

The 11th Santa Fe Conference on Rock Magnetism



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Group foto taken at the Coyote Call trailhead/ outlook spot within the Valles Caldera during the pre conference field trip. Photo: Anita Di Chiara

The official tourism site of Santa Fe describes Santa Fe, New Mexico, as “a magical, exuberant, colorful journey at any time of year”, and it’s no wonder that Subir Banerjee liked the city so much that he wanted to permanently host the IRM conference on rock magnetism there. Many years have passed since that decision was made and this year marked the 11th occurrence of the conference, not counting the international meetings held at Erice (Italy), Cargèse (Corsica), and Utrecht (The Netherlands).

As always, the meeting was funded by the National Science Foundation with generous donations from Lake Shore Cryotronics, Quantum Design, 2G Enterprises and Frontiers. The support allows the Santa Fe meeting to be free of charge to conference participants, with room and board also included in the package. Most importantly, the format of the conference is different from most meetings, with four topical half-day sessions convened by invited scientists. The conveners then invite 3-4 speakers to give 15-30 minute “lead-talks”, followed by ample time for discussion. Probably unique to the Santa Fe conference are the keynote talks, presented by renowned scientists whose expertise lies outside of rock magnetism, but directly pertains and complements specific research within our community. Last but not least, Santa Fe conferences are capped at 50 participants, ensuring a collegial atmosphere and strong interactions during and outside of the sessions. A pre-conference fieldtrip also

serves this purpose and provides the far-travelled participants the opportunity to get over jet-lag while admiring the local geology and archaeology before the conference kicks-off. St. John’s College has always served the conference very well, providing a relatively intimate and low-key ambiance for a hassle-free experience.

This year’s conference was preceded by a Thursday field trip to the Bandelier National Monument. An area inhabited by ancient Pueblo people between 1150 and 1600 AD, who excavated and built structures in and around the Bandelier ash-flow tuff, the product of a 1.1 Ma eruption, which resulted in the collapse of the caldera and producing the Valles Caldera. Younger rhyolitic products (< 100 ka) erupted within the caldera are “dear” to paleomagnetists because they recorded the Jaramillo geomagnetic sub-chron, which provided the evidence utilized by Vine to confirm the Vine-Matthews and Morley hypothesis of seafloor spreading and continental drift. The field trip ended with a (group) photo-opportunity from the Coyote Call trailhead/ outlook spot within the Valles Caldera, and to admire from afar the famous rhyolite domes and the extent of the caldera.

The conference proper kicked-off on Thursday night with a welcome by IRM director Bruce Moskowitz, who also introduced the first keynote speaker, **Ron Walsworth** of Harvard University. Ron delivered a captivating talk on “Quantum Diamond Sensors”, their development by his team, the functioning principles and the many applications, including for magnetic imaging purposes. Ron also shared his vision for making the QDM technology broadly available across the country and resulting

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Visiting Fellow Reports

Environmental magnetism of lake sediments from Xochimilco sub-basin, to the south of Mexico City

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The Xochimilco sub-basin

One of the most productive and sustainable agricultural systems in the world, called chinampa or 'floating' garden, was developed by Pre-Hispanic civilizations in the middle of the flooded lands of the ancient Mexico City basin. As the Metropolitan Area of Mexico City has disorderly grown and engulfed the southern lands of the Xochimilco lake, where the last relicts of chinampas exist, the region has been registered at the UNESCO World Heritage List to protect them from disappearing (UNESCO, 2013, pp. 192-194). The Xochimilco sub-basin, to the south of the Mexico City basin, is an enclosed volcanic basin where the ancient Xochimilco lake was developed. Nowadays, just a small flooded area still remains. The paleoenvironmental studies in the Mexico City basin help us to better understand the natural context of the civilizations before historic human modification and the climate changes in the center of Mexico during the Pleistocene and Holocene.

