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Inside...


# Practical Magnetism I: Discriminating SD and MD magnetite particle behavior through FC-ZFC remanence curves

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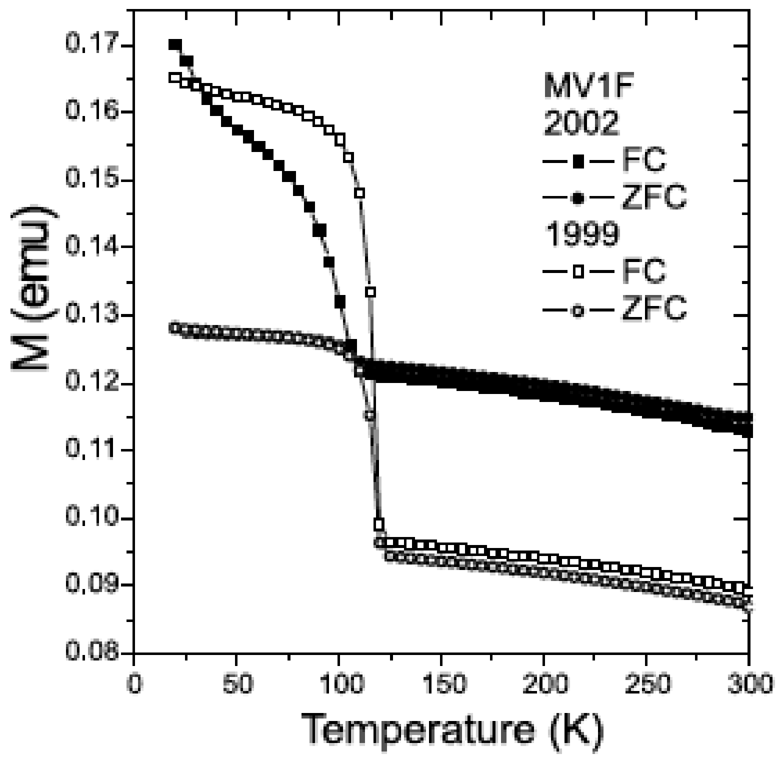
There are a number of magnetic phenomena that have been frequently observed and described, but lack an appropriate "go-to" citation offering a comprehensive explanation. IRM Quarterly articles offer a prime opportunity for such articles: for example, the low temperature magnetism series of articles provide explanations for the magnetic observations and the development of research on properties like the magnetite Verwey transition, $T_V$ (Jackson et al. 2011a, b; Bowles et al., 2012), the hematite Morin transition, $T_M$ (Bowles et al., 2010), or the pyrrhotite Besnus transition, $T_B$ (Rochette et al., 2011). These are typically written more as review articles that explain the theory behind the observations rather than practical guides on interpretation of data. Of course, specific review articles that are peer-reviewed would be more desirable, but the truth of the matter is that certain phenomena, not necessarily the magnetic transitions mentioned above, may be relatively known and discussed in publications, but often still lack appropriate and concise articles that explain them comprehensively in a practical manner. As of today, for example, the IRM Quarterly article "What do the Mumpsies do?" (Bilardello and Jackson, 2013) according to Google Scholar has 14 citations in peer-reviewed articles. I find this amusing, firstly because I enjoy seeing the title reported in peer-reviewed scientific journals, but most importantly because that article doesn't provide explanations or supporting citations for some of the phenomena it is being cited for, for example determining whether a remanence is carried by SD or MD magnetite grains. Jackson et al., (2011b) did a much better job at this but somehow the Mumpsies have stolen the scene. While I appreciate the vote of confidence, I think it may be useful to initiate a series of targeted short articles that addresses this and similar topics in order to "drive the point home", while providing the appropriate references to cite.

*SD or not SD, that is the question.*
~Edmund C. Stoner (attributed)




Field cooled and zero field cooled remanence on warming for the same sample of MV1 magnetotactic bacteria measured in 1999 and 2002. Note that the FC and ZFC curves have similar shapes in the fresh specimen, which become distinctly different upon oxidation. From Carter-Stiglitz et al. (2004).

## The observation

For SD grains, the field-cooled (FC) remanence, the magnetization measured upon warming in zero field after cooling the specimen in an applied field (typically 2.5 T), has stronger magnetization than the zero field-cooled (ZFC) remanence, the magnetization measured upon warming after cooling the specimen in a zero field and applying a low temperature (LT) saturation isothermal remanence (SIRM), or LTSIRM (typically 2.5 T). The opposite is true for MD grains.

