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Inside...

Where do we go from here?
Past, Present and Future trends in Rock Magnetism

IRM staff, the RAC and community members

Look closely enough at any natural material and you will find traces of magnetic minerals. Ranging from nano- to macro-scales across the solar system, they provide a singular view of its evolution (especially for Earth), because the magnetic remanence and hysteresis associated with ferromagnetic minerals preserve a record of past events. The idea that magnetic minerals in rocks and archeological artifacts can serve as proxy magnetometers to measure prehistoric magnetic fields surfaced in the late 19th century. However, the subject truly gained momentum as paleomagnetism provided critical evidence for continental drift and plate tectonics, established that reversals are an intrinsic feature of geomagnetic field variability, and developed the magnetostratigraphic polarity time scale in conjunction with radiometric dating. Rock and mineral magnetism have provided the theoretical and experimental underpinnings for these discoveries and, through studies of specific materials, continue to provide crucial insights into how and why materials acquire and retain magnetization in a broad range of both stable and evolving environments. Stable magnetic structures were discovered in bacteria and other organisms, and their remains are being found in the geological record with increasing ease. The development of environmental magnetism as a mechanism for studying paleoclimate and the environment is another important watershed within our community.

Over 140 research groups exist today worldwide, working on a wide range of topics in rock- and paleomagnetism, and every year hundreds of papers are published on these topics in peer reviewed scientific journals. For each of the last three years the Institute for Rock Magnetism's annual bibliographic compilation has logged over 500 magnetics related papers excluding those primarily related to space physics (http://www.irm.umn.edu/IRM/refs.html).

The idea of compiling a document that collects the community's thoughts on "Our Science" dates back at least as far as the 1986 Asilomar conference (Banerjee, 1987, EOS 68, 650-663). The current incarnation originated at a meeting of the IRM's Review and Advisory Committee with IRM faculty and staff in 2011, and an initial draft by Joshua Feinberg and Catherine Constable was circulated to ~50 prominent researchers in the different fields of rock and mineral magnetism. Such a document was meant to mention some broadly acknowledged magnetic success stories, note how views have evolved over the past decades, describe some anticipated directions for the 21st century magnetics research, and include a synopsis of the resources needed to conduct this kind of science. It is an attempt to collect scientific ideas with international currency, reflecting the global collegiality and collaborations inherent to our discipline, outlining for community discussion some views on captivating problems in mineral, rock, and paleomagnetic research that have important links into broad-based Earth Science Problems.

At the 2012 9th Santa Fe Conference on Rock Magnetism the floor was opened for further discussion and the input received was condensed into an article by Josh Feinberg and circulated to the Institute for Rock Magnetism's Research and Advisory Committee for further screening and suggestions. The result of this effort is a white paper entitled Mineral, Rock, and Paleomagnetism: 21st Century Strengths and Directions, authored by the Institute for Rock Magnetism, Members of its Re-

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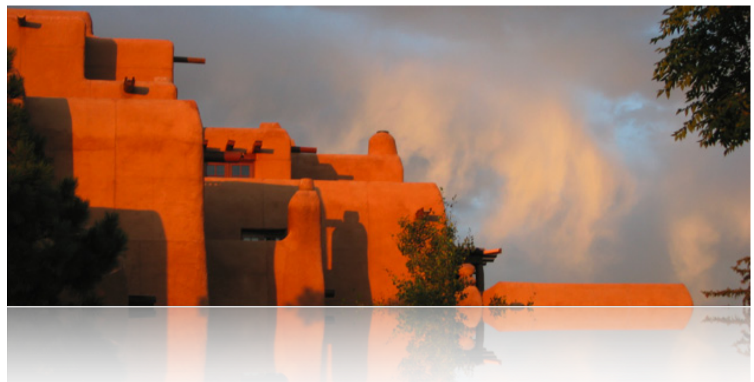

The 2014 Santa Fe Conference on Rock Magnetism is approaching!

The 10th Santa Fe Conference on Rock magnetism will be help at St. John's College in Santa Fe New Mexico from June 26-30 2014. An optional field trip will be offered on Thursday June 26 and conference sessions will begin later that evening. On Sunday June 30th there will be an optional all day FORC worshop for those who wish to attend. Registration and travel information is available on the IRM website and other media!

Visiting Fellows' Reports

Formation of monoclinic pyrrhotite in slightly metamorphosed argillaceous rocks: Some new insights.

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In slightly metamorphosed rocks, the contribution of monoclinic pyrrhotite has been reassessed thanks to the (re) discovery of the Besnus transition at 32K in the late 80's (e.g. (Rochette, Fillion et al. 2011) for an update). Its occurrence in sub greenschist metamorphism is particularly well demonstrated in metamorphosed argillaceous rocks from the Alps (Crouzet, Ménard et al. 1999), Himalaya (Appel, Crouzet et al. 2012) and Taiwan (Horng, Huh et al. 2012). It is generally assumed that the formation of monoclinic pyrrhotite results from the breakdown of magnetite for burial temperature in the range ~200-300°C and from the breakdown of pyrite for temperature >300°C (Rochette 1987).

In the Taiwan belt, Horng et al. (2012) have investigated the occurrence of monoclinic pyrrhotite in metamorphosed argillaceous rocks. Using hysteresis loops, they observed a mix of 'straight lines' and 'pyrrhotite-like' trends. The 'pyrrhotite-like' loops are restricted to the epizone while the 'straight-lines' are localized in the anchizone. The transition between the two behaviors is sharp, and suggests that formation of pyrrhotite is relatively sudden. The aim of my stay at the IRM was to investigate low-temperature magnetic properties of argillaceous rocks in the Taiwan belt to 1) verify the occurrence of pyrrhotite and magnetite, 2) establish a relationship between the formation of pyrrhotite and burial temperatures.

The burial temperature is obtained from Raman Spectroscopy analysis (RSCM). Calibration curve provided by Beyssac et al. (Beyssac, Simoes et al. 2007) allows the detection of a minimum burial temperature near the Curie temperature of pyrrhotite with an absolute accuracy of ±30°C. Lafhid et al. (2010) extended the calibration curve in the range ~200°C to 320°C. However, the absolute accuracy of RSCM in the range 200-320°C is more questionable. Hence, the RSCM technique is particularly adapted to monitor the formation of pyrrhotite in argillaceous rocks.

We sampled argillaceous Tertiary marine rocks (claystones and siltstones) from fresh road cuts along sections from the Hushshan Range (Taiwan). To elucidate both Verwey (~120K) and Besnus (~35K) transitions, we measured low-temperature properties of a remanence acquired at 300K under a magnetic field of 2.5 T (RT-SIRM). In addition, we measured the FORC's at room temperature of representative samples.

For burial temperature ~200-330°C, the RT-SIRM is low (~10-5 Am2/kg). we observe both the Verwey and the Besnus transitions (Fig. 1A-B). The Besnus transition is reversible, meaning that pyrrhotite is SD and close to 1 µm. The Verwey transition indicates that magnetite is stoichiometric. Magnetite is likely neoformed during diagenesis (Kars et al., 2012; Aubourg et al., 2012). For burial temperature >350 ±30°C, the Verwey transition is no longer detected and only the non-reversible Besnus transition is observed. In addition, the RT-SIRM increases by one to three orders in magnitude.

Our result suggests therefore that most of the magnetite consumption takes place for temperature near 350°C. At ~350°C, the pyrite breakdown starts, leading to the production of large amounts of pyrrhotite. This temperature is higher than the Curie temperature of pyrrhotite (Tc~325°C). Hence, the remanence acquired by argillaceous rocks is essentially a thermo remanent magnetization (Appel, Crouzet et al. 2012).

References

Appel, E., C. Crouzet, et al. (2012). "Pyrrhotite remagnetizations in the Himalaya: a review." Geological Society, London, Special Publications 371(1): 163-180.

Beyssac, O., M. Simoes, et al. (2007). "Late Cenozoic metamorphic evolution and exhumation of Taiwan." Tectonics 26(TC6001).

Crouzet, C., G. Ménard, et al. (1999). "High-precision threedimensional paleothermometry derived from paleomagnetic data in an alpine metamorphic unit." Geology 27: 503-506.

Horng, C.-S., C.-A. Huh, et al. (2012). "Pyrrhotite as a tracer for denudation of the Taiwan orogen." Geochem. Geophys. Geosyst. 13: Q08Z47.

Lahfid, A., O. Beyssac, et al. (2010). "Evolution of the Raman spectrum of carbonaceous material in low-grade metasediments of the Glarus Alps (Switzerland)." Terra Nova 22(5): 354-360.

Rochette, P. (1987). "Metamorphic control of the magnetic mineralogy of the black shales in the Swiss Alps: toward the used of 'magnetic isograd'." Earth and Planet. Sci. Lett. 84: 446-456.

Rochette, P., G. Fillion, et al. (2011). "Interpretation of low-temperature data part 4: The low-temperature magnetic transition of monoclinic pyrrhotite." The IRM Quarterly 21(1): 1-7-11.

The next Visiting Fellowship application deadline is April 30, 2014.

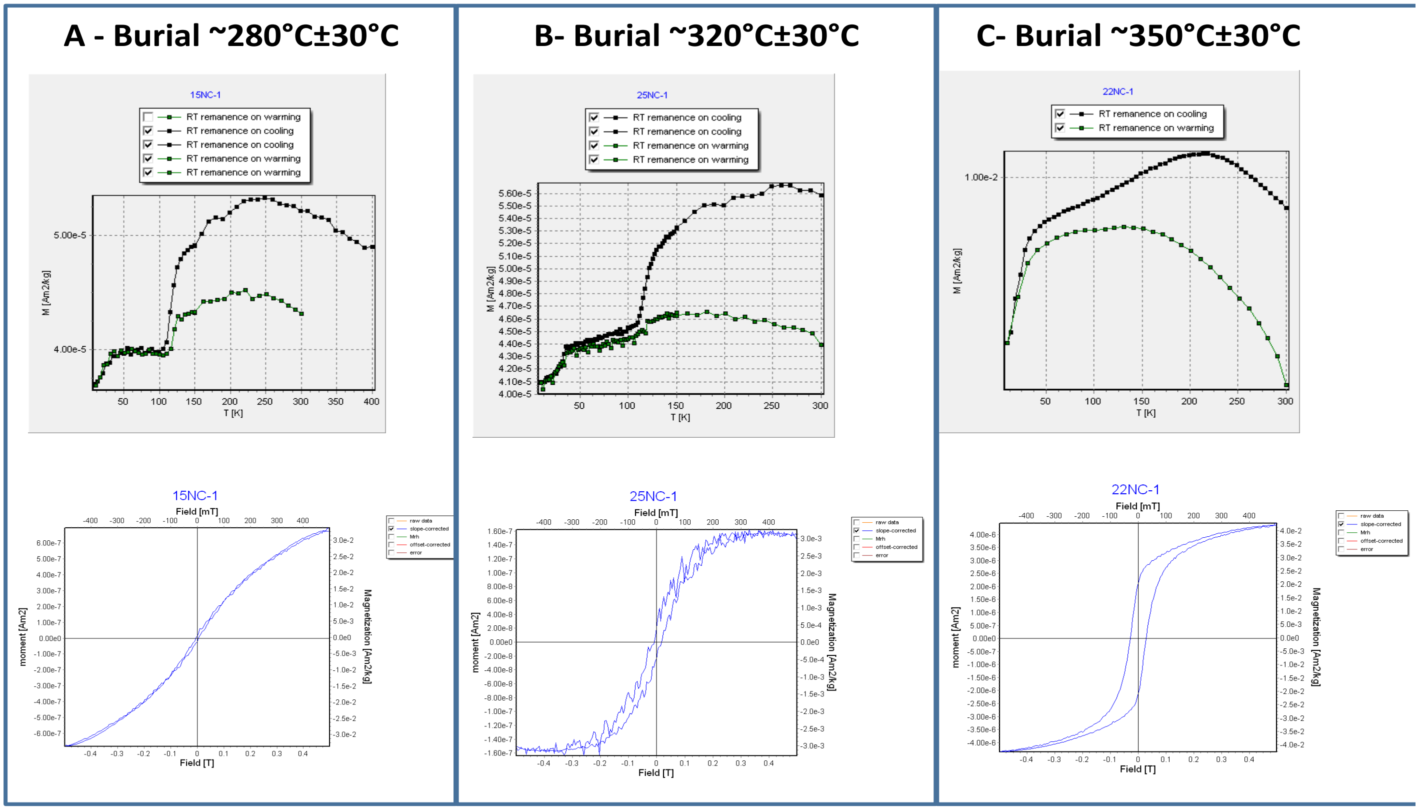

Fig 1. RT-SIRM monitoring and histeresis loops of representative argillaceous rocks from the Taiwan belt. Burial temperature is obtained with the RSCM technique.