Lab procedures at the IRM

A nearly 16-meter sedimentary sequence from the Xochimilco sub-basin was sampled in 8-cm³ plastic cubes every five centimeters to conduct a high-resolution paleoenvironmental reconstruction. The samples were brought to the IRM and hysteresis loops and backfields were measured in VSMs in all samples to obtain the hysteresis parameters, calculate different magnetic ratios and perform magnetic unmixing. Room-temperature FORC and remanence-in-function-of-temperature measurements were also run in selected samples, representative of the different sedimentary facies. Magnetic unmixing was performed on MAX UnMix software (Maxbauer, Feinberg, & Fox, 2016) using detailed 100-step log-spaced backfields with a maximum field of 1.1 T. FORC diagrams were processed on FORCinel 3.06 (Harrison & Feinberg, 2008). Remanence measurements in function of temperature were performed as follows: 1) cooling from 300 K to 10 K in the presence of a 2.5 T field (FC) and subsequent measuring of the remanence on warming back to 300 K; 2) after cooling to 10 K, in

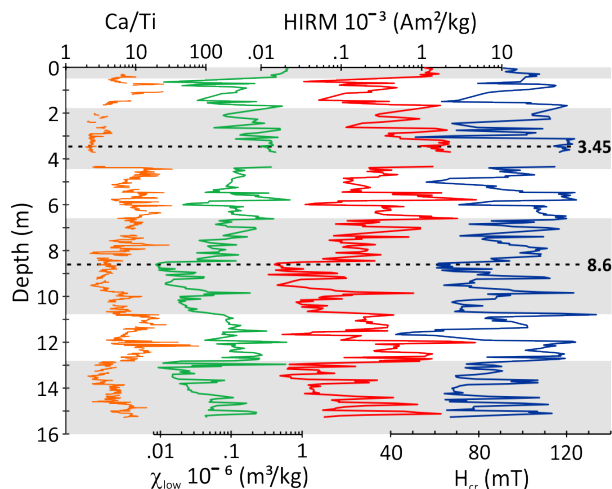


Figure 1. Selected magnetic and geochemical profiles. The pattern of covariation of the four parameters changes at approximately 4.5 meters of depth. This may be attributable to a change of the climatic controlling factors in the Xochimilco sub-basin. Dashed lines indicate depths of the samples with high (3.45 m) and low (8.6 m) HIRM and Hcr values; detailed results of these samples are presented in Figure 2.

absence of magnetic field (ZFC), a 2.5 T field SIRM was applied and the remanence was measured on warming to 300 K; 3) a room temperature saturation isothermal magnetization (RTSIRM) was imparted with a 2.5 T field and the remanence was then measured upon cooling to 10 K (RTSIRM cooling) and on warming back to 300 K (RTSIRM warming).

Results

The HIRM (e.g. Thompson & Oldfield, 1986) and Hcr profiles are plotted in Figure 1 as hard mineralogy proxies, along with normalized bulk magnetic susceptibility (χ_{low}) as an indicator of the abundance of magnetic particles by means of sediment runoff from the basin to the lake. Also, Ca/Ti ratio (an indicator of authigenic carbonate precipitation), which was measured in the Laboratory of Paleoenvironments at the UNAM, is presented. HIRM and χ_{low} covariate closely all along the sedimentary sequence. As an absolute magnetization value, HIRM is affected directly by the abundance of magnetic particles in the samples, but Hcr is not. The latter parameter shows a similar trend as HIRM and χ_{low} , hence the hard mineralogy phases appear to enter the lake with the runoff material. The Ca/Ti ratio also covariates with the magnetic parameters from the bottom of the sequence up to 4.5 meters of depth. This could be a misleading result because the authigenic carbonate precipitation is favored when the lake level decreases, which is assumed to happen in lower precipitation regimes. A better understanding of this phenomena will require information from additional experiments. From 4.5 meters up to the surface of the sequence, the Ca/Ti ratio inversely covariates with the magnetic parameters. This change in covariation has been observed in other sub-basins inside the Mexico City basin, suggesting a regional change of climatic controlling factors rather than changes of local environmental conditions.

