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Inside...

The Tenth Santa Fe^{3+} Conference on Rock-Magnetism

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While the world was glued to its televisions eagerly following the 2014 football World Cup, a different, more exciting international event was taking place in a remote college campus in New Mexico, drawing together over 50 top players from all over the world: The 2014 Tenth Santa Fe Conference on Rock Magnetism, June 26th-29th.

Tailgating started on Thursday 26th, when John Geissman (UT Dallas) and Michael Petronis (New Mexico Highlands University) led ~20 participants on a geo-archeological field trip. The morning was spent visiting the San Marcos Pueblo archeological site, guided by Bill Baxter (the Archeological Conservancy) and John Ferguson (UT Dallas and SAGE). The site is located within the Galisteo Basin, which had been inhabited by Paleo Indians as early as 7500 to 6000 B.C. Pueblo San Marcos, one of the largest pueblos in the Southwest in the 15th and 16th centuries, was the site of significant 'cultural contact' and by the 17th century, Spanish Jesuits began construction of a mission inside the pueblo. Archeological excavations were started in 1912. The pueblo is thought to have controlled the Cerrillos turquoise and lead mines for many centuries and was a major manufacturing center for Rio Grande Glazeware ceramics, as testified by the countless ceramic shards and somewhat less abundant turquoise fragments which were encountered on the archeological walk.

In the afternoon, the group was led on a geology trip, mostly aimed at exploring the Laramide/ Rio Grande Rift relationships in the Galisteo area, where Laramide laccoliths belonging to the Cerrillos Hills Igneous Complex are cross-cut by dikes, intruded as a result of the regional stress change. The sills forming the laccoliths are ~34 My old quartz-bearing andesite-latite porphyry, which were intruded ~30 My ago by quartz-poor latite and monzonite dikes and stocks, the latter forming the highest hills of the Cerrillos. Lead-, zinc- and silver-bearing veins along northeast-trending fractures formed within ~1 My. More details can be found in the field trip guide on the IRM's website.

The starting whistle was officially blown by IRM director Bruce Moskowitz later in the evening, who gave a welcome speech and introduced the keynote lecture. By design and by tradition, the keynote talks are meant to provide transdisciplinary perspectives and are from outside the "strictly-magnetism" domain. This year, the kick-off talk was delivered by Frieder Klein from Woods Hole Oceanographic institution who offered a marine/ geochemists' perspective on "Magnetite in Seafloor Serpentinite," an appropriate topic to introduce next morning's session on Ocean Crust magnetization. Case studies from ODP legs 209, 173 and 125 showed that high-temperature (~300°C) serpentinization produces abundant magnetite, whereas in lower-temperature serpentinization most of the available iron ends up in paramagnetic brucite. For details see Klein et al. [2013] or view his talk on the conference web site (http://www.irm.umn.edu/SantaFe10/Photos & Downloads.html).

"Group photo" at Devil's Throne, an Oligocene hornblende-latite porphyry. (photo by Betsy Leach)

A reception followed on the venue's terrace, where meeting participants could enjoy the company of new and old friends in the warmth of a classic New Mexico evening.

The Santa Fe Conference on Rock Magnetism has a different format than most scientific meetings: there are no concurrent sessions, and ample time is left free between talks for in-depth discussion (and sometimes confrontation). All talks are invited by the session conveners, which are in turn invited by the conference organizers, who also propose the session topics. Occasionally the conveners may accept a voluntary submission by other conference participants in the form of a small, up to 5 minute, contribution or give such a mini-talk themselves to promote discussion and better tie-in the different talks of the session.

This year's meeting first session, on Friday the 27th,

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Visiting Fellows' Reports

Transition of magnetic fabric types in fine-grained sedimentary rocks.

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The main goal of the Visiting fellowship project was to perform a high-field AMS approach, using directional magnetic hysteresis measurements, on deformed, low-grade metapelites of Palaeozoic Armorica (France). Furthermore, magnetic remanence demagnetization and low temperature experiments have been performed in order to identify the ferromagnetic (s.l.) phases present in these rocks. The project is part of a larger project that investigates the behaviour of the rock's AMS in progressively deformed, metasedimentary rocks undergoing a transition of an intermediate to a tectonic magnetic fabric type. Because, we're interested in the magnetic fabric due to the paramagnetic, rock-forming minerals, i.e. phyllosilicates and chloritoid, the high-field approach is necessary to isolate their contribution from that of possible ferromagnetic (s.l.) phases present.

