-1}$, it is because they know the mass more accurately than the volume, and they may be interested in the properties of the material. Even Stacey et al. (2014) accept a plot of M vs H , where M is in teslas or Néels, yet the product of M and H does not give the hysteresis loss.

6. Honoring Néel

There is still the question whether a magnetization unit should be named after Néel. In the Gaussian system, both H and B were once measured in units of gauss (Brown Jr, 1984). Then, in 1936, the International

Electrotechnical Commission adopted the oersted as the unit for H (Roche, 2000). This was done to honor Hans Christian Oersted, but it also reflected a belief that the two quantities are somehow different in kind (Roche, 2000). Nevertheless, for all practical purposes, the gauss and oersted are two names for the same thing.

Perhaps Stacey et al. (2014) were inspired by the example of the oersted. The name change would not seem to serve any purpose besides honoring Néel. Brown Jr (1984), referring to the oersted, has this to say: "At this point I wish to question the commonly accepted notion that one function of the names of units is to honor scientists. I am not against honoring people; but I think there are good and bad ways of doing it. A good way to honor someone is to establish a scholarship in his name. A bad way is to rename a street, building or unit for him. The function of street, building and unit names is to help people find their way around the city, the campus, or the unit system; and when Collins Street becomes Tedesco Street, or Main Engineering becomes Lind Hall, or the mho becomes the siemens, this function is interfered with."

7. Conclusions

In conclusion, there is no evidence for one of B and H having primacy over the other, and M is neither an H -field nor a B -field. The proposals by Stacey et al. (2014) seem to introduce more problems than they solve. However, I do feel that there is reason to be concerned with the generally bad coverage of magnetism in textbooks on electromagnetism. I think that the most effective approach to this problem would be to reach out to the authors of these textbooks and gently remind them of a few facts that are known to everyone studying magnetic materials.

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Visiting Fellow Report

Magnetic properties of agglutinate-like particles from planar shock-recovery experiments on basalts

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Micrometeoroid bombardment contributes to soil formation on the surfaces of airless solid solar system bodies such as the Moon and asteroids; its role in regolith evolution is comparable to that of crater-forming events. Indeed, the micrometeoroid flux in the vicinity of the Earth was estimated as $(40 \pm 20) \times 10^6$ kg/yr [1] and the flux of crater-forming extraterrestrial bodies ranging in size from ~100 m to ~4.5 km was estimated as $\sim 80 \times 10^6$ kg/yr [2]. Both fluxes are of the same order of magnitude. The main consequence of micrometeoroid impacts is agglutination, or the formation of clastic detritus bound by glass. High-resolution imagery reveals that the surfaces of many asteroids are covered by regolith. However, at present, the lunar regolith is the only form of regolith available for laboratory investigations (in addition to regolith breccia meteorites). Lunar agglutinates represent an important fraction of lunar soil (e.g., 16% in Apollo 16 [3]); as such, it is important to investigate their magnetic properties as they may contribute to the observed lunar crustal magnetism.

As lunar agglutinates represent a rare and precious

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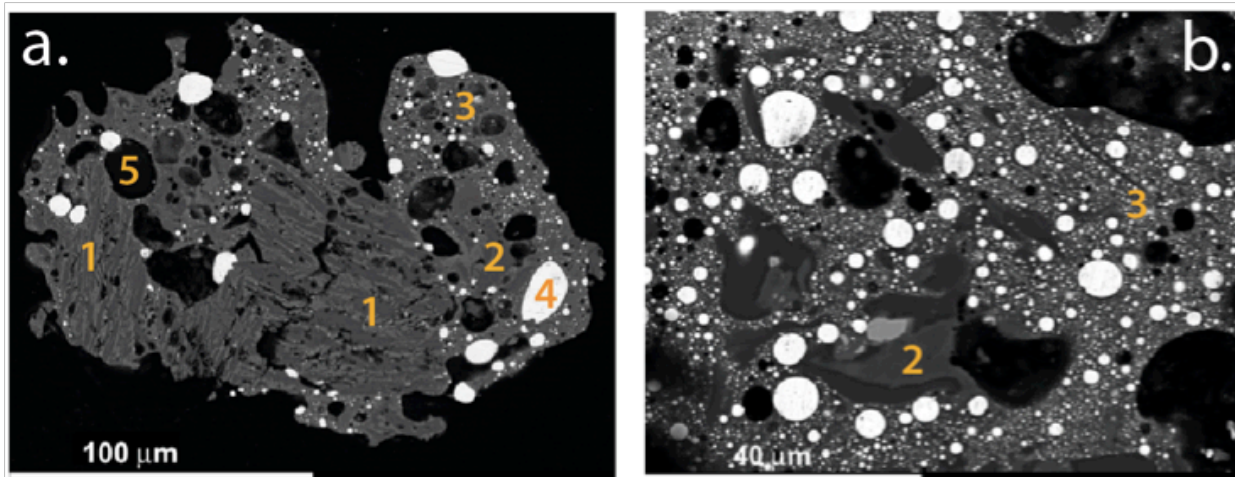