More detailed results from samples at 3.45 (upper

sample) and 8.6 (lower sample) meters depth, corresponding to relatively high and low values of HIRM and Hcr (dashed lines in Figure 1), respectively, are presented in Figure 2.

The FORC diagram of the upper sample (Figure 2A) shows diverging contours above 30 mT, a MD-like behavior (Roberts, Pike, & Verosub, 2000). Even though also SP-like features can be observed, namely the contours are not symmetrical, the main peak is lower than ~10–20 mT and a vertical contour plots in the lower left-hand portion of the diagram. The wide spreading of the contours along Bc-axis (~450 mT) indicates the presence of a high coercivity mineral, possibly hematite, as a similar FORC diagram was observed by Ahmadzadeh, Romero, & McCloy (2018) in a commercial mixture of 99% hematite + 1% magnetite. The lower sample has a very low intensity and, as a result, the FORC diagram was noisy (Figure 2B). The diverging pattern of the contours is not as clear as in the upper sample, but it is present in all the contours. The main peak occurs near the origin, around 10 mT. We conclude that this is attributable to a MD-state magnetite component. There's a secondary peak around 100 mT which is slightly moved below the Bc-axis and is indicative of hematite.

Unmixing of the upper sample (Figure 2C) shows two components with mean coercivities (Bh) of 2.17 log10 units (~148 mT) and 1.57 log10 units (~37 mT); dispersion parameters (DP) of 0.31 and 0.44; and observed contributions (OC) to the total coercivity distribution of 75% and 25%, respectively. Additionally, the low-coercivity component showed a skew-left distribution, with S=0.87. We interpret the high-coercivity (High-Bh) component as hematite, as suggested by the FORC diagram. Both the IRM demagnetization curve and the coercivity distribution (dM/dlog B) (Figure 2C) are very similar to the 99% hematite + 1% magnetite mixture mentioned above (Figure 4a in Ahmadzadeh et al., 2018), strengthening the interpretation of hematite in the sample. For the low-coercivity (Low-Bh) component we have interpreted it as partially oxidized titanomagnetites, with different degree of oxidation. The relatively high DP of a secondary component with similar Bh (1.51) has been interpreted as the result of an increase of the range of coercivities due to partial (or full) oxidation of magnetite (Maxbauer et al., 2016). Unmixing couldn't be performed for the lower sample as the data was too noisy for the derivation process.

The normalized curves for measurements of remanence in function of temperature are shown in Figure 2. Remanences for FC and ZFC curves are normalized to the remanence at 10 K of the FC sequence. RTSIRM curves are normalized to the SIRM at 300 K before cooling. A first observation is the lack of Verwey transition (TV) in FC and ZFC curves from both samples, as pointed out by their first derivatives (dashed lines in Figure 2D and E). It is slightly visible on the RTSIRM cooling curve of the 3.45-m sample, around 106 K. The lowering of the temperature of transition, the suppression of the transition on FC/ZFC curves and the humpiness of RTSIRM curves, especially on cooling, could be due to