Alternating-field demagnetization, using peak AF fields up to 170 mT, of a 1 T IRM and a 200 mT ARM, shows strongly variable coercivity ranges for the different samples. 11 out of 24 samples have a median destructive field of the 1 T IRM below 50 mT and hence, have a rather low coercivity. Out of the other samples, nine still have more than 25% of the initial remanence left after the procedure, indicating that the applied field range is quite ineffective in demagnetizing these samples and hence, a significant part of the remanence is carried by hard (anti)ferromagnetic phases.

The low temperature experiments consist of two measurements series. In the first series, the thermal demagnetization of a saturation isothermal remanent magnetization (SIRM) imparted at 10 K is measured from 10 K to 300 K, both after cooling in the presence of a 2.5 T field (field-cooling, FC) and after cooling in a zero field (zero-field-cooling, ZFC). Secondly, a room temperature SIRM is cycled to 10 K and back up to room temperature. Both FC and ZFC curves display a continuous decrease in magnetization with increasing temperature. The temperature at which both curves merge varies strongly for the different samples, i.e. it ranges from 75 K to more than 300 K (see Fig 1a). This is interpreted as the effect of goethite particles that become thermally unblocked and that have a variable size distribution and blocking temperature (TB) over the different samples [cf. Guyodo et al., 2003]. However, also note that for some samples there is hardly any difference between the FC and ZFC SIRM at 10 K. In these samples, goethite is not likely to be the dominant ferromagnetic (s.l.) phase present. The RT SIRM curves often show a rather continuous increase with decreasing temperature. This is interpreted as an effect of a rise in saturation magnetization with decreasing temperature and hence, it could be attributed to goethite, which is far from being saturated by the 2.5 T field at room temperature. Furthermore, nearly all samples show some decrease in the trend of the cooling curve when cooling through the Verwey temperature, $T_V \approx 120$ K (see Fig. 1b). This drop in remanence is not recovered when reheating. Therefore, it looks like magnetite particles are also present in these samples [cf. Özdemir and Dunlop, 1999; Dunlop, 2003].

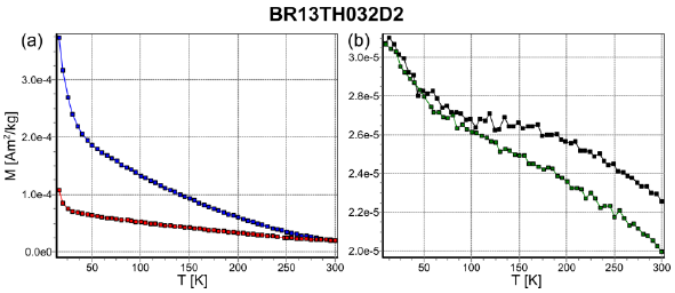

Fig 1. The (a) ZFC (red) and FC (blue) SIRM behaviour during heating and (b) RT SIRM behaviour on cooling (black) and heating (green), are indicative for the presence of both goethite and magnetite.

So, the remanence experiments have shown that the ferromagnetic contribution to the Armorican metasediments' magnetic susceptibility and anisotropy is carried by both magnetite and (nano) goethite minerals. This is problematic for our HF-AMS approach, which uses a VSM with a maximum applied field of 1 T, because it is not possible to saturate the contribution of the goethite particles. However, the remanence of all samples is very weak. Low temperature magnetization curves show a nearly perfect behaviour according to the Curie-Weiss law and also, the hysteresis loops show an (almost) perfect linear behaviour. Hence, the effect of these particles on the HF-AMS properties should be rather limited.

The HF-AMS approach consisted in measuring a magnetic hysteresis loop (max applied field of 1 T in field increments of 10 mT) in 24 directions and calculating the (paramagnetic) high-field susceptibility κhf for each direction from the slope of a linear fit of the high-field part of the loop (> 700 mT). As this approach is quite sensitive to geometrical effects (shape of the cubic specimens, imperfect centering, etc.), the idea was to normalize the different directions by the saturation magnetization, Ms, which is an isotropic property. However, because of the very weak ferromagnetic (s.l.) contribution to the induced magnetization, Ms is poorly defined. As a consequence, normalizing κ_{hf} by Ms only makes the error on the HF-AMS tensor worse (i.e. errors of 30 to 70° on the direction of the principal magnetic susceptibilities). So, the inability to quantify Ms biases the accuracy of the HF-AMS approach [cf. Bilardello and Jackson, 2014]. We had to use the unnormalized data (only