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.

Anisotropy and Magnetic Fabrics

Chakraborty, P. P., K. Das, S. Saha, P. Das, S. Karmakar, and M. A. Mamtani (2013), Reply to the discussion of Deb (2013) on the paper of Saha et al. (2013) entitled 'Tectono-magmatic evolution of the Mesoproterozoic Singhora basin, central India: Evidence for compressional tectonics from structural data, AMS study and geochemistry of basic rocks', Precambrian Research, 236, 297-302.

Dawai, D., J. L. Bouchez, J. L. Paquette, and R. Tchameni (2013), The Pan-African quartz-syenite of Guider (north-Cameroon): Magnetic fabric and U-Pb dating of a late-orogenic emplacement, Precambrian Research, 236, 132-144.

Fleming, E. J., H. Lovell, C. T. E. Stevenson, M. S. Petronis, D. I. Benn, M. J. Hambrey, and I. J. Fairchild (2013), Magnetic fabrics in the basal ice of a surge-type glacier, Journal of Geophysical Research-Earth Surface, 118(4), 2263-2278.

Gomonay, O., S. Kondovych, and V. Loktev (2014), Shape-induced anisotropy in antiferromagnetic nanoparticles, Journal of Magnetism and Magnetic Materials, 354, 125-135.

Gutierrez, F., I. Payacan, S. E. Gelman, O. Bachmann, and M. A. Parada (2013), Late-stage magma flow in a shallow felsic reservoir: Merging the anisotropy of magnetic susceptibility record with numerical simulations in La Gloria Pluton, central Chile, Journal of Geophysical Research-Solid Earth, 118(5), 1984-1998.

Izquierdo-Llavall, E., A. M. Casas-Sainz, and B. Oliva-Urcia (2013), Heterogeneous deformation recorded by magnetic fabrics in the Pyrenean Axial Zone, Journal of Structural Geology, 57, 97-113.

Liodas, N. T., A. Gebelin, E. C. Ferre, and G. M. Misgna (2013), Deformation coupling between the Archean Pukaskwa intrusive complex and the Hemlo shear zone, Superior Province, Canada, Tectonophysics, 608, 1226-1237.

Morgan, S., R. Law, and M. de Saint Blanquat (2013), Forceful emplacement of the Eureka Valley-Joshua Flat-Beer Creek composite pluton into a structural basin in eastern California; internal structure and wall rock deformation, Tectonophysics, 608, 753-773.

Schmidt, P. W., and G. E. Williams (2013), Anisotropy of thermoremanent magnetisation of Cryogenian glaciogenic and Ediacaran red beds, South Australia: Neoproterozoic apparent or true polar wander?, Global and Planetary Change, 110, 289-301.

Schobel, S., H. de Wall, and C. Rolf (2013), AMS in basalts: is there a need for prior demagnetization?, Geophysical Journal International, 195(3), 1509-1518.

Yang, T., T. Mishima, K. Ujiie, F. M. Chester, J. J. Mori, N. Eguchi, S. Toczko, and S. Expedition (2013), Strain decoupling across the decollement in the region of large slip during the 2011 Tohoku-Oki earthquake from anisotropy of magnetic susceptibility, Earth and Planetary Science Letters, 381, 31-38.

Bio- Geomagnetism

Jandacka, P., P. Alexa, J. Pistora, J. H. Li, H. Vojtkova, and A. Hendrych (2013), Size distributions of nanoparticles from magnetotactic bacteria as signatures of biologically controlled mineralization, American Mineralogist, 98(11-12), 2105-2114.

Kodama, K. P., R. E. Moeller, D. A. Bazylinski, R. E. Kopp, and A. P. Chen (2013), The mineral magnetic record of magnetofossils in recent lake sediments of Lake Ely, PA, Global and Planetary Change, 110, 350-363.

Krylov, V. V., Y. G. Izumov, E. I. Izvekov, and V. A. Nepomnyashchikh (2013), Magnetic fields and fish behavior, Zhurnal Obshchei Biologii, 74(5), 354-365.

Li, J. H., K. Benzerara, S. Bernard, and O. Beyssac (2013), The link between biomineralization and fossilization of bacteria: Insights from field and experimental studies, Chemical Geology, 359, 49-69.

Liboff, A. R. (2013), Weak-field ELF magnetic interactions: Implications for biological change during paleomagnetic reversals, Electromagnetic Biology and Medicine, 32(4), 442-447.

Miot, J., N. Recham, D. Larcher, F. Guyot, J. Brest, and J. M. Tarascon (2014), Biomineralized alpha-Fe2O3: texture and electrochemical reaction with Li, Energy & Environmental Science, 7(1), 451-460.

Ouyang, B. J., X. C. Lu, H. Liu, J. Li, T. T. Zhu, X. Y. Zhu, J. J. Lu, and R. C. Wang (2014), Reduction of jarosite by Shewanella oneidensis MR-1 and secondary mineralization, Geochimica Et Cosmochimica Acta, 124, 54-71.

Pan, Y., N. Li, R. H. Zhou, and M. Zhao (2013), Nano-Magnetosomes in Magnetotactic Bacteria, Progress in Chemistry, 25(10), 1781-1794.

Peng, X. T., S. Chen, and H. C. Xu (2013), Formation of biogenic sheath-like Fe oxyhydroxides in a near-neutral pH hot spring: Implications for the origin of microfossils in high-temperature, Fe-rich environments, Journal of Geophysical Research-Biogeosciences, 118(4), 1397-1413.

Percak-Dennett, E. M., J. L. Loizeau, B. L. Beard, C. M. Johnson, and E. E. Roden (2013), Iron isotope geochemistry of biogenic magnetite-bearing sediments from the Bay of Vidy, Lake Geneva, Chemical Geology, 360, 32-40.

Wu, W. F., F. P. Wang, J. H. Li, X. W. Yang, X. Xiao, and Y. X. Pan (2013), Iron reduction and mineralization of deep-sea iron reducing bacterium Shewanella piezotolerans WP3 at elevated hydrostatic pressures, Geobiology, 11(6), 593-601.

Yamazaki, T., and T. Shimono (2013), Abundant bacterial magnetite occurrence in oxic red clay, Geology, 41(11), 1191-1194.

Yang, Y. F., J. R. Chen, D. R. Qiu, and J. Z. Zhou (2013), Roles of UndA and MtrC of Shewanella putrefaciens W3-18-1 in iron reduction, Bmc Microbiology, 13.

Yuan, J., Y. W. Chen, G. Q. Zhou, H. J. Chen, and H. C. Gao (2013), Investigation of roles of divalent cations in Shewanella oneidensis pellicle formation reveals unique impacts of insoluble iron, Biochimica Et Biophysica Acta-General Subjects, 1830(11), 5248-5257.

Geo-Archeomagnetism and Spectroscopy

Bu, K., J. V. Cizdziel, and J. Russ (2013), the source of iron-oxide pigments used in pecos river style rock paints, Archaeometry, 55(6), 1088-1100.

Cardeira, A. M., S. Longelin, A. Le Gac, I. Nogueira, M. L. Carvalho, and M. Manso (2013), Spectroscopic Characterization of a Contemporary Indian Miniature Painting, Applied Spectroscopy, 67(12), 1376-1381.

Downey, W. S., and I. Liritzis (2013), Archaeomagnetic intensity of ceramic sherds from two Rhodian Byzantine churches: A preliminary initiative, Mediterranean Archaeology & Archaeometry, 13(2), 221-229.

Ech-Chakrouni, S., J. Hus, and S. Spassov (2013), Constraints of archaeomagnetic dating and field intensity determinations in three ancient tile kilns in Belgium, Studia Geophysica Et Geodaetica, 57(4), 585-604.

El-Rahman, Y. A., A. A. Surour, A. H. W. El Manawi, M. Rifai, A. A. Motelib, W. K. Ali, and A. M. El Dougdoug (2013), Ancient mining and smelting activities in the Wadi Abu Gerida area, Central Eastern desert, Egypt: Greliminary results, Archaeometry, 55(6), 1067-1087.

Garcia, J., K. Martinez, and E. Carbonell (2013), The Early Pleistocene stone tools from Vallparadis (Barcelona, Spain): Rethinking the European Mode 1, Quaternary International, 316, 94-114.

Iriarte, M., A. Hernanz, J. F. Ruiz-Lopez, and S. Martin (2013), mu-Raman spectroscopy of prehistoric paintings from the Abrigo Remacha rock shelter (Villaseca, Segovia, Spain), Journal of Raman Spectroscopy, 44(11), 1557-1562.

Joordens, J. C. A., G. Dupont-Nivet, C. S. Feibel, F. Spoor, M. J. Sier, J. van der Lubbe, T. K. Nielsen, M. V. Knul, G. R. Davies, and H. B. Vonhof (2013), Improved age control on early Homo fossils from the upper Burgi Member at Koobi Fora, Kenya, Journal of Human Evolution, 65(6), 731-745.

Kapper, K. L., D. Anesin, F. Donadini, D. E. Angelucci, F. Cavulli, A. Pedrotti, and A. M. Hirt (2014), Linking site formation processes to magnetic properties. Rock- and archeomagnetic analysis of the combustion levels at Riparo Gaban (Italy), Journal of Archaeological Science, 41, 836-855.

Kosarova, V., D. Hradil, I. Nemec, P. Bezdicka, and V. Kanicky (2013), Microanalysis of clay-based pigments in painted artworks by the means of Raman spectroscopy, Journal of Raman Spectroscopy, 44(11), 1570-1577.

Kostadinova-Avramova, M., and M. Kovacheva (2013), The magnetic properties of baked clays and their implications for past geomagnetic field intensity determinations, Geophysical Journal International, 195(3), 1534-1550.

Licht, A., G. Hulot, Y. Gallet, and E. Thebault (2013), Ensembles of low degree archeomagnetic field models for the past three millennia, Physics of the Earth and Planetary Interiors, 224, 38-67.

Medeghini, L., S. Mignardi, C. De Vito, D. Bersani, P. P. Lottici, M. Turetta, J. Costantini, E. Bacchini, M. Sala, and L. Nigro (2013), The key role of micro-Raman spectroscopy in the study of ancient pottery: the case of pre-classical Jordanian ceramics from the archaeological site of Khirbet al-Batrawy, European Journal of Mineralogy, 25(5), 881-893.

Morales, J., A. Goguitchaichvili, M. D. O. Barrientos, C. Carvallo, and B. A. Reyes (2013), Archeointensity investigation on pottery vestiges from Puertas de Roln, Capacha culture: In search for affinity with other Mesoamerican pre-Hispanic cultures, Studia Geophysica Et Geodaetica, 57(4), 605-626.

Nastova, I., O. Grupce, B. Minceva-Sukarova, M. Ozcatal, and L. Mojsoska (2013), Spectroscopic analysis of pigments and inks in manuscripts: I. Byzantine and post-Byzantine manuscripts (10-18th century), Vibrational Spectroscopy, 68, 11-19.