Figure 1. Backscatter electron (BSE) images of an agglutinate-like particle. The particle is composed of unmelted or partially melted basalt clasts (1) and heterogeneous glass (2) cemented by homogeneous glass (3) with disseminated copper droplets and nuggets (4); Black-colored areas (5) reflect pores within the material.

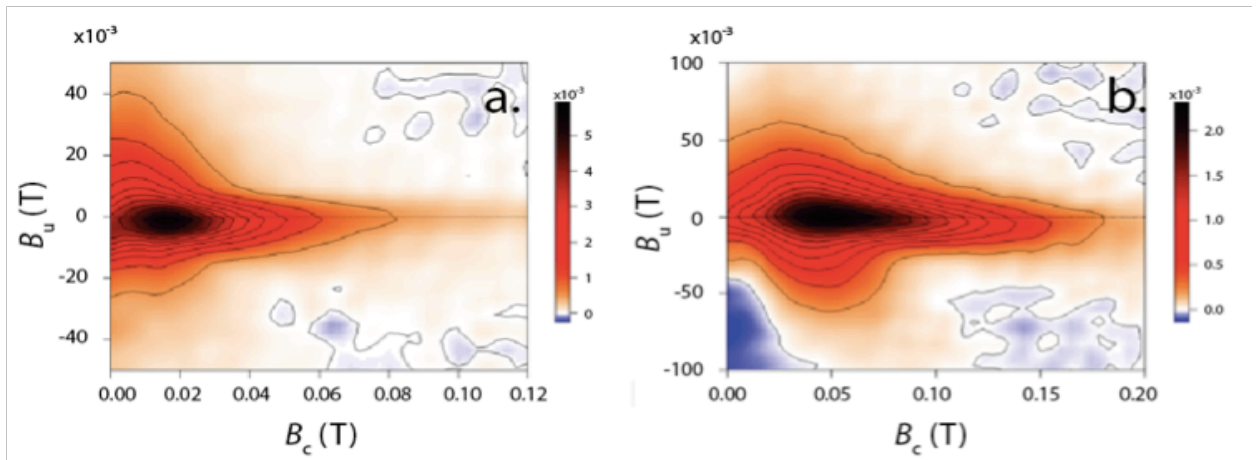


Figure 2. FORC (first order reversal curve) distributions for (a) the unshocked olivine basalt (Kamchatka, Russia) and (b) the corresponding agglutinate-like particle (Cu-basalt particle). FORC data were converted into FORC diagrams using FORCinel software [8].

material, it is helpful to work on their synthetic analogs. To form synthetic agglutinates in the laboratory, we carried out hypervelocity impact experiments using a two-stage light gas-gun at the Institute of Mechanics, M.V. Lomonosov Moscow State University. 5 mm spherical copper projectiles were directed towards four different types of basaltic targets with ~ 6 km/s impact velocities (seven independent shots, see [4-5] for details). Shock-recovery experiments resulted in the formation of agglutinate-like particles similar in texture to lunar agglutinates. These agglutinate-like particles include copper droplets ranging from 1 to ~ 600 μm , unmelted and partially melted basaltic clasts, as well as homogeneous and heterogeneous glasses (Fig.1) [5].