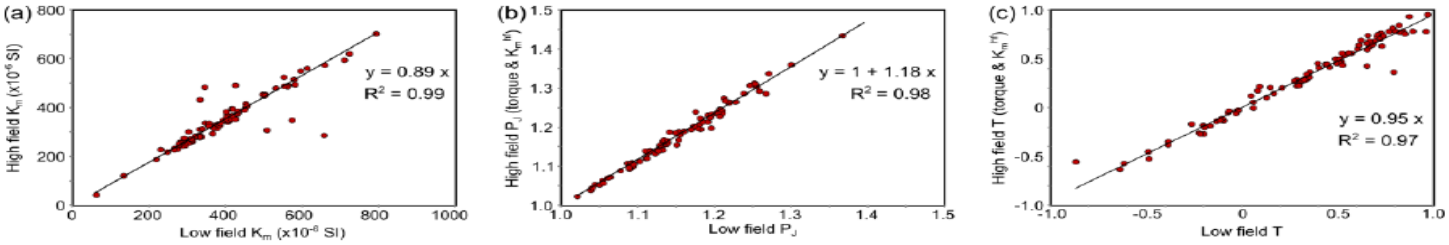

Fig 2. Plots of the high field vs. low field value of (a) the bulk susceptibility Km (note: R^2 coeff. is calculated without outliers), (b) the corrected degree of anisotropy P_J and (c) the shape parameter T, respectively.

corrections for the common measurement positions between the different rotation sets have been made) and therefore, the HF-AMS is likely affected by geometrical effects typical of measuring anisotropy on a VSM. This is confirmed by the large errors on the direction of the principal magnetic susceptibilities, i.e. 20 to 60°.

Therefore, we used the directional hysteresis approach only to determine the paramagnetic bulk susceptibility, K_{mhf}. The paramagnetic anisotropy is obtained from high field torque magnetometry, performed prior to the visiting fellowship. Fig. 2a shows a comparison of the obtained K_{mhf} values and the low-field Km values determined with a kappabridge. Except for 5 outliers, the graph shows a very good linear correlation with K_{mhf} being ca. 89% of K_m. Hence, it looks like 89% of the bulk (low-field) susceptibility of the Armorican metasediments is due to the paramagnetic minerals. However, the consistent value (i.e. strong linear trend) could also argue for some kind of instrumental effect. Finally, Fig. 2b and 2c show a comparison for the degree of anisotropy, P_J, and the shape parameter T between the paramagnetic (high-field) parameter (y-axis) and the low-field parameter (x-axis), respectively. Both parameters show a strong linear relationship. It can be noted that for P_J, the isolated paramagnetic (high-field) parameter is consistently a bit higher than the low-field value. This can be interpreted in two ways. Either, the small ferromagnetic contribution decreases the low-field P_J value somewhat, or alternatively, the discrepancy is merely related to the consistently lower Kmhf compared to the low-field K_m because of the instrumental effects (note that the deviatoric paramagnetic tensors are very similar).

In conclusion, magnetic remanence demagnetization and low temperature experiments have shown that the investigated Armorican metasediments contain some (nano)goethite and magnetite particles. Their contribution to the rock magnetic susceptibility and its anisotropy is however, very limited. The VSM approach to measure magnetic anisotropy is biased by the inability to quantify Ms and therefore, only the paramagnetic bulk susceptibility (K_{mhf}) values are used from this approach. Except for 5 outliers, K_{mhf} shows a very strong linear correlation with low-field K_m, albeit 11% lower than the latter. It is not clear whether this difference is real or due to an instrumental effects. The full (paramagnetic) HF-AMS tensors are calculated from K_{mhf} and deviatoric paramagnetic tensors obtained from high-field torque magnetometry.

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The next Visiting Fellowship application deadline is October 31, 2014.

John Ferguson (UT Dallas and SAGE) Explains the geological context of the San Marcos Pueblos site. (photo by Betsy Leach)

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.

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John Geissman (UT Dallas) reviews the geology and evolution of the Rio Grande Rift. (photo by Mike Jacskon)

Bill Baxter (the Archeological Conservancy) points to room wall remains at Pueblo San Mancos. (photo by Dario Bilardello)

cont'd. from pg. 1...

was dedicated to a 'novel' area of research, which has been receiving increasing attention lately, oceanic crust and serpentinization. The session, aptly titled "Ocean Crust" was convened by Julie Bowles from University of Wisconsin and Gary Acton from Sam Houston State University.