Ostrooumov, M., and A. Gogichaishvili (2013), Raman and Infrared reflection spectroscopic study of pre-Columbian Mesoamerican pottery, European Journal of Mineralogy, 25(5), 895-905.

Reyes, B. A., A. Goguitchaichvili, J. Morales, V. H. Garduno, M. Pineda, C. Carvallo, T. G. Moran, I. Israde, and M. C. Rathert (2013), An integrated archeomagnetic and C-14 study on pre-Columbian potsherds and associated charcoals intercalated between Holocene lacustrine sediments in Western Mexico: Geomagnetic implications, Journal of

Geophysical Research-Solid Earth, 118(6), 2753-2763.
Van Pevenage, J., D. Lauwers, D. Herremans, E. Verhaeven, B. Vekemans, W. De Clercq, L. Vincze, L. Moens, and P. Vandenabeele (2014), A combined spectroscopic study on Chinese porcelain containing ruan-cai colours, Analytical Methods, 6(2), 387-394.
Wang, H. G., Z. Y. Jin, Z. Xie, A. C. Fan, L. F. Yan, B. Q. Zhu, and J. H. Wang (2013), Multi-Spectroscopy Applied to Study on a Late Neolithic Colored Stone from Yuhui Site in Huaihe Basin, Spectroscopy and Spectral Analysis, 33(9), 2305-2310.

Geo- and Planetary dynamo

Cox, G., and W. Brown (2013), Rapid dynamics of the Earth's core, Astronomy & Geophysics, 54(5), 32-37.
Lhuillier, F., and S. A. Gilder (2013), Quantifying paleosecular variation: Insights from numerical dynamo simulations, Earth and Planetary Science Letters, 382, 87-97.
Malkin, Z. (2013), Free core nutation and geomagnetic jerks, Journal of Geodynamics, 72, 53-58.
Masada, Y., K. Yamada, and A. Kageyama (2013), Effects of penetrative convection on solar dynamo, Astrophysical Journal, 778(1).

Geo-, Planetary Magnetism and Paleointensity

Chang, B., W. Kim, S. J. Doh, and Y. Yu (2013), Paleointensity determination of Late Cretaceous basalts in northwest South Korea: implications for low and stable paleofield strength in the Late Cretaceous, Earth Planets and Space, 65(12), 1501-1513.
Cromwell, G., L. Tauxe, H. Staudigel, C. G. Constable, A. A. P. Koppers, and R. B. Pedersen (2013), In search of long-term hemispheric asymmetry in the geomagnetic field : Results from high northern latitudes, Geochemistry Geophysics Geosystems, 14(8), 3234-3249.
de Groot, L. V., A. J. Biggin, M. J. Dekkers, C. G. Langereis, and E. Herrero-Bervera (2013), Rapid regional perturbations to the recent global geomagnetic decay revealed by a new Hawaiian record, Nature Communications, 4.
Dobrica, V., C. Demetrescu, and C. Stefan (2013), Toward a better representation of the secular variation. Case study: The European network of geomagnetic observatories, Earth Planets and Space, 65(7), 767-779.
Dong, B., D. W. Danskin, R. J. Pirjola, D. H. Boteler, and Z. Z. Wang (2013), Evaluating the applicability of the finite element method for modelling of geoelectric fields, Annales Geophysicae, 31(10), 1689-1698.
Ge, S. L., X. F. Shi, Y. H. Huang, Z. H. Chen, J. X. Liu, and S. J. Yan (2013), Geomagnetic intensity and direction for the last 14 ka recorded in Bering Sea core, Chinese Journal of Geophysics-Chinese Edition, 56(9), 3071-3084.
Genevey, A., Y. Gallet, E. Thebault, S. Jesset, and M. Le Goff (2013), Geomagnetic field intensity variations in Western Europe over the past 1100 years, Geochemistry Geophysics Geosystems, 14(8), 2858-2872.
Herbst, K., A. Kopp, and B. Heber (2013), Influence of the terrestrial magnetic field geometry on the cutoff rigidity of cosmic ray particles, Annales Geophysicae, 31(10), 1637-1643.
Hong, H., Y. Yu, C. H. Lee, R. H. Kim, J. Park, S. J. Doh, W. Kim, and H. Sung (2013), Globally strong geomagnetic field intensity circa 3000 years ago, Earth and Planetary Science Letters, 383, 142-152.
Ivanov, K. G., and A. F. Kharshiladze (2013), Dynamics of the large-scale open solar magnetic field and its specific features in the zone of the main active longitudes in 2006-2012, Geomagnetism and Aeronomy, 53(6), 677-689.
Krainov, M. A., A. Y. Peskov, A. V. Kosynkin, and M. I. Kuz'min (2013), A record of the behavior of the geomagnetic field in the sediments of Lake Baikal (BDP-99 borehole), Russian Geology and Geophysics, 54(11), 1402-1408.
Kulakov, E. V., A. V. Smirnov, and J. F. Diehl (2013), Absolute geomagnetic paleointensity as recorded by similar to 1.09 Ga Lake Shore Traps (Keweenaw Peninsula, Michigan), Studia Geophysica Et Geodaetica, 57(4), 565-584.
Michalk, D. M., H. N. Bohnel, N. R. Nowaczyk, G. J. Aguirre-Diaz, M. Lopez-Martinez, S. Ownby, and J. F. W. Negendank (2013), Evidence for geomagnetic excursions recorded in Brunhes and Matuyama Chron lavas from the trans-Mexican volcanic belt, Journal of Geophysical Research-Solid Earth, 118(6), 2648-2669.
Nowaczyk, N. R., U. Frank, J. Kind, and H. W. Arz (2013), A high-resolution paleointensity stack of the past 14 to 68 ka from Black Sea sediments, Earth and Planetary Science Letters, 384, 1-16.
Panovska, S., C. C. Finlay, and A. M. Hirt (2013), Observed periodicities and the spectrum of field variations in Holocene magnetic records, Earth and Planetary Science Letters, 379, 88-94.
Ptitsyna, N. G., I. M. Demina, M. I. Tyasto, and B. A. Khrapov (2013), Secular Variations in the Geomagnetic Field in St. Petersburg and the Adjacent Area from Historical Data, 1630-1930, Geomagnetism and Aeronomy, 53(5), 642-649.
Usui, Y. (2013), Paleointensity estimates from oceanic gabbros: Effects of hydrothermal alteration and cooling rate, Earth Planets and Space, 65(9), 985-996.

Chronostratigraphy/Magnetostratigraphy

Angelucci, D. E., D. Anesin, M. L. Martinez, M. H. Uriarte, T. R. Estrella, and M. J. Walker (2013), Rethinking stratigraphy and site formation of the Pleistocene deposit at Cueva Negra del Estrecho del Rio Quipar (Caravaca de la Cruz, Spain), Quaternary Science Reviews, 80, 195-199.
Giaccio, B., F. Castorina, S. Nomade, G. Scardia, M. Voltaggio, and L. Sagnotti (2013), Revised Chronology of the Sulmona Lacustrine Succession, Central Italy, Journal of Quaternary Science, 28(6), 545-551.
Hinnov, L. A. (2013), Cyclostratigraphy and its revolutionizing applications in the earth and planetary sciences, Geological Society of America Bulletin, 125(11-12), 1703-1734.
Lawrence, K. T., I. Bailey, and M. E. Raymo (2013), Re-evaluation of the age model for North Atlantic Ocean Site 982 - arguments for a return to the original chronology, Climate of the Past, 9(5), 2391-2397.
McDougall, I. (2013), Retrospective on the plate tectonic revolution focusing on k/ar dating, linear volcanic chains and the geomagnetic polarity time scale, Earth Sciences History, 32(2), 313-331.
Muttoni, G., G. Scardia, and D. V. Kent (2013), A critique of evidence for human occupation of Europe older than the Jaramillo subchron (similar to 1 Ma): Comment on 'The oldest human fossil in Europe from Orce (Spain)' by Toro-Moyano et al. (2013), Journal of Human Evolution, 65(6), 746-749.
Rico, Y., and J. C. Bidegain (2013), Magnetostratigraphy and environmental magnetism in a sedimentary sequence of Miramar, Buenos Aires, Argentina, Quaternary International, 317, 53-63.
Wendler, I. (2013), A critical evaluation of carbon isotope stratigraphy and biostratigraphic implications for Late Cretaceous global correlation, Earth-Science Reviews, 126, 116-146.

Environmental Magnetism and Climate

Benson, L. V., J. P. Smoot, S. P. Lund, S. A. Mensing, F. F. Foit, and R. O. Rye (2013), Insights from a synthesis of old and new climate-proxy data from the Pyramid and Winnemucca lake basins for the period 48 to 11.5 cal ka, Quaternary International, 310, 62-82.

Bhardwaj, S. K., and P. Rao (2013), Secular trend of geomagnetic elements in the Indian region, Earth Planets and Space, 65(12), 1515-1523.

Brachfeld, S., J. Pinzon, J. Darley, L. Sagnotti, G. Kuhn, F. Florindo, G. Wilson, C. Ohneiser, D. Monien, and L. Joseph (2013), Iron oxide tracers of ice sheet extent and sediment provenance in the ANDRILL AND-1B drill core, Ross Sea, Antarctica, Global and Planetary Change, 110, 420-433.

De Schepper, S., J. Groeneveld, B. D. A. Naafs, C. Van Renterghem, J. Hennissen, M. J. Head, S. Louwye, and K. Fabian (2013), Northern Hemisphere Glaciation during the Globally Warm Early Late Pliocene, Plos One, 8(12).

Dlouha, S., E. Petrovsky, A. Kapicka, L. Boruvka, C. Ash, and O. Drabek (2013), Investigation of Polluted Alluvial Soils by Magnetic Susceptibility Methods: a Case Study of the Litavka River, Soil and Water Research, 8(4), 151-157.

Frenk, S., T. Ben-Moshe, I. Dror, B. Berkowitz, and D. Minz (2013), Effect of Metal Oxide Nanoparticles on Microbial Community Structure and Function in Two Different Soil Types, Plos One, 8(12).

Herb, C., W. L. Zhang, A. Koutsodendris, E. Appel, X. M. Fang, and J. Pross (2013), Environmental implications of the magnetic record in Pleistocene lacustrine sediments of the Qaidam Basin, NE Tibetan Plateau, Quaternary International, 313, 218-229.

Heslop, D., and A. P. Roberts (2013), Calculating uncertainties on predictions of palaeoprecipitation from the magnetic properties of soils, Global and Planetary Change, 110, 379-385.

Jacques, F. M. B., T. Su, Y. J. Huang, L. Wang, and Z. K. Zhou (2013), A global-scale test for monsoon indices used in palaeoclimatic reconstruction, Palaeoworld, 22(3-4), 93-100.

Jordanova, N., D. Jordanova, Q. S. Liu, P. X. Hu, P. Petrov, and E. Petrovsky (2013), Soil formation and mineralogy of a Rhodic Luvisol - insights from magnetic and geochemical studies, Global and Planetary Change, 110, 397-413.

Lanci, L., and B. Delmonte (2013), Magnetic properties of aerosol dust in peripheral and inner Antarctic ice cores as a proxy for dust provenance, Global and Planetary Change, 110, 414-419.

Lascu, I., and C. Plank (2013), A new dimension to sediment magnetism: Charting the spatial variability of magnetic properties across lake basins, Global and Planetary Change, 110, 340-349.

Liu, Z. F., Q. S. Liu, J. Torrent, V. Barron, and P. X. Hu (2013), Testing the magnetic proxy chi(FD)/HIRM for quantifying paleoprecipitation in modern soil profiles from Shaanxi Province, China, Global and Planetary Change, 110, 368-378.

Lourenco, A. M., E. Sequeira, H. St'Ovaia, and C. R. Gomes (2014), Magnetic, geochemical and pedological characterisation of soil profiles from different environments and geological backgrounds near Coimbra, Portugal, Geoderma, 213, 408-418.