Peak shock pressures were calculated using the shock adiabats of copper and basalts [6]. According to our pressure estimations, the maximum peak pressures of the shock waves ranged between 91 and 132 GPa. The agglutinate-like particles (or Cu-basalt particles) consist of a mixture of materials representing different shock stages. Unmelted basaltic clasts from all shots were shocked to a minimum of 40-45 GPa, as evidenced by the conversion of plagioclase to diaplectic glass.

Thermomagnetic analyses, hysteresis measurements

and low-temperature magnetometry show that unshocked target basalts contain mostly single-domain and pseudo-single-domain (Ti)magnetite grains. Agglutinate-like particles had higher values of coercivity (B_c) and remanent coercivity (B_{cr}) than the unshocked basaltic material (e.g., a factor of 2 to 7 increase for B_{cr}). This coercivity difference is evident in the first order reversal curve (FORC) diagrams for an unshocked basaltic sample (Fig.2a) and the corresponding Cu-basalt particle (Fig.2b). The observed shock-induced magnetic hardening is consistent with previous shock experiments [7].

We observed an increased frequency dependence of the 'out-of-phase' component of magnetic susceptibility of Cu-basalt particles in the 10-300K range (Fig.3b). While this behavior may be interpreted as an evidence of shock-induced formation of nm-sized superparamagnetic grains, MPMS AC measurements of copper standard (see IRM Quarterly 12(1), 2002) and additional numerical simulations instead demonstrate that this is entirely due to the electrical conductivity of the numerous copper droplets in Cu-basalt particles inherited from the projectile.

Our results have implications for terrestrial impact craters in basalts (e.g., Lonar impact structure, India), as

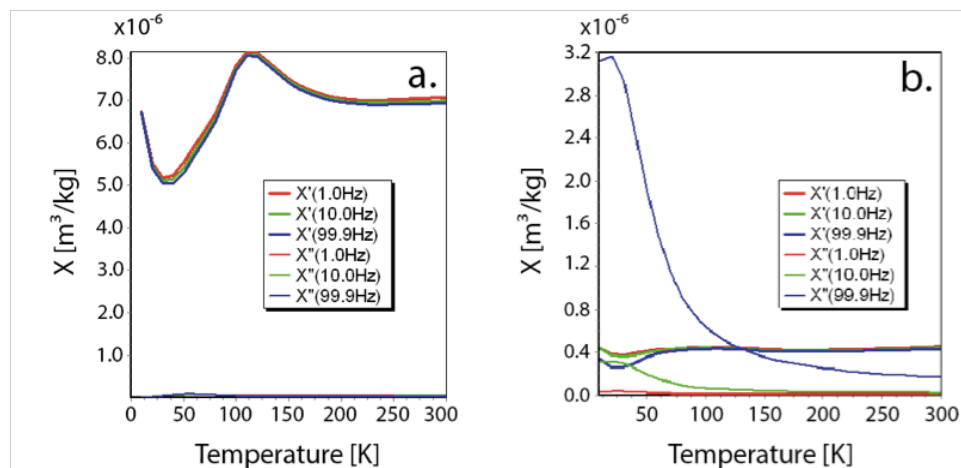


Figure 3.MPMS AC dataset: frequency dependence of 'in-phase' (X') and 'out-of-phase' (X'') components of magnetic susceptibility between 10 and 300K for (a) the unshocked basalt and (b) the corresponding shock-induced agglutinate-like particle (Cu-basalt particle). Minor frequency dependence in (a) between 50K and 100K is a known feature of multidomain titanomagnetite; it is related to rearrangement and localization of Fe^{2+} - Fe^{3+} cations within the domain walls [9-10]. Major frequency dependence in (b) is related to copper inclusions in the agglutinate-like particle (see text).