## The explanation

*Single Domain Case*

Take a population of SD magnetite with randomly oriented crystallographic axes, magnetized to saturation,

***cont'd. on pg. 12...***

# Visiting Fellow Reports

## Rock magnetic and paleotemperature evaluation of the host sedimentary strata recovered in the KWV-1 drilling experiment, Karoo Basin, South Africa.

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The approximately 100 million years record of almost continuous sedimentation in the largely continental environment of the Karoo Basin of South Africa (Smith 1990, Catuneanu et al., 2005), that terminated by the early Jurassic magmatic intrusions is believed to have geothermal energy potential, and has been the subject of extensive studies. Recent studies (e.g. Maré et al., 2014; Scheiber-Enslin et al., 2014; Smithard et al., 2015; Campbell et al., 2016; Maré et al., 2016) have given some insight on the effect of the dolerite intrusions on the energy resources potential of the Karoo Basin sedimentary strata in South Africa. As part of my PhD research, I am investigating the paleomagnetism and rock magnetism of a continuous core recovered in the eastern part of the Karoo Basin, with the objective of quantifying the thermal history of these rocks during burial and subsequent intrusion by Early Jurassic Karoo Large Igneous Province intrusions.

Several rock magnetic experiments (low-temperature and high-temperature) were carried out at the Institute of Rock Magnetism (IRM) between July 15th 2019 and July 25th 2019 to better identify the magnetization carriers in the Karoo host sedimentary strata, and to understand the effects of alteration on the magnetic mineralogy resulting from diagenesis and the emplacement of the Karoo sills, including any possible remagnetization. Samples of host sedimentary strata were carefully selected at several distances from Karoo sills, including some from very clearly defined thermal contact aureoles, especially for the thick sills, and others from distances as far as possible from the margins of Karoo sills.

Low temperature rock magnetism experiments were carried out using the Magnetic Properties Measurement Systems (MPMS). Two protocols (sequences) have been used for this experiment: a) Room-temperature saturation isothermal remanent magnetization (RTSIRM), which produces cooling and warming curves of RT induced SIRM of 2.5 T field and b) Field-cooled, Zero Field-Cooled Low-Temperature SIRM and the addition of the RTSIRM LTD (FC-ZFC-LTSIRM-RTSIRM) sequence mentioned above. Here the warming curves of SIRM induced in fields of 2.5 T at 20 K after field cooling (2.5 T) and zero field cooling from 300K to 20 K steps), are measured to aid the identification of low-temperature crystallographic transitions of magnetic minerals, as well as oxidation and domain state (Özdemir and Dunlop, 2010). Characteristic magnetic transitions at ~ 30 K and 120 K have been shown on the warming and cooling curves experiments carried out using the Magnetic Property Measurements Systems (MPMS). The FC and ZFC remanence display a steady decay at ~120 (e.g. figure 1A), which represents the Verwey transition for magnetite (Verwey, 1939; Walz, 2002). The FC remanence in most cases have been found to be higher than the ZFC remanence curve (e.g. for KWV 74 the FC SIRM at 20 K is 0.00047 $Am^2kg^{-1}$ and the ZFC SIRM intensity at 20 K is 0.00035 $Am^2kg^{-1}$), and this is indicative of single domain magnetite, but this behavior can be flipped in the presence of a multi domain magnetite (Carter-Stiglitz et al., 2006). RT warming and cooling SIRM show decay at ~120 (figure 1A and 1B) is also indicative of magnetite as the dominant magnetization carrier. The low temperature transition exhibited by figure 1B, 1C and 1E at ~30 K (Besnus transition) is characteristic of the presence of pyrrhotite, within the vicinity of the contact aureole of the Karoo sills. The results suggest the presence of pyrrhotite and magnetite as the dominant magnetization carriers in the Karoo host sedimentary strata, at specific stratigraphic levels.