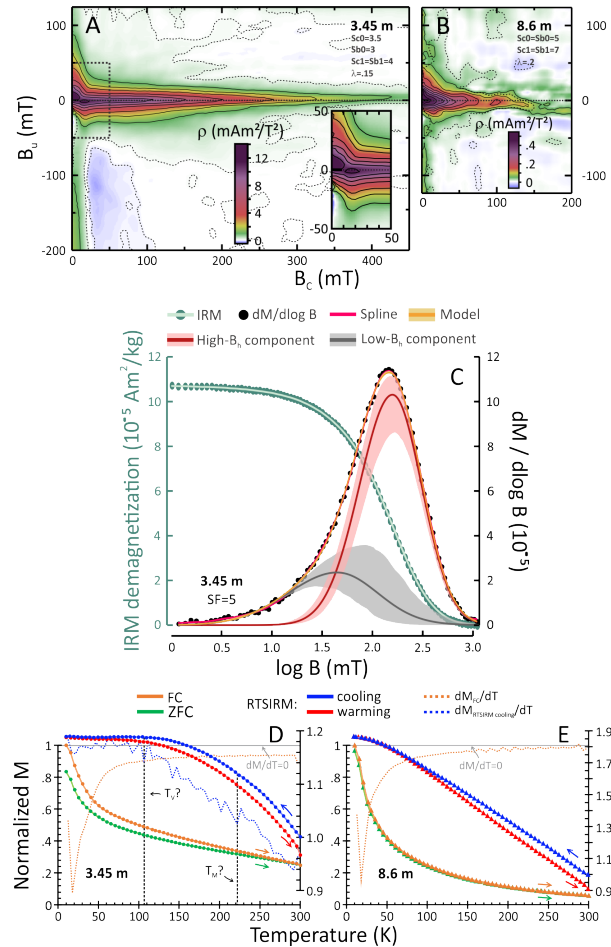


Figure 2. FORC diagrams of the A) upper (3.45 m) and B) lower (8.6 m) samples. Dashed box in A shown as an inset. C) Unmixing of the upper sample. FC, ZFC and RTSIRM cycling of the D) upper sample and E) lower sample. Gray horizontal line denotes $dM/dT=0$. TV: Verwey transition; TM: Morin transition. Remanences are normalized (see text). Note that the scale is the same for FC/ZFC curves, but not for RTSIRM curves. Arrows denote the direction of temperature change while measurements were performed.

low-temperature oxidation (maghemitization) of magnetite (Özdemir & Dunlop, 2010; Özdemir, Dunlop, & Moskowitz, 1993). This observation supports the low-Bh component hypothesis in the unmixing. Additionally, a slight decrease of the derivative of the RTSIRM on cooling points towards a Morin transition (TM) around 220 K, supporting the presence of hematite particles. The upper sample shows a separation of FC and ZFC curves up to 300 K and an increase of remanence upon cooling of RTSIRM, two features observed in high coercivity, unsaturated materials, namely goethite (Guyodo et al., 2006; Rochette & Fillion, 1989). Even more, Guyodo et al. (2006) confirmed the presence of this mineral, mixed with magnetite and hematite, on natural samples with remarkably similar FC and ZFC curves than the one here presented for the upper sample. On the other hand, the FC/ZFC curves of the lower sample are highly reversible, indicating no substantial difference of FC against ZFC routines. During warming, approximately 60% of the magnetization is lost below 50 K, and the final relative remanence is just 5% of the initial, indicating that the mineralogy is dominated by minerals with re-

manence at low temperatures, but that are paramagnetic at room temperature. The large increase of RTSIRM upon cooling, nearly a two-fold increase (note the different scaling in Figure 2E), suggests again the presence of a magnetically unsaturated material. Similar behavior was observed by Lagroix & Guyodo (2017) in synthetic goethite powder composed of micrometer size needle crystals (30x350 nm). As the samples analyzed here are natural and possibly mixtures of different magnetic minerals, we expect deviations from the results of synthetic materials. Finally, in both samples, there's an initial loss of remanence (below $T < 50$ K) on the FC/ZFC curves that is characteristic of superparamagnetic nanoparticles (Reynolds et al., 2014).

For the Xochimilco sub-basin, some magnetic measurements (initial χ , ARM, hysteresis parameters, k-T measurements) had been reported to date (Ortega-Guerrero et al., 2018). More detailed characterization of the mineralogy and domain state lacked for this sub-basin, hence a more complete interpretation of the environmental and climatic conditions that controlled the deposition, source and transformation of the magnetic mineralogy can be now assessed.

Acknowledgments

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Visiting Fellowship Awardees

Concragutulations to the 2019b Visiting Fellows!