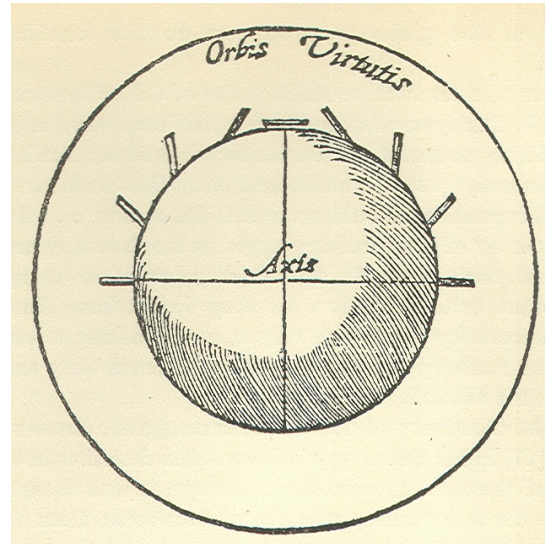
well as for the Moon and other airless solid solar system bodies such as asteroids, where agglutination process is likely to take place. Moreover, basalt is a terrestrial analogue of planetary crustal material and it is known that (Ti-)magnetite is present in the Martian crust. So, although agglutination may be hindered on the surface of Mars due to its atmosphere, impact bombardment of the Martian crust may result in similar features as found in this work.

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**Mike Jackson
of the IRM
is awarded
the 2015
American Geophysical Union
William Gilbert Award!**



**Congratulations to Mike on this
great achievement from all of us
at the IRM!**

**Comment regarding a previous IRM
Quarterly cover article (A long review
from a curt peer: a peek into the peer
review system, IRM Quarterly, 24-3)**

**by Chris Harrison,
University of Miami**

Dear Dario,

I was interested in your article in The IRM Quarterly about reviews of proposed publications. I think that you missed an opportunity of mentioning one of the great mistakes made by reviewers, when they recommended that a paper by Larry Morley should not be published. It takes nothing away from the paper by Vine and Matthews to say that Morley had a similar idea (without the data that Vine and Matthews had). His paper was turned down by both Nature and the Journal of Geophysical Research. It was eventually published by Cesare Emiliani as an appendix to "The Sea volume 7" and one of the comments made by a reviewer is given there. The hypothesis is sometimes called the Vine, Matthews and Morley Hypothesis.

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

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Letter sent to the American Geophysical Union, 29th April 2015, regarding:

Proposed Name Change to the Geomagnetism and Paleomagnetism Section

Dear AGU GP Section Current, Past and Incoming Presidents, In an email letter on 3 April 2015, current and past GP Presidents Andy Jackson and Richard Gordon, respectively, solicited comments on changes to the bylaws of the section. This letter highlighted that the most significant revision was a change in the name of the section to "Geomagnetism, Paleomagnetism and Electromagnetism".

We strongly object to the change in the section name, and would propose a more inclusive, community-driven process to change the GP name, as we explain below.

Our section has always sought to be inclusive, and we certainly wish to include the interested parties of the Electromagnetism discipline. However, adding Electromagnetism to the section name at this time, in our opinion, sends the wrong message with respect to priority and future directions of our community, and by default, such a name begins to exclude other sub-disciplines that compose our growing scientific diversity.

Much like the title "AGU", "GP" represents a wide range of scientific endeavors that are not represented by a literal reading of the name. One prominent example of a growth field active in the GP community is "Planetary Magnetism". An example of a fundamental field is "Rock Magnetism". An example of an arguable nascent field with future growth potential is "Bio-geomagnetism". A strong field solidly within GP is "Environmental Magnetism". We see no justification for giving "Electromagnetism" priority over these other fields, as would be the effect of changing the section name as proposed.

We see the following alternatives:

1. Keep the GP name for branding purposes. GP has a loyal following and, like "AGU" it is a brand. It has worked well in the past, and could serve us well in the future.
2. If change is needed, a wholesale name change to "Earth and Planetary Magnetism," or another similarly inclusive broad name would better represent the core activities of the section for the future.

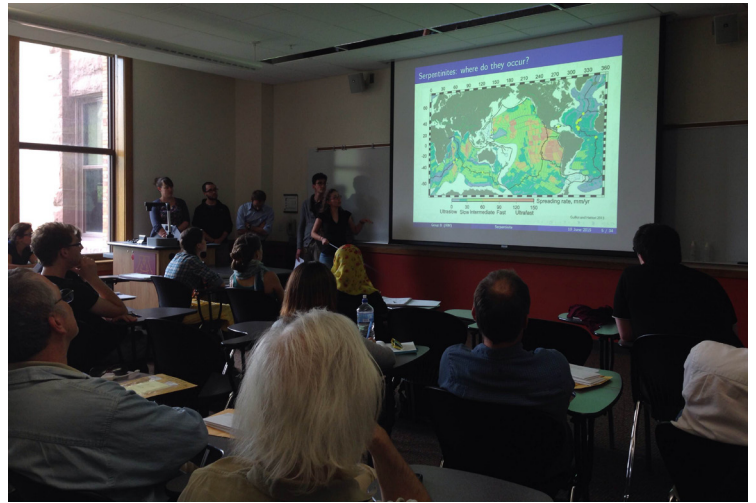
Finally, any name change to the section should first undergo a formal vote by the membership. That vote should be hierarchical. First, members should be asked whether they agree that a change is needed, then they should be given alternative names. Such a vote is a relatively straightforward process to conduct online and would not hinder the timely resolution of the issue. Sincerely,