Presentations by Julie Carlut (Institut de Physique du Globe de Paris), Masako Tominaga (Michigan State University) and Jeff Gee (Scripps Institution of Oceanography), gave a comprehensive coverage of magnetic investigation of oceanic crust, not at all limited to the magnetic properties, comprising intrinsic mineral-physical and geochemical processes of serpentinization. Mantle rocks are generally magnetite-poor because of the low fO_2 in the mantle, and serpentinization is a key process by which ophiolites become magnetic ("Magnetite grains and the history of exhumed mantle rocks," Julie). Modern techniques and instrumentation employed for high-resolution bathymetric and magnetic surveys of in-situ oceanic crust provide views of fractures, structural displacements and alteration ("Near-source magnetic sensing to delineate in-situ structural and lithological features in ocean crust: serpentinization and carbonation of serpentinites," Masako). Structural, thermal and chemical evolution of the lower oceanic crust leaves complex and interesting magnetic records ("Magnetic constraints on the thermal and tectonic history of lower oceanic crust," Jeff), with multicomponent NRMs acquired during slow cooling across geomagnetic polarity boundaries and rotation along detachment faults resulting in shallowing of magnetic inclinations.

The second topic of the conference was "Diagenesis, alteration and remagnetization", introduced by session chairs Doug Elmore (University of Oklahoma, Norman, OK) and Charly Aubourg (Université de Pau, France).

The session was opened by a mini-talk by Charly Aubourg on burial-temperature effects on magnetic mineralogy in shales, effectively on the development of reliable "magnetic geothermometer".

The first invited talk by Jean Pierre Valet (Institut de Physique du Globe de Paris) titled "Magnets in the soup" reviewed IPGP research on DRM acquisition, magnetic properties of turbidites, and the reliability of marine magnetic records, investigating the lock-in depth using cosmogenic radionuclides.

The next talk by Mark Dekkers (Fort Hoofddijk, Utrecht, The Netherlands) "End-member modeling and remagnetization" looked at coercivity spectra and magnetizations carried by Ti-magnetite and hematite in red beds from the Lhasa terrane, demonstrating that mathematical unmixing allows recognition of chemical remagnetizations, with implications on diagenetic history and paleogeographic reconstruction.

Shannon Dulin (University of Oklahoma, Norman, OK) examined remagnetization mechanisms in a talk titled "Summary of integrated paleomagnetic and diagenetic investigations of shale cores," and showed that in some cases migration of tectonic brines or other fluids are responsible for alteration of iron minerals, but in other cases burial diagenesis produces secondary minerals and magnetizations without exotic fluid interaction.

The session was then closed by a captivating "off topic" mini-talk by Doug Elmore on earthquakes in Oklahoma presumably related to water injection at oil production sites, an interesting and curious twist to the session.

The following day's sessions were on anisotropy and fundamental rock magnetism.

The morning session, matter-of-factly titled "Magnetic Fabrics" was organized and chaired by Ken Kodama (Lehigh University, PA) and Bjarne Almquist (Uppsala Universitet) and Mike Jackson (IRM). In fact, it was unfortunate that Bjarne could not attend the meeting due to a last minute work obligation.

Josep Parés (CENIEH- Centro Nacional de Investigación sobre la Evolución Humana, Burgos, Spain) opened the session with a talk titled "Magnetic fabrics in sedimentary rocks: From varves to accretionary prisms" which provided a state-of-the-art coverage of AMS theory and applications in most sedimentary geological settings, and discussed the initial overprinting of sedimentary fabrics by nascent tectonic fabrics and the evolution of AMS as this process occurs.

Darío Bilardello (IRM, University of Minnesóta) spoke about remanence fabrics, giving a more technical presentation focused specifically on the measurement of hematite anisotropy for inclination shallowing corrections: "Isolating the anisotropy of the ChRM-carrying hematite grains in red beds."

Edgardo Cañón-Tapia (CICESE- Centro de Investigación Científica y de Educación Superior de Ensenada, México), then took the stage, shifting the attention to igneous rocks and the use of magnetic fabrics to characterize flow and emplacement processes: "The AMS of volcanic rocks: lessons from obsidians and pyroclastic deposits". So-called "anomalous" AMS ellipsoids in volcanic rocks complicate efforts to determine flow orientations, and Edgardo presented a critical evaluation of various potential mechanisms for generation of and recongnition of anomalous magnetic fabrics.

Lastly, Arlo Wéil (Bryn Mãwr, PA) capped the session delivering a very up-beat and energizing talk on tectonic applications of anisotropy, mostly in the context of oroclinal settings: "Establishing AMS as a robust proxy for Layer-Parallel Shortening in weakly deformed clastic rocks from complex foreland systems."

Like all well-respected traditions, a conference organized by the Institute for Rock Magnetism could not but end with a session titled "Fundamental Rock Magnetism: Problems and Opportunities" and chaired by Aleksey Smirnov (Michigan Technological University) and Michael Winklhofer (Ludwig-Maximilians Universität, Munich.)