Solomon Akatakpo, VF, University of Texas at Dallas
 Sebastian Fearn, USVF, University of Wisconsin-Milwaukee
 Daniel Maxbauer, VF, Carleton College
 Congcong Gai, VF, Australian National University
 Min Zhang, VF, Chinese Academy of Sciences
 Boris Reznik, VF, Karlsruhe Institute of Technology
 Pablo Calvín, VF, Universidad de Burgos
 Jessica Til, VF, University of Iceland

Visitor Categories:

VF= Visiting Fellowship (10 days)
 USVF= US Student Fellowship (5 days)

ERRATUM

Jude Osamor, Imperial College was erroneously omitted from the list published in the IRM Q28-4. Jude was a VF in the 2018a period.

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.

Archaeomagnetism

- Aldazabal, V., M. Reinoso, G. Custo, L. Cerchetti, E. B. Halac, G. Polla, and E. Freire (2019), Characterization of Natural Pigments from the Archaeological Context of Trafal Lake (Neuquen, Argentina), *Latin American Antiquity*, 30(1), 127-141.
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Environmental magnetism and Climate

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in “next generation” instruments to be installed soon in Berkeley (West Coast) and the IRM (Midwest), together with the one(s) already functioning at the home institution (Harvard, East Coast).

The keynote lecture was followed by a cheese and wine reception on the terrace kindly sponsored by Frontiers.

The Friday Morning Session, titled “Fundamental rock magnetism, micromagnetic modeling and imaging”, was chaired by **Claire Nichols** (MIT) and **Josh Feinberg** (IRM).

The first talk was given by **Lesleis Nagy** (Scripps Institution of Oceanography) on “Micromagnetic modeling of thermal stability”. Lesleis provided an overview on the state of the art of micromagnetic modeling, its principles, minimizing the competing energies within grains of different shapes and grain sizes, and made a convincing case for a positive correlation between models and theory. A database is being developed for user-friendly modeling of grains of varying size, shape and stoichiometry.

Karl Fabian (Geological Survey of Norway, NGU) delivered a talk on “Determining particle moments from magnetic microscopy and XRCT”. Karl detailed the limitations one faces when inverting data from scanning methods, involving scale and resolution, the temperature of the measurements (the “Kelvin problem”), the fields in which the measurements are performed (“Tesla problem”), the number of particles that can be measured to obtain a significant statistical average (“Boltzmann problem”), and the non-uniqueness of the inversion solutions (the “Maxwell problem”). These limitations may be circumvented with the combination of the newer QDM and X-Ray Computed Tomography (XRCT) technologies. It is mathematically proven that it is impossible to uniquely reconstruct the magnetic sources from surface field measurements alone; however, grain geometries and locations may be obtained by high-resolution XRCT and these can be fed into inversion algorithms to obtain moments. The other limitations can be circumvented today with the QDM. Nevertheless, “Boltzmann” may still have the last laugh and be the largest limiting factor in obtaining “natural” $\sim 10^6$ particle averages.

James Bryson (Cambridge University) concluded the session with a talk on “Using x-ray photoemission electron microscopy as a paleomagnetic tool”. James discussed using XPEEM to study the cloudy zones in tetraenite rims in meteorites, allowing investigation of long-term thermo-chemical evolution of taenite-tetraenites. James presented an improvement on paleomagnetic applications from multiple observations on groups of meteorites and concluded that paleointensity estimates are probably lower than previously stated, with accompanying lower uncertainties. Moreover, since the cloudy zones form by spinodal decomposition rather than by nucleation and growth of the tetraenite islands, the gradient in island size is no longer thought to correspond to a distribution of ages, and the previous interpretation of

time-resolved paleointensity no longer holds.

The afternoon Session was presided by **Ramon Egli** (Central Institute for Meteorology and Geodynamics (ZAMG)) and **Nicholas Swanson-Hysell** (UC Berkeley), and titled “Processing Procedures and Protocols: Pitfalls, Progress and Promise”

Lisa Tauxe (Scripps Institution of Oceanography) opened the session with a talk on “Domain states and magnetic characterization”. Lisa started by questioning the curvature that is sometime observed in Arai plots that is generally attributed to MD grains, and investigated domain stability through different processes, ranging from the drop in viscosity associated in the reversal of a SD moment through a vortex state, and the differences between TRM and ARM acquisition from a domain state perspective. The relevance to Arai plots and paleointensity determinations pertains to the thermal demagnetization behavior of grains, as opposed to the acquisition mechanism, which may not be along the same path or in the same domain state. Lisa also emphasized that it is not possible to use hysteresis properties to evaluate whether samples will behave reliably in Thellier experiments.