Gilbert: Natural Magnetism in Smithing.

Erwin Appel (Germany)
 Subir Banerjee (USA)
 Jean Besse (France)
 Andy Biggin (UK)
 Harald Böhnell (Mexico)
 Stefanie Brachfeld (USA)
 Maria Cioppa (Canada)
 Mark Dekkers (The Netherlands)
 Ramon Egli (Austria)
 Karl Fabian (Norway)
 Josh Feinberg (USA)
 Yves Gallet (France)
 Jérôme Gattacceca (France)
 Christoph Geiss (USA)
 John Geissman (USA)
 Avto Gogichaishvili (Mexico)
 Richard Harrison (UK)
 Emilio Herrero-Bervera (USA)
 Bernie Housen (USA)
 Michael Jackson (USA)
 Joe Kirschvink (USA)
 Gunther Kletetschka (Czech Republic)
 Ken Kodama (USA)
 Evgeniy Kulakov (Russia)
 France Lagroix (France)
 Zheng-Xiang Li (Australia)
 Bruce Moskowitz (USA)
 Adrian Muxworthy (UK)
 Norihiro Nakamura (Japan)
 Junsheng Nie (China)
 Hirokuni Oda (Japan)
 Yongxin Pan (China)
 Josep Pares (Spain)
 Sergei Pisarevskiy (Australia)
 Leonardo Sagnotti (Italy)
 Aleksey Smirnov (USA)
 Ian Snowball (Sweden)
 Nick Swanson-Hysell (USA)
 John Tarduno (USA)
 Yoichi Usui (Japan)
 Jean-Pierre Valet (France)
 Benjamin Weiss (USA)
 Wyn Williams (UK)
 Michael Winklhofer (Germany)
 Yuhji Yamamoto (Japan)
 Toshitsugu Yamazaki (Japan)

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Group B presents their results on serpentinization.

acterization measurements were performed, together with substantial unmixing of coercivities. Data clearly showed that the locations of the grab samples define three main regions with distinct magnetic properties, which opened a possibility of interpretations as to sediment provenance and transport mechanisms. Of course, without “control” measurements of the source materials conclusions remain speculations, but never-the-less the project provided insight into the type of information and methodologies that are involved in an environmental magnetic study of ocean sediment.

Group B studied the magnetic properties of natural and synthetic serpentinite samples. Serpentinites are the low temperature (<350 °C) hydrothermal alteration product of mantle peridotite, which generates serpentinite plus magnetite and brucite (plus H₂) from olivine, plus or minus enstatite and water at mid-ocean ridge settings. Serpentinites are widely studied because they pose interesting scientific questions: could their rheology enhance steady-state creep during faulting? How does dehydration during subduction control magma flux and magma chemistry? Does serpentinization provide a fundamental mechanism of hydration of the mantle during subduction? Do magnetic properties of ophiolites provide insights into tectonic processes? Are serpentinites sinks for CO₂? Also, the interaction of carbon and free hydrogen may abiotically produce methane gas and from complex amino acids, which may have implications for the origin and stability of early life on Earth.

Because of the above, serpentinites have been studied experimentally (petrology), through analytical techniques (optical, SEM, EMPA, XRF, Raman spectroscopy), through isotope geochemistry and more recently with rock magnetism. Magnetic evidence points to a correlation between serpentinization temperature and magnetite concentration, and in turn, magnetite concentration may reflect setting and style of ocean-ridge spreading.

Group C investigated the magnetic properties of middle eastern pottery from 800-1000 years before present. The rationale for this project is that archeological artefacts that have been heated up past magnetite’s Curie temperature, very accurately preserve information of the

The IRM has acquired a pXRF!