Nelson, F. E., G. S. Wilson, and H. L. Neil (2013), Marine magnetic signature of the Last Glacial Maximum and last deglaciation from the Southern Hemisphere mid-latitudes, Marine Geology, 346, 246-255.

Ortega, B., P. Schaaf, A. Murray, M. Caballero, S. Lozano, and A. Ramirez (2013), Eolian deposition cycles since AD 500 in Playa San Bartolo lunette dune, Sonora, Mexico: Paleoclimatic implications, Aeolian Research, 11, 1-13.

Peralta, A., V. Costanzo-Alvarez, E. Carrillo, L. E. Duran, M. Aldana, and D. Rey (2013), Numerical relationships between magnetic parameters measured in Quaternary sediments and global paleoclimatic proxies, Studia Geophysica Et Geodaetica, 57(4), 647-668.

Roberts, A. P., L. Sagnotti, F. Florindo, S. M. Bohaty, K. L. Verosub, G. S. Wilson, and J. C. Zachos (2013), Environmental magnetic record of paleoclimate, unroofing of the Transantarctic Mountains, and volcanism in late Eocene to early Miocene glaci-marine sediments from the Victoria Land Basin, Ross Sea, Antarctica, Journal of Geophysical Research-Solid Earth, 118(5), 1845-1861.

Roman, S. A., W. C. Johnson, and C. E. Geiss (2013), Grass fires-an unlikely process to explain the magnetic properties of prairie soils, Geophysical Journal International, 195(3), 1566-1575.

Shen, J., X. D. Wu, Z. Zhang, W. M. Gong, T. He, X. M. Xu, and H. L. Dong (2013), Ti content in Huguangyan maar lake sediment as a proxy for monsoon-induced vegetation density in the Holocene, Geophysical Research Letters, 40(21), 5757-5763.

Srivastava, P., A. Kumar, A. Mishra, N. K. Meena, J. K. Tripathi, Y. P. Sundriyal, R. Agnihotri, and A. K. Gupta (2013), Early Holocene monsoonal fluctuations in the Garhwal higher Himalaya as inferred from multi-proxy data from the Malari paleolake, Quaternary Research, 80(3), 447-458.

St-Onge, M. P., and G. St-Onge (2014), Environmental changes in Baffin Bay during the Holocene based on the physical and magnetic properties of sediment cores, Journal of Quaternary Science, 29(1), 41-56.

Wang, X. S. (2013), Magnetic properties and heavy metal pollution of soils in the vicinity of a cement plant, Xuzhou (China), Journal of Applied Geophysics, 98, 73-78.

Wang, B., D. S. Xia, Y. Yu, J. Jia, and S. J. Xu (2014), Detection and differentiation of pollution in urban surface soils using magnetic properties in arid and semi-arid regions of northwestern China, Environmental Pollution, 184, 335-346.

Yang, Y. B., X. M. Fang, A. Galy, E. Appel, and M. H. Li (2013), Quaternary paleolake nutrient evolution and climatic change in the western Qaidam Basin deduced from phosphorus geochemistry record of deep drilling core SG-1, Quaternary International, 313, 156-167.

Zhang, W. X., Z. T. Shi, G. J. Chen, Y. Liu, J. Niu, Q. Z. Ming, and H. Su (2013), Geochemical characteristics and environmental significance of Talede loess-paleosol sequences of Ili Basin in Central Asia, Environmental Earth Sciences, 70(5), 2191-2202.

Extraterrestrial and planetary magnetism

Cervini-Silva, J., A. Nieto-Camacho, H. Cornejo-Garrido, P. del Angel, N. Maya, E. Palacios, J. A. Montoya, V. Gomez-Vidales, and M. T. Ramirez-Apan (2013), Biological dissolution and activity of the Allende meteorite, Geological Society of America Bulletin, 125(11-12), 1865-1873.

Fraeman, A. A., et al. (2013), A hematite-bearing layer in Gale Crater, Mars: Mapping and implications for past aqueous conditions, Geology, 41(10), 1103-1106.

Gattacceca, J., et al. (2013), Opaque minerals, magnetic properties, and paleomagnetism of the Tissint Martian meteorite, Meteoritics & Planetary Science, 48(10), 1919-1936.

Hewins, R. H., et al. (2014), The Paris meteorite, the least altered CM chondrite so far, Geochimica Et Cosmochimica Acta, 124, 190-222.

Isa, J., A. E. Rubin, and J. T. Wasson (2014), R-chondrite bulk-chemical compositions and diverse oxides: Implications

for parent-body processes, Geochimica Et Cosmochimica Acta, 124, 131-151.
Jiang, Z. X., P. Rochette, Q. S. Liu, J. Gattacceca, Y. J. Yu, V. Barron, and J. Torrent (2013), Pressure demagnetization of synthetic Al substituted hematite and its implications for planetary studies, Physics of the Earth and Planetary Interiors, 224, 1-10.
Kimura, Y., T. Sato, N. Nakamura, J. Nozawa, T. Nakamura, K. Tsukamoto, and K. Yamamoto (2013), Vortex magnetic structure in framboidal magnetite reveals existence of water droplets in an ancient asteroid, Nature Communications, 4.
Kohout, T., M. Gritsevich, V. I. Grokhovsky, G. A. Yakovlev, J. Haloda, P. Halodova, R. M. Michallik, A. Penttila, and K. Muinonen (2014), Mineralogy, reflectance spectra, and physical properties of the Chelyabinsk LL5 chondrite - Insight into shock-induced changes in asteroid regoliths, Icarus, 228, 78-85.
Mills, S. J., F. Nestola, V. Kahlenberg, A. G. Christy, C. Hejny, and G. J. Redhammer (2013), Looking for jarosite on Mars: The low-temperature crystal structure of jarosite, American Mineralogist, 98(11-12), 1966-1971.
Popova, O. P., et al. (2013), Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization, Science, 342(6162), 1069-1073.
Schmidt, M. E., C. M. Schrader, and T. J. McCoy (2013), The primary fO(2) of basalts examined by the Spirit rover in Gusev Crater, Mars: Evidence for multiple redox states in the martian interior, Earth and Planetary Science Letters, 384, 198-208.

Imaging and Spectroscopy

Jiang, L. T., G. N. Chen, and Z. L. Peng (2013), Experimental Study of the Red-Bed Pigment with Diffuse Reflectance Spectroscopy, Spectroscopy and Spectral Analysis, 33(10), 2727-2730.
Lima, E. A., B. P. Weiss, L. Baratchart, D. P. Hardin, and E. B. Saff (2013), Fast inversion of magnetic field maps of unidirectional planar geological magnetization, Journal of Geophysical Research-Solid Earth, 118(6), 2723-2752.
Li, X., and Y. F. Cai (2013), Constraining the colouration mechanisms of Cretaceous Oceanic Red Beds using diffuse reflectance spectroscopy, Cretaceous Research, 46, 257-266.
Liu, H. B., T. H. Chen, X. H. Zou, C. S. Qing, and R. L. Frost (2013), Effect of Al content on the structure of Al-substituted goethite: a micro-Raman spectroscopic study, Journal of Raman Spectroscopy, 44(11), 1609-1614.
Meijer, J. M., D. V. Byelov, L. Rossi, A. Snigirev, I. Snigireva, A. P. Philipse, and A. V. Petukhov (2013), Self-assembly of colloidal hematite cubes: a microradian X-ray diffraction exploration of sedimentary crystals, Soft Matter, 9(45), 10729-10738.
Pankratov, D. A. (2014), Mossbauer study of oxo derivatives of iron in the Fe2O3-Na2O2 system, Inorganic Materials, 50(1), 82-89.
Sander, D., H. Oka, M. Corbetta, V. Stepanyuk, and J. Kirschner (2013), New insights into nano-magnetism by spin-polarized scanning tunneling microscopy, Journal of Electron Spectroscopy and Related Phenomena, 189, 206-215.
Szalai, Z., K. Kiss, G. Jakab, P. Sipos, B. Belucz, and T. Nemeth (2013), The use of UV-VIS-NIR reflectance spectroscopy to identify iron minerals, Astronomische Nachrichten, 334(9), 940-943.
Xu, Y. Q., M. Yang, C. D. He, and H. X. Xiong (2013), Characterization and Spectral Analysis of the Stable Mineral Phases alpha,beta-FeOOH Included in Iron Oxyhydroxides, Spectroscopy and Spectral Analysis, 33(12), 3330-3333.
Yakushkin, S. S., G. A. Bukhtiyarova, and O. N. Martyanov (2013), formation conditions of a magnetically ordered phase epsilon-Fe2O3. A FMR in situ study, Journal of Structural Chemistry, 54(5), 876-882.
Yuan, L., X. L. Weng, W. F. Du, J. L. Xie, and L. J. Deng (2014), Optical and magnetic properties of Al/Fe3O4 core-shell low infrared emissivity pigments, Journal of Alloys and Compounds, 583, 492-497.

Ore deposits and Magnetic Mineralogy

Chai, F. M., F. Q. Yang, F. Liu, M. Santosh, X. X. Geng, Q. Li, and G. R. Liu (2014), The Abagong apatite-rich magnetite deposit in the Chinese Altay Orogenic Belt: A Kiruna-type iron deposit, Ore Geology Reviews, 57, 482-497.
Hu, H., J. W. Li, D. Lentz, Z. Ren, X. F. Zhao, X. D. Deng, and D. Hall (2014), Dissolution-reprecipitation process of magnetite from the Chengchao iron deposit: Insights into ore genesis and implication for in-situ chemical analysis of magnetite, Ore Geology Reviews, 57, 393-405.
Jowitt, S. M., K. Cooper, R. J. Squire, N. Thebaud, L. A. Fisher, R. A. F. Cas, and I. Pegg (2014), Geology, mineralogy, and geochemistry of magnetite-associated Au mineralization of the ultramafic-basalt greenstone hosted Crusader Complex, Agnew Gold Camp, Eastern Yilgarn Craton, Western Australia; a Late Archean intrusion-related Au deposit?, Ore Geology Reviews, 56, 53-72.
Luan, Y., X. Y. Song, L. M. Chen, W. Q. Zheng, X. Q. Zhang, S. Y. Yu, Y. W. She, X. L. Tian, and Q. Y. Ran (2014), Key factors controlling the accumulation of the Fe-Ti oxides in the Hongge layered intrusion in the Emeishan Large Igneous Province, SW China, Ore Geology Reviews, 57, 518-538.
Nold, J. L., M. A. Dudley, and P. Davidson (2014), The Southeast Missouri (USA) Proterozoic iron metallogenic province Types of deposits and genetic relationships to magnetite-apatite and iron oxide-copper-gold deposits, Ore Geology Reviews, 57, 154-171.
She, Y. W., S. Y. Yu, X. Y. Song, L. M. Chen, W. Q. Zheng, and Y. Luan (2014), The formation of P-rich Fe-Ti oxide ore layers in the Taihe layered intrusion, SW China: Implications for magma-plumbing system process, Ore Geology Reviews, 57, 539-559.
Yilmazer, E., N. Gulec, I. Kuscu, and D. R. Lentz (2014), Geology, geochemistry, and geochronology of Fe-oxide Cu (+/- Au) mineralization associated with Samli pluton, western Turkey, Ore Geology Reviews, 57, 191-215.
Zhang, Z. J., and R. G. Zuo (2014), Sr-Nd-Pb isotope systematics of magnetite: Implications for the genesis of Makeng Fe deposit, southern China, Ore Geology Reviews, 57, 53-60.
Zhang, Z. H., W. Hong, Z. S. Jiang, S. G. Duan, F. M. Li, and F. P. Shi (2014), Geological characteristics and metallogenesis of iron deposits in western Tianshan, China, Ore Geology Reviews, 57, 425-440.
Zhang, Z. C., T. Hou, M. Santosh, H. M. Li, J. W. Li, Z. H. Zhang, X. Y. Song, and M. Wang (2014), Spatio-temporal distribution and tectonic settings of the major iron deposits in China: An overview, Ore Geology Reviews, 57, 247-263.