Room-temperature (RT) and high-temperature (HT) magnetic hysteresis experiments were carried out using the vibrating sample magnetometer to maximum fields of 1.8 T. Room temperature hysteresis was used to further identify samples with high concentration of ferromagnetic samples for high-temperature hysteresis experiments. HT hysteresis experiment results (figure 1D and 1F) have been used to better understand the alteration in the magnetic mineral assemblage, e.g. discrimination of both the antiferromagnetic hexagonal pyrrhotite, identified based on its characteristic λ transition at ~ 250 ˚C (Schwarz and Vaughan, 1972) and the ferrimagnetic monoclinic pyrrhotite (Dekker et al., 1989; Rochette et al., 1990). The existence of hexagonal pyrrhotite in the Karoo host sedimentary strata within a baked contact can be attributed to quenching, in which the high temperature metastable ferromagnetic phase may be retained. And this may be paleomagnetically significant (Bennett and Graham, 1981). First-order reversal curve (FORC) experiments were also carried out at ambient temperature using the Vibrating Sample Magnetometer to further aid in characterizing the domain state of the magnetic mineral assemblage intersected in the KWV-1 borecore. Results obtained from research conducted at the IRM and other rock magnetic and paleomagnetic experiments such as anisotropy of magnetic susceptibility, alternating field and thermal demagnetization are being used to provide both qualitative and quantitative analyses of the thermal effects of the Karoo sills and quantification of the paleotemperature of the Karoo host sedimentary strata encountered at varying distances from the sills.

### Acknowledgment

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## References

Campbell, S. A., Mielke, P., & Götz, A. E. (2016). Geothermal energy from the Main Karoo Basin? New insights from borehole KWV-1 (Eastern Cape, South Africa). Geothermal Energy, 4(1), 9.

Carter-Stiglitz, B., Moskowitz, B., Solheid, P., Berquó, T. S., Jackson, M., & Kosterov, A. (2006). Low-temperature magnetic behavior of multidomain titanomagnetites: TM0, TM16, and TM35. Journal of Geophysical Research: Solid Earth, 111(B12).

Catuneanu, O., Wopfner, H., Eriksson, P. G., Cairncross, B., Rubidge, B. S., Smith, R. M. H., & Hancox, P. J. (2005). The Karoo basins of south-central Africa. Journal of African Earth Sciences, 43(1-3), 211-253.

Graham, J., Bennett, C. E., & Van Riessen, A. (1987). Oxygen in pyrrhotite; 1, Thermomagnetic behavior and annealing of pyrrhotites containing small quantities of oxygen. American Mineralogist, 72(5-6), 599-604.

Maré, L. P., De Kock, M. O., Cairncross, B., & Mouri, H. (2014). Application of magnetic geothermometers in sedimentary basins: an example from the western Karoo Basin, South Africa. South African Journal of Geology, 117(1), 1-14.

Maré, L. P., De Kock, M. O., Cairncross, B., & Mouri, H. (2016). Magnetic evaluation of the palaeothermal variation across the Karoo Basin, South Africa. South African Journal of Geology 2016, 119(2), 435-452.

Özdemir, Ö., & Dunlop, D. J. (2010). Hallmarks of maghemitization in low-temperature remanence cycling of partially oxidized magnetite nanoparticles. Journal of Geophysical Research: Solid Earth, 115(B2).

Rochette, Pierre, Gérard Fillion, Jean-Luc Mattéi, and Marinus J. Dekkers. "Magnetic transition at 30–34 Kelvin in pyrrhotite: insight into a widespread occurrence of this mineral in rocks." Earth and Planetary Science Letters 98, no. 3-4 (1990): 319-328.

SCHEIBER-ENSLIN, S. E., WEBB, S. J., & EBBING, J. (2014). Geophysically Plumbing the Main Karoo Basin, South Africa. South African Journal of Geology, 117(2), 275-300.

Smith, R. M. H. (1990). A review of stratigraphy and sedimentary environments of the Karoo Basin of South Africa. Journal of African Earth Sciences (and the Middle East), 10(1-2), 117-137.

Smithard, T., Bordy, E. M., & Reid, D. (2015). The effect of dolerite intrusions on the hydrocarbon potential of the lower Permian Whitehill Formation (Karoo Supergroup) in South Africa and southern Namibia: A preliminary study. South African Journal of Geology, 118(4), 489-510.

Schwarz, E. J., & Vaughan, D. J. (1972). Magnetic phase relations of pyrrhotite. Journal of geomagnetism and geoelectricity, 24(4), 441-458.

Verwey, E. J. W. (1939). Electronic conduction of magnetite (Fe 3 O 4) and its transition point at low temperatures. Nature, 144(3642), 327.