Read all about it in the next cover article of the IRM Quarterly by post-doc and expert

Ellery Frahm!



Smile for the camera! Students enjoy the finest University of Minnesota sandwiches at the Interstate State Park pic-nic area!

geomagnetic field they cooled in and thus make excellent paleointensity recorders. Main caveats are stable single domain grain sizes and knowledge of the anisotropy degree, therefore detailed magnetic characterization, magnetic granulometry and anisotropy measurements are the basic measurements to be performed to assess the quality of the material as a reliable paleointensity recorder. The findings of group C were that the pottery under investigation from Khirbet Summeily in Israel is not the ideal material for paleointensity studies owing to the low magnetite content, and with varying degree of oxidation. A combination of high and low temperature experiments are the most valuable tools for preliminary rock-magnetic characterization.

The project of Group D involved studying the magnetic properties of the Tiva Canyon Tuff, a rhyolitic flow from Yucca Mountain, Nevada. The Tiva Canyon Tuff displays an increase in magnetic particle size from its base upward: the rapidly cooled base possesses superparamagnetic particles which increase to stable single domain upwards within the flow. About six meters of the flow's thickness had been sampled, and the specimens analyzed provided a picture of the thermal evolution of the flow. A magnetic characterization was performed using low and high temperature techniques, which revealed a magnetite Verwey transition, yet somewhat suppressed, and a Curie temperature of ~ 525 °C, both suggesting Ti-magnetites as the dominant carriers. Hysteresis parameters plotted on a squareness plot (M_r/M_s versus H_c) indicate a range in composition from stoichiometric magnetite to TM60. Plotted on a Day et al. diagram, the specimens mostly plot within the PSD grain-size range, close to (and along) the SD-SP mixing curves, again confirming an increase of grain-size upsection. Magnetic susceptibility as a function of frequency at room and at liquid helium temperatures also clearly show the upward increase of grain size, displaying fre-

quency-dependent SP particles at the base with subdued frequency-dependence towards the top of the stratigraphy.

Taking advantage of the beautiful Minnesota weather, we went on a field trip and pic-nic at Taylor's Falls, Interstate State Park. Taylor's Falls are renowned for some of the largest potholes in the world, carved into basalt by outflow from Glacial Lake Duluth as ice retreated at the end of the Wisconsinian glaciation (~ 11 ka). The basalts are another impressive feature in themselves, since they represent the emplacement products of the Keweenaw midcontinental rift system that initiated and then failed at ca 1.1 Ga.

Above the basalts, a trail permits a short hike to Curtain Falls, a picturesque waterfall within the Cambrian Franconia Sandstone, also displaying primary sedimentary and diagenetic structures.

Downstream the St. Croix river, we made a final stop (before the ultimate ice cream stop, of course) to visit the historic St. Croix Boom Site, where logs cut upstream were collected and sorted, prior to being delivered to the saw mills in Stillwater Minnesota. The boom site operated until 1914, and to give an idea of the amount of timber it went through, during the 1870's logs were frequently backed up for 15 miles upstream!

At the site, the Franconia Sandstone crops out again, only here displaying a multitude of worm tubes... Logs, worms and ice cream, what an end to a beautiful day...

To cap the Summer School experience, the different groups presented their research in an informal symposium. The students gave 15-20 minute talks that highlighted the results and methodologies applied. All groups of course gave stellar performances, demonstrating the knowledge and skills acquired during the Summer School. Undoubtedly, the certificates awarded were all very well-deserved. A party at a local brew-pub ensued,

where everybody had a chance to unwind, eat, have a drink, and of course in the best of IRM traditions, draw a pig whilst blindfolded!

Looking forward to the next three Summer Schools on Rock Magnetism at the IRM!

IRM



Bruce M
6/10/2015



SP RAINBOW
Dario
6/10/15



Pat
6/10/15



Pig Pottery
Michele
6/10/15
Stilling



Mike
6/10/15

In an attempt to eliminate bias into which students' pigs get the "honour" of making the Quarterly, here are pigs from the IRM folk! Ta-da!

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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 Solheid** and **Dario Bilardello**, Staff Scientists.

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