Rock and Mineral Magnetism

Bouilloux, A., J. P. Valet, F. Bassinot, J. L. Joron, M. M. Blanc-Valleron, E. Moreno, F. Dewilde, M. Kars, and F. Lagroix (2013), Diagenetic modulation of the magnetic properties in sediments from the Northern Indian Ocean, Geochemistry Geophysics Geosystems, 14(9), 3779-3800.
Chang, L., M. Winklhofer, A. P. Roberts, D. Heslop, F. Florindo, M. J. Dekkers, W. Krijgsman, K. Kodama, and Y. Yamamoto (2013), Low-temperature magnetic properties

of pelagic carbonates: Oxidation of biogenic magnetite and identification of magnetosome chains, Journal of Geophysical Research-Solid Earth, 118(12), 6049-6065.

da Silva, M. B., and J. A. M. da Luz (2013), Magnetic scavenging of ultrafine hematite from itabirites, Rem-Revista Escola De Minas, 66(4), 499-505.

da Silva, J. F., G. T. Pereira, L. A. Camargo, and J. Marques (2013), Geostatistical methods in spatial modelling of the middle diameter of the goethite crystal, Revista Brasileira De Engenharia Agricola E Ambiental, 17(11), 1127-1134.

Dar, M. I., and S. A. Shivashankar (2014), Single crystalline magnetite, maghemite, and hematite nanoparticles with rich coercivity, Rsc Advances, 4(8), 4105-4113.

de la Figuera, J., et al. (2013), Real-space imaging of the Verwey transition at the (100) surface of magnetite, Physical Review B, 88(16).

Dill, H. G., S. I. Balaban, B. Witt, and H. Wershofen (2014), Capturing digital data of rock magnetic, gamma-ray and IR spectrometry for in-situ quality control and for the study of the physical-chemical regime of residual kaolin deposits, SE Germany, Ore Geology Reviews, 57, 172-190.

Ding, W., R. Wu, Z. Y. Xiu, G. Q. Chen, J. B. Song, Y. Q. Liao, and G. H. Wu (2014), Effect of Iron Particle Size and Volume Fraction on the Magnetic Properties of Fe/Silicate Glass Soft Magnetic Composites, Journal of Superconductivity and Novel Magnetism, 27(2), 435-441.

Egli, R. (2013), VARIFORC: An optimized protocol for calculating non-regular first-order reversal curve (FORC) diagrams, Global and Planetary Change, 110, 302-320.

Egli, R., F. Florindo, and A. P. Roberts (2013), Introduction to 'Magnetic iron minerals in sediments and their relation to geologic processes, climate, and the geomagnetic field', Global and Planetary Change, 110, 259-263.

Frison, R., G. Cernuto, A. Cervellino, O. Zaharko, G. M. Colonna, A. Guagliardi, and N. Masciocchi (2013), Magnetite-Maghemite Nanoparticles in the 5-15 nm Range: Correlating the Core-Shell Composition and the Surface Structure to the Magnetic Properties. A Total Scattering Study, Chemistry of Materials, 25(23), 4820-4827.

Hu, X. F., et al. (2013), Discontinuous properties of current-induced magnetic domain wall depinning, Scientific Reports, 3.

Je, S. G., D. H. Kim, S. C. Yoo, B. C. Min, K. J. Lee, and S. B. Choe (2013), Asymmetric magnetic domain-wall motion by the Dzyaloshinskii-Moriya interaction, Physical Review B, 88(21).

Lu, H. H., W. G. Zhang, Y. L. Li, C. Y. Dong, T. Q. Zhang, Z. Y. Zhou, and X. M. Zheng (2013), Rock magnetic properties and paleoenvironmental implications of an 8-Ma Late Cenozoic terrigenous succession from the northern Tian Shan foreland basin, northwestern China, Global and Planetary Change, 111, 43-56.

Ludwig, P., R. Egli, S. Bishop, V. Chernenko, T. Frederichs, G. Rugel, S. Merchel, and M. J. Orgeira (2013), Characterization of primary and secondary magnetite in marine sediment by combining chemical and magnetic unmixing techniques, Global and Planetary Change, 110, 321-339.

Mang, C., and A. Kontny (2013), Origin of two Verwey transitions in different generations of magnetite from the Chesapeake Bay impact structure, USA, Journal of Geophysical Research-Solid Earth, 118(10), 5195-5207.

Mozaffari, M., Y. Hadadian, A. Aftabi, and M. O. Moakhar (2014), The effect of cobalt substitution on magnetic hardening of magnetite, Journal of Magnetism and Magnetic Materials, 354, 119-124.

Muscas, G., et al. (2013), Magnetic Properties of Small Magnetite Nanocrystals, Journal of Physical Chemistry C, 117(44), 23378-23384.

Nie, J. S., M. Jackson, J. King, and X. M. Fang (2013), Characterizing the superparamagnetic grain distribution of Chinese red-clay sequences by thermal fluctuation tomography, Global and Planetary Change, 110, 364-367.

Ouabego, M., Y. Quesnel, P. Rochette, F. Demory, E. M. Fozing, T. Njanko, J. C. Hippolyte, and P. Affaton (2013), Rock magnetic investigation of possible sources of the Bangui magnetic anomaly, Physics of the Earth and Planetary Interiors, 224, 11-20.

Roberts, A. P., F. Florindo, L. Chang, D. Heslop, L. Jovane, and J. C. Larrasoana (2013), Magnetic properties of pelagic marine carbonates, Earth-Science Reviews, 127, 111-139.

Tema, E., D. Kondopoulou, and S. Pavlides (2013), Palaeotemperature estimation of the pyroclastic deposit covering the pre-Minoan palaeosol at Megalochori Quarry, Santorini (Greece): Evidence from magnetic measurements, Studia Geophysica Et Geodaetica, 57(4), 627-646.

Wei, Q. G., and S. A. Gilder (2013), Ferromagnetism of iron under pressure to 21.5 GPa, Geophysical Research Letters, 40(19), 5131-5136.

Wu, Z. C., F. S. Guo, L. Q. Liu, and Y. B. Jiang (2013), Study of Relation between Crushed Lava Spectrum and Magnetic Susceptibility in Xiangshan Uranium Orefield, Spectroscopy and Spectral Analysis, 33(12), 3282-3285.

Yang, T., J. T. Gao, Z. W. Gu, B. Dagva, and B. Tserenpil (2013), Petrophysical Properties (Density and Magnetization) of Rocks from the Suhbaatar-Ulaanbaatar-Dalandzadgad Geophysical Profile in Mongolia and Their Implications, Scientific World Journal.

Paleomagnetism and Tectonics

Akhmetev, P. M. (2013), Application of singularity theory for statistics of paleomagnetic data, Geomagnetism and Aeronomy, 53(6), 804-808.

Anchuela, O. P., A. J. Pocovi, A. G. Imaz, and A. M. Casas-Sainz (2013), Factors influencing magnetic susceptibility in the southern Pyrenees, Studia Geophysica Et Geodaetica, 57(4), 692-709.

Barreca, G., and C. Monaco (2013), Vertical-axis rotations in the Sicilian fold and thrust belt: new structural constraints from the Madonie Mts. (Sicily, Italy), Italian Journal of Geosciences, 132(3), 407-421.

Bennett, S. E. K., M. E. Oskin, and A. Iriondo (2013), Transtensional rifting in the proto-Gulf of California near Bahia Kino, Sonora, Mexico, Geological Society of America Bulletin, 125(11-12), 1752-1782.

Bourne, M. D., C. Mac Niocaill, A. L. Thomas, and G. M. Henderson (2013), High-resolution record of the Laschamp geomagnetic excursion at the Blake-Bahama Outer Ridge, Geophysical Journal International, 195(3), 1519-1533.

Carlson, C. W., C. J. Pluhar, J. M. G. Glen, and M. J. Farner (2013), Kinematics of the west-central Walker Lane: Spatially and temporally variable rotations evident in the Late Miocene Stanislaus Group, Geosphere, 9(6), 1530-1551.

Corti, G., M. Philippon, F. Sani, D. Keir, and T. Kidane (2013), Re-orientation of the extension direction and pure extensional faulting at oblique rift margins: comparison between the Main Ethiopian Rift and laboratory experiments, Terra Nova, 25(5), 396-404.

Cromwell, G., C. G. Constable, H. Staudigel, L. Tauxe, and P. Gans (2013), Revised and updated paleomagnetic results from Costa Rica, Geochemistry Geophysics Geosystems, 14(9), 3379-3388.

Crowley, S. F., J. D. A. Piper, T. Bamarouf, and A. P. Roberts (2014), Palaeomagnetic evidence for the age of the Cumbrian and Manx hematite ore deposits: implications for the origin of hematite mineralization at the margins of the East Irish Sea Basin, UK, Journal of the Geological Society, 171(1), 49-64.

Evans, D. A. D. (2013), Reconstructing pre-Pangean supercontinents, Geological Society of America Bulletin, 125(11-12), 1735-1751.

Fedorova, N. M., N. M. Levashova, M. L. Bazhenov, J. G. Meert, N. D. Sergeeva, I. V. Golovanova, K. N. Danukalov, N. B. Kuznetsov, A. F. Kadyrov, and M. M. Khidiyatov (2013), The East European Platform in the late Ediacaran: new paleomagnetic and geochronological data, Russian Geology and Geophysics, 54(11), 1392-1401.

Florindo, F., R. K. Farmer, D. M. Harwood, R. D. Cody, R. Levy, S. M. Bohaty, L. Carter, and A. Winkler (2013), Paleomagnetism and biostratigraphy of sediments from Southern Ocean ODP Site 744 (southern Kerguelen Plateau): Implications for early-to-middle Miocene climate in Antarctica, Global and Planetary Change, 110, 434-454.

Fu, C. J., J. H. Li, and X. Mao (2013), Longitude of the ca. 290 Ma Tarim Block: Constraint from the Tarim Large Igneous Province of NW China, Chinese Journal of Geophysics-Chinese Edition, 56(9), 3061-3070.

Heslop, D., A. P. Roberts, L. Chang, M. Davies, A. Abrajevitch, and P. De Deckker (2013), Quantifying magnetite magnetofossil contributions to sedimentary magnetizations, Earth and Planetary Science Letters, 382, 58-65.

Jean, M. M., J. W. Shervais, D. E. Champion, and S. K. Vetter (2013), Geochemical and paleomagnetic variations in basalts from the Wendell Regional Aquifer Systems Analysis (RASA) drill core: Evidence for magma recharge and assimilation-fractional crystallization from the central Snake River Plain, Idaho, Geosphere, 9(5), 1319-1335.

Kawasaki, K., and D. T. A. Symons (2014), Paleomagnetic dating of magmatic phases at the Cantung tungsten deposit, Northwest Territories, Canada, Canadian Journal of Earth Sciences, 51(1), 32-42.

Kidane, T., V. Bachtadse, M. Alene, and U. Kirscher (2013), Palaeomagnetism of Palaeozoic glacial sediments of Northern Ethiopia: a contribution towards African Permian palaeogeography, Geophysical Journal International, 195(3), 1551-1565.

Kocbulut, F., Z. Akpinar, O. Tatar, J. D. A. Piper, and A. P. Roberts (2013), Palaeomagnetic study of the Karacadag Volcanic Complex, SE Turkey: Monitoring Neogene anticlockwise rotation of the Arabian Plate, Tectonophysics, 608, 1007-1024.

Kristjansson, L. (2013), The Stardalur magnetic anomaly, SW-Iceland: a review of research in 1968-2012, Jokull, 63, 1-16.

Kulakov, E. V., A. V. Smirnov, and J. F. Diehl (2013), Paleomagnetism of similar to 1.09 Ga Lake Shore Traps (Keweenaw Peninsula, Michigan): new results and implications, Canadian Journal of Earth Sciences, 50(11), 1085-1096.