Anna Lindquist (Macalester College) delivered a talk titled “TEM techniques for magnetic materials”, and provided a useful overview of many microscopy techniques that are relevant to magnetic applications. Anna showed mesmerizing “real time” Lorentz microscopy

videos of wall domain motion and pinning as a function of stress-generated dislocations and twin formation impediment during the Verwey transition in magnetite.

Ramon Egli (ZAMG), gave a presentation on “Seeing thermal activations with FORC diagrams from the PMC3900 VSM and the new Lake Shore 8600 VSM”. The talk focused on the enhanced sensitivity of the new generation VSMS, through the application to thermal activations. Thermal activation generates an asymmetry in FORC measurements, which results in a measurable offset in a FORC central ridge. Assuming the ridge is due to SD grain response, from the offset one can calculate particle moment assuming Stoner-Wohlfarth theory. From there it is possible to successfully back-calculate the mean particle length and axial ratio for those grains.

For the first time at a Santa Fe conference, a poster session was held at the end of the Friday talk sessions. Poster presentations had been introduced by 1 slide-2 minute “lightning talks” (in lieu of Subir’s one overhead talks), and the poster session followed in the adjacent room. About 20 posters were hung on precarious easels and flimsy boards (something to improve on), but the session overall worked and offered every participant the possibility to present and discuss their research. “Discussion” is the mission of the Santa Fe meeting and the collegial setting allowed for extensive interaction and feedback to be provided for the whole duration of the conference.



Gary Scott gives an impromptu talk on the Jemez Volcanic Field, the formation of the Valles Caldera and the importance of the Jaramillo “event”. Photo: Anita Di Chiara.



Shelby Jones-Cervantes points out "clay pockets" within fallout deposits which were collected by the autochthonous people for the production of artifacts. Photo: Anita Di Chiara.

Saturday opened with a Morning Session on "Environmental magnetism and Biomagnetism" chaired by **France Lagroix** (IPGP, France) and **Jessica Till** (University of Iceland).

Mark Dekkers (Utrecht University) talked about "Magnetic properties in the geosciences". Mark presented two topics. One revolved around two greigite populations identified in a fresh/brackish water system in Hungary: a hard S-type framboidal greigite carrying a primary remanence, and a second softer M-type greigite which grew and acquired remanence over 10ka's. These components can be distinguished using thermal demagnetization in small increments and the derived magnetostratigraphy refines the biozone ages. Unmixing of coercivity spectra fully allows separating the two contributions to the remanence.

The second topic was more unusual and described freshwater filamentous "cable bacteria" (desulfobulbaceae) that are capable of conducting electricity throughout the sediment. In doing so, ~90% of the sediment oxygen is taken up, resulting in the oxidation of sulfide.

Open questions posed are: can these bacteria affect the

primary nature of a DRM? Do they record short-lived features of the geomagnetic field? How can their signature be recognized in old sediments? And lastly, because the bacteria effectively add a horizontal component to the Earth's magnetic field, do they contribute to inclination shallowing?

Ioan Lascu (Smithsonian Institution) followed by "Hunting for magnetofossils in deep time". Ioan investigated the 1.9 By Gunflint Chert Fm., famous for the putative discovery (and questioned by some) of ancient stromatolites and magnetotactic bacteria (MTB) chains, by conducting FORC measurements, using Focused Ion Beam nanotomography to image particle morphology and distribution, and feeding these into micromagnetic models. The first outcome was that within the sample collection of the Smithsonian, the MTB-like central ridge of FORC diagrams is of too high coercivity. Most of the magnetization of the sample analyzed resides in tabular siderite structures that have been converted to magnetite. These structures are responsible for the FORC distributions identified and the question remains open as to whether the MTB-like chains identified in earlier microscopic studies truly belong to MTB or whether central ridges on FORC diagrams are fingerprints for magnetofossils. As a side-note, the secessionists within our community might take a hit from the notion presented by Fabian that the tabular structures identified possess a "true" PSD behavior, which is independent of vortex structures.