The first invited talk was given by Julie Bowles (University of Wisconsin, Milwaukee), who spoke about "Cation reordering in titanomagnetites: applications and implications" with case studies of lavas from Mt. St. Helens and Montserrat showing Curie temperature variations as a consequence of cooling history and cation ordering.

Next, Liao Chang (Australian National University) re-

viewed the crystal structure and intrinsic magnetic properties of greigite: "Current challenges with understanding greigite magnetism: structures, magnetocrystalline anisotropy and rock magnetic behavior." Greigite (Fe_3S_4) is the sulfide equivalent of magnetite, but its essential properties (e.g. spontaneous magnetization and cubic magnetocrystalline anisotropy coffeicients) are less well known.

Richard Harrison (University of Cambridge, UK), gave the last presentation of the day, a look into the most advanced developments of magnetic imaging "Magnetic microscopy: Seeing is believing [or is it?]" Most images obtained by such methods are indirectly related to the spatial distribution of magnetization, and therefore micromagnetic models and image simulations are important keys to proper understanding of their significance.

Robert Coe (UC Santa Cruz, CA) contributed an intriguing mini-talk on identifying the magnetic carriers of VRM in lavas from Steens Mountain in Oregon. Rob presented evidence of a VRM overprint that could be successfully removed using the Triaxe magnetometer without thermochemical alteration of the basalts and complementary rock-magnetic data.

FORC Workshop

An additional all day workshop entirely dedicated to FORC data processing and interpretation was offered on Sunday. About 40 conference participants including representatives from Lake Shore Cryotronics registered for the workshop, which then evolved into an open discussion led by Lake Shore on the future developments of hardware and software for the Vibrating Sample Magnetometer.

Opening ceremonies were officiated by Josh Feinberg (University of Minnesota), who made some introductory remarks before introducing the keynote lecture by Richard Harrison (University of Cambridge, UK), "The philosophy of FORC: What to do, how to do it, and why…" a convincing talk on why no rock-magnetic study is complete without a FORC diagram. Richard also provided a lot of useful background on FORC diagrams, from data acquisition to processing, smoothing and displaying (his talk is available for download at http://geoarch.net/FORC_Workshop). During the afternoon workshop Richard walked the audience through the processing of data using the Cambridge-developed software FORCinel (https://wserv4.esc.cam.ac.uk/nanopaleomag/?page_id=31.)

The second talk of the morning session was given by Ramon Egli (Zentralanstalf für Metereologie und Geodynamik, Wien) "General FORC processing criteria – a primer" (also available at http://geoarch.net/FORC_Workshop). As the title implies, Ramon focused on general criteria to be followed when processing FORC data and implementations brought to his MATHEMATICA code, including the "cleaning" VARIFORC technique developed by himself. Ramon also led the afternoon audience through a practical step-by-step example of FORC data processing using his code (Egli, R. (2013) VARIFORC: An optimized protocol for the calculation of non-regular first-order reversal curve (FORC) diagrams. Global and Planetary Change, doi: 10.1016/j.gloplacha.2013.08.003.)

David Helsop (Australian National University), then looked into the error in acquired FORC data and the associated uncertainty of the processed product, in a talk titled "Uncertainty is your friend." (also available at http://geoarch.net/FORC_Workshop.)

Michael Winklhofer concluded the workshop by giving a more applied talk that correlated rock-magnetic properties to FORC measurements of different minerals/assemblages and demonstrated a variety of physical effects observed in FORC distributions of rare-earth magnets and other industrial materials. Michael gave a very interactive lesson using both PowerPoint slides and chalk-and-blackboard, complemented by FORC examples processed using his own MATLAB code (email Michael for details: michael@geophysik.uni-muenchen.de.)

The FORC day was concluded with an open discussion on the Vibrating Sample Magnetometer with Lake Shore representatives. Lake Shore opened offering a prospective of goals set for implementations to the VSM and then turned the floor over to the audience asking for ideas and suggestions about what we rock-magnetists would like to see in the next generation of magnetometers. The discussion turned out to be very productive and useful on both sides, and confirmed that Lake Shore is keen on providing the best service to our community.

The three-day event turned out a great a success: much was learnt and everybody left happy. While Germany ended taking home the World Cup, every participant was a winner in Santa Fe, with one big advantage: the next meeting will be in 2016, two years before the next World Cup! And, there are rumors that the next conference might be held in Kiama, Australia, THE original Kiaman (this rock-mag thing is catching on.) Nothing is set in stone but we'll keep you posted. Stay tuned.

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