Latyshev, A. V., R. V. Veselovskiy, A. V. Ivanov, A. M. Fetisova, and V. E. Pavlov (2013), Short intense bursts in magmatic activity in the south of Siberian Platform (Angara-Taseeva depression): the paleomagnetic evidence, Izvestiya-Physics of the Solid Earth, 49(6), 823-835.

Levashova, N. M., M. L. Bazhenov, J. G. Meert, N. B. Kuznetsov, I. V. Golovanova, K. N. Danukalov, and N. M. Fedorova (2013), Paleogeography of Baltica in the Ediacaran: Paleomagnetic and geochronological data from the clastic Zigan Formation, South Urals, Precambrian Research, 236, 16-30.

Lurcock, P. C., and G. S. Wilson (2013), The palaeomagnetism of glauconitic sediments, Global and Planetary Change, 110, 278-288.

Mankinen, E. A., C. S. Gromme, and W. P. Irwin (2013), Paleomagnetic contributions to the Klamath Mountains terrane puzzle-A new piece from the Ironside Mountain batholith, northern California, Tectonophysics, 608, 401-407.

Meert, J. G., and M. K. Pandit (2013), Paleomagnetism of bhander sediments from bhopal inlier, vindhyan supergroup, Journal of the Geological Society of India, 82(5), 588-589.

Meert, J. G., M. K. Pandit, and G. D. Kamenov (2013), Further geochronological and paleomagnetic constraints on Malani (and pre-Malani) magmatism in NW India, Tectonophysics, 608, 1254-1267.

Munoz, J. A., E. Beamud, O. Fernandez, P. Arbues, J. Dinares-Turell, and J. Poblet (2013), The Ainsa Fold and thrust oblique zone of the central Pyrenees: Kinematics of a curved contractional system from paleomagnetic and structural data, Tectonics, 32(5), 1142-1175.

Musgrave, R. J. (2013), Evidence for Late Eocene emplacement of the Malaita Terrane, Solomon Islands: Implications for an even larger Ontong Java Nui oceanic plateau, Journal of Geophysical Research-Solid Earth, 118(6), 2670-2686.

Neres, M., J. M. Miranda, and E. Font (2013), Testing Iberian kinematics at Jurassic-Cretaceous times, Tectonics, 32(5), 1312-1319.

Pares, J. M., L. Arnold, M. Duval, M. Demuro, A. Perez-Gonzalez, J. M. B. de Castro, E. Carbonell, and J. L. Arsuaga (2013), Reassessing the age of Atapuerca-TD6 (Spain): new paleomagnetic results, Journal of Archaeological Science, 40(12), 4586-4595.

Paterson, G. A., Y. Z. Wang, and Y. X. Pan (2013), The fidelity of paleomagnetic records carried by magnetosome chains, Earth and Planetary Science Letters, 383, 82-91.

Piskarev, A. L., I. A. Andreeva, and E. G. Gus'kova (2013), Paleomagnetic data on the sedimentation rate near the Mendeleev Rise (Arctic Ocean), Oceanology, 53(5), 620-629.

Radhakrishna, T., N. R. Krishnendu, and G. Balasubramonian (2013), Palaeoproterozoic Indian shield in the global continental assembly: Evidence from the palaeomagnetism of mafic dyke swarms, Earth-Science Reviews, 126, 370-389.

Rusmore, M. E., S. W. Bogue, and G. J. Woodsworth (2013), Paleogeography of the Insular and Intermontane terranes reconsidered: Evidence from the southern Coast Mountains Batholith, British Columbia, Lithosphere, 5(5), 521-536.

Snowball, I., A. Mellstrom, E. Ahlstrand, E. Haltia, A. Nilsson, W. X. Ning, R. Muscheler, and A. Brauer (2013), An estimate of post-depositional remanent magnetization lock-in depth in organic rich varved lake sediments, Global and Planetary Change, 110, 264-277.

Szaniawski, R., S. Mazzoli, L. Jankowski, and M. Zattin (2013), No large-magnitude tectonic rotations of the Subsilesian Unit of the Outer Western Carpathians: Evidence from primary magnetization recorded in hematite-bearing Wglowka Marls (Senonian to Eocene), Journal of Geodynamics, 71, 14-24.

Tong, Y. B., Z. Y. Yang, L. D. Zheng, Y. L. Xu, H. Wang, L. Gao, and X. Z. Hu (2013), Internal crustal deformation in the northern part of Shan-Thai Block: New evidence from paleomagnetic results of Cretaceous and Paleogene redbeds, Tectonophysics, 608, 1138-1158.

Wang, B., G. W. Zhang, and Z. Y. Yang (2013), New Mesozoic paleomagnetic results from the northeastern Sichuan basin and their implication, Tectonophysics, 608, 418-427.

Zhao, P., Y. Chen, B. Xu, M. Faure, G. Z. Shi, and F. Choulet (2013), Did the Paleo-Asian Ocean between North China Block and Mongolia Block exist during the late Paleozoic? First paleomagnetic evidence from central-eastern Inner Mongolia, China, Journal of Geophysical Research-Solid

Earth, 118(5), 1873-1894.

Prospecting and Surveying

Aboelkhair, H., and M. Rabei (2013), Delineation of the subsurface structures and basement surface of the Abu-Rodaym area, Southwestern Sinai, using ground magnetic data, Earth Planets and Space, 65(7), 749-757.

Cole, J., C. A. Finn, and S. J. Webb (2013), Overview of the magnetic signatures of the Palaeoproterozoic Rustenburg Layered Suite, Bushveld Complex, South Africa, Precambrian Research, 236, 193-213.

Dong, C. Z., W. W. Ding, J. B. Li, Y. X. Fang, and Z. H. Cheng (2013), The gravity and magnetic anomaly and crustal structure of Prydz Bay, East Antarctica, Chinese Journal of Geophysics-Chinese Edition, 56(10), 3346-3360.

Elawadi, E., H. Zaman, A. Batayneh, S. Mogren, A. Laboun, H. Ghrefat, and T. Zumlot (2013), Structural interpretation of the Ifal Basin in north-western Saudi Arabia from aeromagnetic data: hydrogeological and environmental implications, Exploration Geophysics, 44(4), 251-263.

Langenheim, V. E., R. C. Jachens, C. M. Wentworth, and R. J. McLaughlin (2013), Previously unrecognized regional structure of the Coastal Belt of the Franciscan Complex, northern California, revealed by magnetic data, Geosphere, 9(6), 1514-1529.

Liu, S., J. Feng, W. L. Gao, L. Q. Qiu, T. Y. Liu, and X. Y. Hu (2013), 2D inversion for borehole magnetic data in the presence of significant remanence and demagnetization, Chinese Journal of Geophysics-Chinese Edition, 56(12), 4297-4309.

Mandal, A., A. Biswas, S. Mittal, W. K. Mohanty, S. P. Sharma, D. Sengupta, J. Sen, and A. K. Bhatt (2013), Geophysical anomalies associated with uranium mineralization from Beldih mine, South Purulia Shear Zone, India, Journal of the Geological Society of India, 82(6), 601-606.

Munoz, G. (2014), Exploring for Geothermal Resources with Electromagnetic Methods, Surveys in Geophysics, 35(1), 101-122.

Osinowo, O. O., and A. I. Olayinka (2013), Aeromagnetic mapping of basement topography around the Ijebu-Ode geological transition zone, Southwestern Nigeria, Acta Geodaetica Et Geophysica, 48(4), 451-470.

Pommier, A. (2014), Interpretation of Magnetotelluric Results Using Laboratory Measurements, Surveys in Geophysics, 35(1), 41-84.

Smith, R. (2014), Electromagnetic Induction Methods in Mining Geophysics from 2008 to 2012, Surveys in Geophysics, 35(1), 123-156.

Synthesis

Adamczyk, Z., M. Nattich-Rak, M. Sadowska, A. Michna, and K. Szczepaniak (2013), Mechanisms of nanoparticle and bioparticle deposition - Kinetic aspects, Colloids and Surfaces a-Physicochemical and Engineering Aspects, 439, 3-22.

Du, Y. M., L. Li, C. W. Leung, P. T. Lai, and P. W. T. Pong (2014), Synthesis and Characterization of Silica-Encapsulated Iron Oxide Nanoparticles, Ieee Transactions on Magnetics, 50(1).

Islam, M. N., M. Abbas, B. Sinha, J. R. Joeng, and C. Kim (2013), Silica encapsulation of sonochemically synthesized iron oxide nanoparticles, Electronic Materials Letters, 9(6), 817-820.

Jia, S., T. T. Song, B. G. Zhao, Q. J. Zhai, and Y. L. Gao (2014), Regular Fe3O4 octahedrons with excellent soft magnetic properties prepared by dealloying technique, Journal of Alloys and Compounds, 585, 580-586.

Kulak, A. N., M. Semsarilar, Y. Y. Kim, J. Ihli, L. A. Fielding, O. Cespedes, S. P. Armes, and F. C. Meldrum (2014), One-pot synthesis of an inorganic heterostructure: uniform occlusion of magnetite nanoparticles within calcite single crystals, Chemical Science, 5(2), 738-743.

Kumar, S. R., M. M. Raja, D. Mangalaraj, C. Viswanathan, and N. Ponpandian (2013), Surfactant free solvothermal synthesis of monodispersed 3D hierarchical Fe3O4 microspheres, Materials Letters, 110, 98-101.

Li, Z. F., L. H. Qiang, S. L. Zhong, H. Y. Wang, and X. J. Cui (2013), Synthesis and characterization of monodisperse magnetic Fe3O4@BSA core-shell nanoparticles, Colloids and Surfaces a-Physicochemical and Engineering Aspects, 436, 1145-1151.

Li, L., Y. M. Du, K. Y. Mak, C. W. Leung, and P. W. T. Pong (2014), Novel Hybrid Au/Fe3O4 Magnetic Octahedron-like Nanoparticles with Tunable Size, Ieee Transactions on Magnetics, 50(1).

Mascolo, M. C., Y. B. Pei, and T. A. Ring (2013), Room Temperature Co-Precipitation Synthesis of Magnetite Nanoparticles in a Large pH Window with Different Bases, Materials, 6(12), 5549-5567.

Mosivand, S., L. M. A. Monzon, K. Ackland, I. Kazeminezhad, and J. M. D. Coey (2014), Structural and magnetic properties of sonoelectrocrystallized magnetite nanoparticles, Journal of Physics D-Applied Physics, 47(5).

Naseri, M. G., M. K. Halimah, A. Dehzangi, A. Kamalianfar, E. B. Saion, and B. Y. Mains (2014), A comprehensive overview on the structure and comparison of magnetic properties of nanocrystalline synthesized by a thermal treatment method, Journal of Physics and Chemistry of Solids, 75(3), 315-327.

Ramadan, W., M. I. Zaki, N. E. Fouad, and G. A. H. Mekhemer (2014), Particle characteristics and reduction behavior of synthetic magnetite, Journal of Magnetism and Magnetic Materials, 355, 246-253.

Riaz, S., A. Akbar, and S. Naseem (2014), Controlled Nanostructuring of Multiphase Core-Shell Iron Oxide Nanoparticles, Ieee Transactions on Magnetics, 50(1).

Riaz, S., M. Bashir, and S. Naseem (2014), Iron Oxide Nanoparticles Prepared by Modified Co-Precipitation Method, Ieee Transactions on Magnetics, 50(1).

Supattarasakda, K., K. Petcharoen, T. Permpool, A. Sirivat, and W. Lerdwijitjarud (2013), Control of hematite nanoparticle size and shape by the chemical precipitation method, Powder Technology, 249, 353-359.

Tan, W. F., Y. T. Yu, M. X. Wang, F. Liu, and L. K. Koopal

Good News!