Pete Lippert (University of Utah) discussed "Environmental magnetism in deep time". Pete touched upon multiple case-studies and examples to drive three main points home: the usefulness of in-situ imaging; the importance of collaborative research with specialists that are outside of our community; and diagenesis being the elephant in the room when dealing with deep time (and raising the question of "how deep is deep?", one may add). The points were illustrated through three study vignettes.

The first described a study of rock/fluid interactions which revealed cryptic remagnetizations, while initial rock-magnetic characterization had suggested ideal paleomagnetic carriers; oxidation of pyrite may produce nice single-domain magnetites. The second involved the study of ocean sediment and how to use magnetic properties to identify source processes, in settings where the magnetic signature may have become biased. Pete highlighted the importance of correlating magnetic grain size to sieved sediment fractions as done by Hatfield et al. (2013, EPSL), though not touching on the further "bias" introduced by magnetic inclusions that those authors discussed. The third vignette illustrated the usefulness of studying sediment ecology by combining component-specific magnetic taphonomy with benthic foraminifera.

Isaac Hillburn (Caltech) gave an "outside the box" talk on "New experimental techniques to test biophysics of magnetoreceptors". Isaac detailed the progress of Caltech studies involving human magnetoreception and the difficulties encountered, including imparting IRMs to the heads of (live) human subjects. The latest results

derive from experiments where subjects are placed within coils that allow for rapid and un-interrupted reorientation of the magnetic field generated. Results so far have been tantalizing, with evidence that humans may be able to detect changes in the ambient field. On a different note, Isaac also discussed the development of a protocol within the RAPID system that allows acquisition of remanent FORCs within a SQUID magnetometer. These utilize IRM pulses and allow for samples larger than most VSMs can accommodate to be measured, integrating over a larger volume, effectively smoothing out heterogeneities within samples, while maximizing the remanent response. All of this, while allowing measuring multiple samples automatically, a win for research and development (we are patiently waiting for the FORC-in-the-brain experience).

After the lunch break, **Raimund Muscheler** from Lund University delivered the second keynote lecture on “Separating solar and geomagnetic field signal contributions to cosmogenic radionuclides”. Raimund gave an in-depth presentation on the coupling between solar wind and Earth’s geomagnetic field and its nuances in modulating the production of ^{10}Be and ^{14}C . Raimund showed how globally-observed magnetic anomalies generate disparities in the amount of solar radiation received at equal northern and southern latitudes, which serves the basis for studies of cosmogenic radionuclide production.

A prominent feature of the “recent” Earth field is the Laschamp excursion. It is useful because it stands out globally and allows dating of Greenland versus Antarctica cores, for example. It allows dating of sediments and synchronizing timescales, including ^{14}C timescales to those obtained from ice cores. Recognition of the Laschamp aids carbon cycle studies and determining the lock-in depth of different sedimentary records.

A generally good correlation between proxies is observed, e.g. highs in the 100 yr delta ^{14}C curves coincide with lows in solar activity, making it possible to separate the solar from the geomagnetic contribution to radionuclide production, which is successfully being attained using Bayesian methods.

The afternoon session on “Highs and lows of short-term geomagnetic field behavior” followed suit and was chaired by **Maxwell Brown** (University of Iceland) and **Catherine Constable** (Scripps Institution of Oceanography).

The first talk was delivered by **Catherine Constable** who talked about modeling short-term geomagnetic field behavior in a presentation (sub?) titled “How high, how low, how fast, how slow”. Cathy made a clear distinction between data-based field models and numerical dynamo simulations, and detailed the pros and cons of dynamic simulations of the Earth’s field highlighting how the large variability in parameters make results difficult to compare and apply to direct observations. In particular, one needs to carefully evaluate the time scale that is most relevant to the process under investigation.