Disappointed that Roy Thompson and Frank Oldfield's (1986) textbook "Environmental Magnetism" has long been unavailable?
If so the 8-keystroke Gooogle "geos roy" search should efficiently get your browser to the authors' .pdfs at:
http://www.geos.ed.ac.uk/homes/thompson/envmag/

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view and Advisory Committee and Colleagues from the International Rock Magnetic and Paleomagnetic Community.

The intent is to circulate the paper via different channels, in the hope that these new frontiers will further foster cross-disciplinary research and excite the next generation of scientists entering our field. The full-version is to be sent to the NSF program directors, to inform and educate on the state-of-the-art of Earth Science-related magnetic research and what we as a community feel the future trends of magnetism will be. A formatted version will be circulated through EOS addressing the wider public to give an appreciation of where magnetism is at today, what has been achieved so far and where we believe it is headed. A web-link to the IRM's website will also direct readers to the full document.

Through the IRM Quarterly, we address our community in a more informal manner, explaining the purpose and history of the paper to all those to whom it may be first-news, and reassuring that the White Paper by no means intends to exclude any research group or field of study, but on the contrary is the result of an open effort that ultimately seeks to foster collaboration, further unite, and strengthen the community.

Questions Driving Magnetics Research

We start by posing some representative broad-based science questions, which can be addressed through the collection of magnetic data, and interdisciplinary collaboration, beginning with those requiring a deep time perspective and ending with those that have a more current focus.

1. Did magnetic fields exist in the early solar nebula and play a major role in planet formation? It was only recently discovered that proto-planetary objects may have had short-lived dynamos. These early solar system fields, in addition to that of the evolving young Sun, may have magnetized many of the oldest extraterrestrial materials and celestial bodies. What can magnetic records from other planets and extraterrestrial objects tell us about their evolutionary history and that of the Earth?

2. What is the long term behavior of the Earth's magnetic field, and how can observations of these behaviors inform questions regarding the geodynamic, atmospheric, and biologic development of the planet? Determining when the Earth's magnetic field began and in what configuration (dipolar vs. non-dipolar) is a first-order geoscience question. As the astrophysics and planetary science communities strive to discover life on bodies outside our solar system, it is important that we better understand the implications of the geodynamo's onset and evolution for terrestrial biologic and atmospheric evolution, as well as long term climate change. Are there changes in the overall strength and variability of the geomagnetic field over the past 4.5 Ga that can inform us about major events in Earth history and geodynamics? Are paleomagnetic observations over geological time consistent with the Geocentric Axial Dipole (GAD) hypothesis, which posits that the planet's geographic poles are coincident with the magnetic poles on timescales >10 ka? This GAD hypothesis is central to all efforts to reconstruct tectonic plate movements, to determine the assembly and disaggregation of super-continents, to normalize paleointensity estimates from different latitudes, and to apply magnetostratigraphic techniques to volcanic and sedimentary sequences. If the field has been significantly non-dipolar over long periods of time, when were these intervals and what was their underlying cause? Has extreme True Polar Wander (dramatic spin axis shifts of the Earth) occurred in the geological past, and if so, what were the controlling factors? Can we use mantle plumes as a fixed reference frame with respect to the mantle, or do these blow in the 'mantle wind' on short time scales with respect to the spin axis? All of these questions require a deeper view of the long-term behavior of the Earth's geomagnetic field and its interconnected relationships with mantle, crustal, atmospheric, and biological systems.

3. What is the short-term behavior of the Earth's magnetic field? What do high-resolution paleomagnetic records and derived paleofield models for the last 1 Ma tell us about the geodynamo and its underlying physical processes? How fast can the geomagnetic field change during secular variation (time scale of <10 ka), dipole reversals (1-10 ka) and short term dipolar excursions (<1 ka)? Are all these processes part of the same continuum or does one influence the others? Can we improve our understanding of the way that sediments acquire a depositional remanence, overcoming such limitations as lock-in depth, redox reactions, and inclination shallowing, so that we can ultimately get a clearer, more continuous view of short-term geomagnetic behavior? Can we improve the integration of paleomagnetic records from sedimentary, volcanic, and archaeological sources to create statistical geomagnetic models with better geographic coverage? Have past short-term geomagnetic variations influenced global and regional climate, and by extension, ancient human cultures? Looking forwards, what are the implications of this short-term behavior on the effects of space weather on human satellite systems? How can we use past geomagnetic behavior to prepare for the future?

4. How accurately are environmental and climate signals recorded by magnetic minerals in soils, sediments, and rocks? It has long been known that minerals in igneous and sedimentary environments are a reflection of the thermodynamic and chemical conditions in which they formed. Environmental magnetists have successfully leveraged this idea to compile histories of regional environmental and global climate change. Magnetic enhancement records from ancient soils in Chinese loess (eolian dust deposits) have provided the first long term (>2 Ma) continental climate record. But why are such enhancements absent in some other loess deposits, and how can other magnetic signatures from these sequences

be used to decipher regional paleoclimatic variations? Paleomagnetic and oxygen isotopic records from marine sediments have verified the Milankovitch hypothesis of climate cycles on timescales >40 ka. Can higher frequency (< 10 ka) records of paleointensity fluctuations in selected marine sediments be made more reliable to extract sharper climate change records to test climate change models? Can we reconstruct iron biogeochemical cycles in the oceans by magnetically tracking iron speciation and chemical alteration in oxides, hydroxides and sulfides in marine sediments? Can we use paleosols, developed on sediments other than loess, to better constrain paleo-precipitation across a diversity of latitudes? Many micro-organisms produce intracellular or extracellular magnetic minerals whose formation and survival can be magnetically sensed with high accuracy. Can we utilize these magnetic signals to reconstruct fluctuating paleoredox states in ocean environments? Magnetic measurements coupled with low-temperature geochemistry and geomicrobiology could help disentangle the complementary inorganic and organic processes that define vague, but critically important terms like "pedogenesis" and "diagenesis."

5. How are magnetic minerals and magnetic fields involved in active Earth processes and can we monitor them to minimize adverse impacts on human communities, while at the same time maximizing the needs of a growing populace? Magnetic minerals occur as natural and anthropogenic components in atmospheric dust, runoff into rivers and oceans, and groundwater. Can we better establish the link between the concentration, composition, and physical properties of Fe-bearing minerals in atmospheric dust and their impact on the absorption of solar radiation, weather, melting of snow and ice, terrestrial and marine fertility, as well as on air quality and human health and safety? Similarly, the concentration of magnetic minerals in soils and river sediments has been shown to correlate with the concentration of heavy metals. Can environmental magnetists create innovative ways to quantitatively leverage their magnetic measurements, which are cheap, efficient, and easily automated, to improve standard environmental monitoring practices? As our communities become increasingly urbanized and require additional raw and processed materials, can we improve magnetic-based exploration tools, such as aeromagnetic surveys, magnetotellurics and magnetic fabric analysis to locate and responsibly extract natural resources such as copper, gold, and platinum group elements? Can we use magnetic methods to monitor the status of sulfide mineralogy within tailing piles to ensure that acid-mine drainage from these endeavors does not compromise our groundwater? While all of these modern applications are tantalizing, studies of such approaches are mostly lacking, and it is the responsibility of the magnetics community to build bridges among diverse disciplines in geology, geophysics, geochemistry, climate modeling, ecology, cryospheric studies, and human health to thereby advance these goals.

Addressing the Questions

Answering questions like the ones listed above requires the design of appropriate experiments and collection of paleomagnetic and rock magnetic data, but also the development of new magnetic instrumentation that is sensitive enough to give us the accuracy that is needed. These go hand in hand, and inevitably technological advances lead to accelerated progress and new possibilities in magnetic research. A notable landmark was the construction of the first superconducting rock magnetometer (see Goree and Fuller, 1976), whose excellent sensitivity made possible measurements of weakly magnetic materials and opened up new applications such as biogeomagnetism and environmental magnetism.

We conducted a simple exercise by searching magnetic areas of research-related keywords in the ISI Web of Knowledge database going back to 1954 in ten year intervals, and noting the number of references that are obtained (Figure 1). The result gives an interesting overview on how magnetics research has evolved, bearing in mind the limitations of such an exercise: not all references are present; not all that are retrieved are in the Earth sciences; keyword searching is by no means comprehensive; and a time-lag (hysteresis?) is always to be expected. Generalized trends, however, can still be teased out.

Rock Magnetism and Paleomagnetism (fortunately for us ISI Web of Knowledge searches for the spelling Palaeomagnetism also) have progressed hand in hand with developments in Magnetometry, and understandably the latter is the keyword that yields the most results, although most of those articles are undoubtedly outside of the geosciences. Rock magnetism and Paleomagnetism are the only Earth science-related keywords for which results date back to the earliest decade searched (1954-1963).

The next fields to appear in the search results are those involving geomagnetic field records and variations at the smaller time scales, like Magnetic Excursions and Paleointensity, which first occur in the decade 1964-73. Biogeomagnetism and Planetary Magnetism also start appearing at this time. Articles with the keywords Magnetostratigraphy, Paleosecular Variation, Depositional (or Detrital) remanent Magnetization, Geodynamo and True Polar Wonder begin appearing in the 1974-83 interval, possibly highlighting an interest shift to longer time scales as recorded by sedimentary stratigraphies and their ability to provide continuous records of the geomagnetic field, allowing insights into its origin. Stratigraphic studies have also experienced a more recent renaissance which is tightly linked to the interest in Environmental studies (below) and brought about by the recognition of Milankovitch cycles and the use of magnetic proxies to identify such cyclicity. Environmental Magnetism, Magnetic Databases and Computation, Extraterrestrial Magnetism are also "up and coming" areas of study and development.

Crust Deformation, Magnetism and Climate, Diagenesis and Magnetism, Core Evolution and Mantle Dynamics are the last areas of research to appear in the database, first occurring in the search results for the mid-eighties to early nineties.

The generalized pattern that appears from this search seems to reflect an evolution from the general study of Rock Magnetism to its applications in Paleomagnetism (Plate Tectonics) and behavior of the geomagnetic field. An outstanding pattern that emerges from these data is the quasi-exponential growth in publication rate in most of the research areas, since the appearance of the first publications in the ISI search engine. What is clear is that projecting these trends into the future will result into well over a thousand articles per year in the next ten years for the most prominent areas of magnetic research. This increasing trend must reflect both the tremendous research advances made in recent years and the increasingly competitive nature of academic research. What is sure, though is that we will all need reading glasses soon, if we don't already.

The top areas of research for the last ten years based on the number of hits in Web of Knowledge, are: Magnetometry (4,118); Paleomagnetism (1,531); Magnetostratigraphy (816); Rock Magnetism (722); Magnetic Excursions (600); Environmental Magnetism combined with Climate studies (408+190, though Climate could also contain articles on climatic effects on the dynamo); Paleointensity (529); Geodynamo (516);. Also notably, True Polar Wander (209) and Paleosecular Variation (139) have seen a steady increase since their inception, whereas Biomagnetism (125) is a 'well-established player' in today's science.

Future trends

Below are examples of new research opportunities that have opened up due to advances in mineral magnetism, nanomaterial analysis and computational modeling (micromagnetic modeling) of magnetic spins in particles.