A relevant question is: what is causing the small-scale variations of the field and what are we missing when we don’t see them? An important point is the geographical variability of field observations, for example the duration of the Laschamp varies between 0 to 5 ky depending on the “observation site”.

Ron Shaar (Hebrew University of Jerusalem) spoke on “Synchronizing high resolution lacustrine and marine DRM records with archaeomagnetic TRMs: a natural laboratory in the Levant”. Ron carefully discussed the differences of paleointensities that can be obtained from TRMs and DRMs and separated the talk into absolute versus relative intensity records. Absolute records obtained from archaeomagnetic data have allowed to precisely synchronize records from different regions. Detailed records across the middle East clearly show how the Levantine spike is made up of two intensity spikes separated by increased inclination of the natural remanence, as predicted by models.

Ron investigated the Levantine spike from a sedimentary record perspective also. The dramatic falling levels of the Dead Sea have uncovered sedimentary sequences that unfortunately are not old enough to capture the spike. Certain levels contain primary greigite which grew fast and provides an accurate recording of the field with no inclination shallowing. Some samples have a GRM component, however, but others do not acquire GRM at all.

From cores collected in the Mediterranean, magnetic records do not reveal the inclination spike and thus do not agree with the TRM data. The culprit is likely the elephant in the room discussed by Lippert, diagenesis.

Ricardo Trindade (University of Sao Paulo), followed with a presentation on “Paleofield records in speleothems”. Ricardo convincingly showed how the magnetization recorded in speleothems is of pedogenic origin and can accurately document annual climate cycles, with layers deposited during dry periods containing low concentrations of magnetic material, whereas the wetter periods contain higher concentrations. To properly interpret the magnetic signatures, however, it is fundamental to properly understand the system and specifically how



Karl Fabian poses in chambers excavated within the compacted ash at Banderlier National Monument. Photo: Anita Di Chiara.

speleothems are precipitated. First the CO₂ is outgassed in the cave, then the pH becomes equilibrated, permitting precipitation of calcite and acquisition of the magnetization, which truly records a DRM. The resolution at which the DRM is investigated can vary largely, centennial to millennial scales can be extrapolated using a 2G magnetometer, however, finer, annual, scale resolution is attainable using a QDM.

The last invited talk of the conference was given by **Andreas Nilsson** (Lund University), who presented “Modeling Holocene field variations and pDRM acquisition in sediments”. Andreas discussed the usefulness and caveats of sediments as recorders of geomagnetic field variations at various timescales. However, pDRM bears significant effects on the signal: the delay of the remanence acquisition results in smoothing of the record on top of the systematic time-offset (lock-in depth) which is controlled by the sedimentation rate. These mask important short-term variations and can impede dating applications and affect models. Andreas utilized detailed stratigraphic information obtained from varved lake sediments and existing field models to reconstruct the geomagnetic field evolution and independently tested results against ¹⁴C curves. Pre-requisite is a field model based on TRM data against which to test the effects of

locking-depth to obtain consistent age-depth models.

On Sunday, **Wyn Williams** (University of Edinburgh) led an all-day technical workshop on “Micromagnetic modeling with MERRILL”. Wyn gave a lecture on the history and fundamentals of micromagnetic modeling, and introduced the MERRILL software package that he and his group wrote to generate the models. Important to note, modeling magnetizations is probably the easiest part, but generating meshes that adequately reproduce grain geometries and assemblages of grains is not a straight-forward nor quick task and requires proprietary software. Wyn had prepared many example files containing a variety of grain sizes and geometries that participants used to learn the nuances of MERRILL and the necessary image rendering software. **Lesleis Nagy** provided invaluable assistance around the room, allowing the participants to generate the internal magnetization models, hysteresis loops and lastly stray field models of core-shell geometries.



Constructions and chambers excavated within the compacted ash at Bandelier National Monument. Photo: Myriam Kars.

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

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