1. Advances in materials and methodologies for paleointensity determination from terrestrial and extraterrestrial materials. Improving our compilation of the history of the strength of geomagnetic field remains one of the central challenges facing rock magnetism and paleomagnetism. Over the last 10 years the community has made great strides in using submicrometer-sized magnetite crystals embedded in many types of silicates and submarine basaltic glasses. The use of such ideal magnetic recorders, which are protected from subsequent alteration by their silicate hosts, needs to be expanded to include oxide exsolution microstructures and single crystal zircons. Parallel experimental studies are needed to utilize new scanning technologies like atomic and magnetic force microscopes capable of operating at temperatures higher than 300 K. Computational micromagnetic models need to become more realistic by including magnetoelastic interactions with internal defects. Better models are also needed for the dependence of magnetization on the rate of change of temperature and magnetic fields. These models can help us separate primary signals from secondary magnetizations due to viscous, chemical and late generation re-heating processes. New thermal and analog paleointensity methods need to be developed to extract paleointensities from extraterrestrial samples including alloys and sulfides of iron nickel and iron phosphates. Meteorites and lunar rocks provide records of past magnetic fields on other planetary bodies and in the nebula. However, most samples cannot be analyzed with alternating field (AF) demagnetization because the alternating field generates a spurious anhysteretic remanence (ARM). Overcoming this problem requires the development of low-ARM noise systems, which would permit the paleomagnetic investigations of a much greater diversity of samples (including entire groups of meteorites) that are currently inaccessible. This instrumental development would also assist in the analysis of multidomain samples on Earth. The rewards for such studies include new knowledge about the magnetic fields associated with the early solar system, the Moon, meteorites, Mercury, as well as an improved understanding of the source of very large crustal magnetic anomalies as on Mars. On Earth, the number of available paleointensity estimates and their temporal continuity might be greatly enhanced by a generally applicable theoretical understanding of what controls the acquisition and strength of magnetization in sediments.

2. Environmental magnetism and paleoclimate reconstruction. Environmental magnetism has existed as a discipline only for the last 30 years. However, the contributions of rock, mineral and sediment magnetism in this area have had a large impact. For example, magnetic records from windblown and fluvial sediments have helped produce the first long (2 Ma) record of Milankovitch cycles on land and have identified modern heavy metal pollution from multiple sources in central Europe and Asia. The mineral magnetic properties of atmospheric dust, as well as other related physical properties, are receiving increasing attention. The parameters sought for environmental studies are composition, concentration and particle size of the magnetic minerals contained in the sediments. However, the last 10 years have seen a strong push to make such results more quantitative and linked specifically to temperature, precipitation, wind intensity, hydrology and even microbial content, making it necessary for environmental magnetists to collaborate with sedimentologists, geochemists, atmospheric, and soil scientists. Such efforts have made it clear that we need to calibrate the magnetic effects of biogeochemical changes in the natural environment. Future studies will require the synthesis (biotic and abiotic) of nanoparticles of iron oxides and hydroxides that are analogous to the materials produced during the first stages of sediment diagenesis. Nanometer-sized, dual-phase grains consisting of a core and a 3-nm skin are commonly produced during diagenesis and atmospheric transport. To characterize their magnetizations and better understand the processes that regulate our environment, diverse tools like low temperature magnetism, Mössbauer spectroscopy, and synchrotron studies using techniques such as Extended X-ray Absorption Fine Structure (EXAFS),

X-ray Absorption Near Edge Structure (XANES), and X-ray Magnetic Circular Dichroism (XMCD) will be needed. The US can play an important role in these applications in the near future because of the availability of synchrotron sources and related environmental research in many centers such as the Pacific Northwest and Oak Ridge National Laboratories. Synchrotron facilities outside the United States, such as ISIS and the Diamond Facility in the United Kingdom and the Beijing Synchrotron Radiation Facility in China, are increasingly leading the charge in leveraging these new tools in the pursuit of magnetics research.

3. Advances in novel magnetometry for high spatial resolution study of single crystals from terrestrial and extraterrestrial sources. Recent advances in magnetic microscopy (e.g., scanning SQUID microscopes and off-axis electron holography) have demonstrated the importance of imaging in-situ fine scale magnetic structures and establishing their contributions to macroscopic phenomena. Dedicated instruments that allow researchers to carefully control the measurement environment (e.g., variable magnetic fields, >300 K temperatures, and controlled atmospheres) are needed for Earth scientists to study the origin and stability of magnetism at a variety of length scales, from nanometers to millimeters. Novel forms of magnetic microscopy and high sensitivity magnetometers need to be adapted for Earth materials. Some advances in magnetometers (e.g. atomic magnetometers) may be relatively affordable and suitable for all paleomagnetic labs. For others, it seems possible that instead of concentrating a number of such expensive instruments at a single center, the US might consider 'multi-pod' centers to exploit the first-generation equipment in existent materials science and nanoscience centers such as the NNINs (National Nanotechnology Infrastructure Network).

4. Development of spacecraft magnetometers for in situ planetary exploration. The continued spacecraft exploration of the solar system is offering unprecedented opportunities for carrying the above kinds of investigations to other bodies. Landers are in development or planned for the surfaces of the Moon, Mars, comets, and asteroids. Spacecraft magnetometers have reached a sweet spot combining a highly robust architecture with low mass and power requirements. The continued development and miniaturization of new fluxgate and atomic magnetometers and the development of spacecraft rock magnetometers offer the possibility of in situ rock magnetic investigations on the surfaces of the other bodies. This will permit unprecedented new constraints on their magnetic mineralogies, geologic, climatic, and geomagnetic histories.

5. Biogeomagnetism. Many organisms, from mammals to bacteria, are sensitive to the geomagnetic field and use it for orientation and navigation (in combination with other environmental cues). While magnetofossils are known to be important contributors to records of the ancient geomagnetic field in sediments, and biogenic magnetite and greigite is believed to be essential for magnetoreception, we have only a poor understanding of how various life forms accommodate large scale changes in field strength, direction, and changing exposure to space weather. The science of magnetoreception is a burgeoning interdisciplinary field involving behavioral biology, biological physics, neuroscience, geophysics, and rock magnetism. Researchers studying magnetotactic bacteria are developing a database for information related to their gene sequencing and basic rock magnetic properties, http://database.biomnsl.com/index.html). Such studies complement the increasing successful effort to identify magnetofossils and other Fe-biominerals throughout geologic history, and to determine their first appearance in the geologic record.

6. Community Databases, Computational Resources, and Cyberinfrastructure. Most of the topics listed above have been of major interest for several decades, and significant progress still requires high quality global data sets spanning relevant time intervals. The magnetics community has anticipated the move towards large-scale database development that has culminated in the NSF EarthCube Initiative, and recent efforts like the Magnetics Information Consortium (MagIC) and related services devoted to individual data types (e.g. Geomagia50, PINT) preserve access to the cumulative body of knowledge necessary to make progress on both regional and global scale problems. For example, such databases are required for researchers to isolate evidence, or lack thereof, for dominantly dipolar field structure in paleointensity data. The MagIC database opens the doors for understanding bias in published data through the careful documentation of materials, methodology, and data. Much work remains to be done in order to provide computational resources for the magnetics community. Specific computational needs vary according to whether a study is rock magnetic, enviromagnetic, paleomagnetic, or geomagnetic in nature, and no single research is capable of satisfying all of these needs. However as a community, we advocate for streamlining our computational needs under a single, or at least a minimal number, of cyberinfrastructures. EarthRef.org, which currently hosts MagIC, is perhaps the best existing platform for our community, and can in the future also provide public access for various types of modeling, fitting, and inversion software provided by researchers from around the world. These software applications can be developed at any institution, but should ultimately be hosted through EarthRef.org, and integrated with MagIC databases. Along these lines EarthRef.org already serves as a host for geomagnetic field models through ERDA (Earth Reference Digital Archive), and these models provide a strategic method for dating and/or evaluating new archeomagnetic or other Holocene data.

Concluding Remarks:

The innovative use of rock and paleomagnetism is a rich and commonly under-utilized source of geophysical information in an increasingly interdisciplinary science environment. Other areas that stand to benefit from progress in paleo and rock magnetic research include planetary science, geodynamo studies, paleooceanography, paleoclimate, environmental science, archaeology, geochronology and tectonic studies. A recent National Research Council report, “New Research Opportunities in the Earth Sciences” emphasized the need for synergistic approaches involving rock and paleomagnetism. The NSF EarthCube Initiative currently being developed provides the vision of using the cyberinfrastructure generated in EarthCube as an experimental instrument in its own right, giving access to experimental data and modeling tools across a broad range of fields and using them to make new linkages that drive the agenda for cutting-edge interdisciplinary science. The international rock- and paleomagnetic community are eager to contribute with new data, theoretical ideas, and numerical modeling.

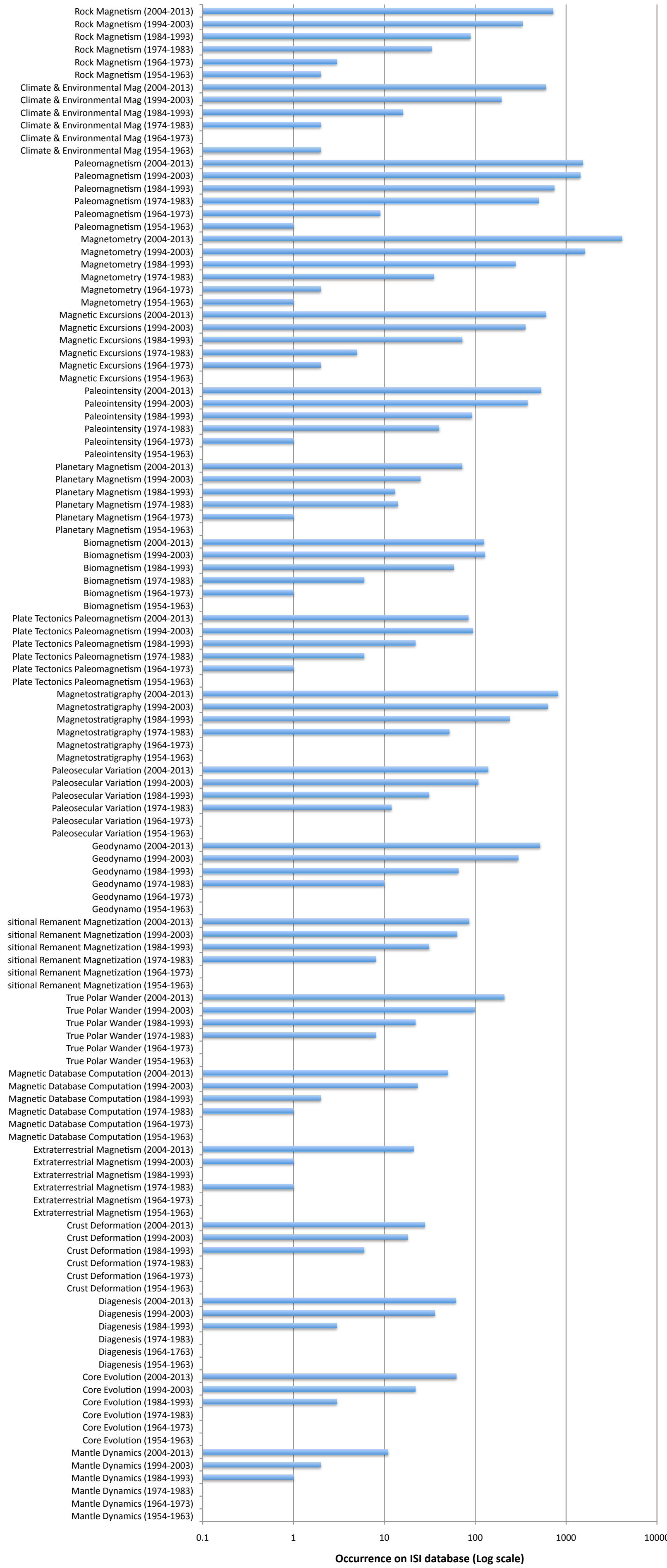

Figure 1. Results of a keyword search on the ISI Web of Knowledge performed for different areas of research in magnetism for ten-year intervals going back from November 2013 to 1954 (Note the logarithmic scale!)

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The IRM Quarterly

The *Institute for Rock Magnetism* is dedicated to providing state-of-the-art facilities and technical expertise free of charge to any interested researcher who applies and is accepted as a Visiting Fellow. Short proposals are accepted semi-annually in spring and fall for work to be done in a 10-day period during the following half year. Shorter, less formal visits are arranged on an individual basis through the Facilities Manager.

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