Walz, F. (2002). The Verwey transition-a topical review. Journal of Physics: Condensed Matter, 14(12), R285.


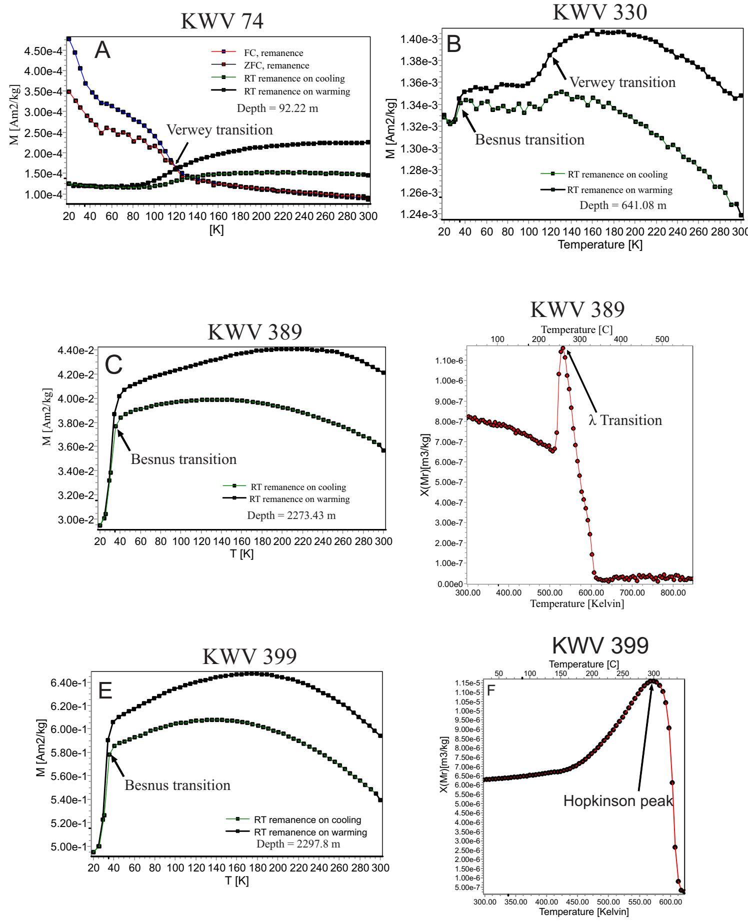


Figure 1: Results from FC-ZFC-LTSIRM LTD (A) and RTSIRM LTD curves (B, C & E) and results from high-temperature hysteresis (D, F)

# Rock magnetic properties of recent and historical etna ashes: relationships with the explosive activity


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## Introduction and Materials

One of the major challenges in volcanology is to understand the history of explosive eruptions, identify the resulting deposits and finally try to reconstruct the magmatic constraints leading to different volcanic activity.

Mt Etna located on the eastern coast of Sicily (Italy) is the largest and most active volcano in Europe and is considered a volcano-laboratory for its persistent activity characterized by eruptions of effusive nature with the explosive activity confined to Strombolian to Plinian events that rarely evolve to Plinian eruptions. In fact during historical and recent times explosive activity punctuated Etna eruptions with sub-plinian intensity that has usually been considered very subordinate with respect to the lava flow eruptions. However, since 1990, Etna has shown an extraordinarily high number of violent explosive events, including more than 150 fire fountain episodes (Del Carlo et al. 2004). During the 2001-2002 a period of "unusual activity" with prolonged phreatomagmatic lava fountaining and Strombolian activity (Dellino and Kyriakopoulos, 2003; Andronico et al., 2005; Scollo et al., 2007; Andronico et al. 2008) was responsible of the ejection of a great amount of volcanic ash. This has been interpreted as a transition between different styles of basaltic explosive activity (Andronico et al. 2009).

Aim of this work is to the test the possibility to use the magnetic properties to characterize different explosive events and use the result as discriminant factor of different eruptive cycles recognized since the formation of the Ellittico Volcano (18ka BP) up to the recent volcanic activity of Etna. The materials used include pyroclastic deposits representing the plinian Biancavilla tephra (Y1 tephra; age 16-18 ka) collected in marine core ET97-70 (Jonian Sea), the sub-plinian basaltic eruptions of late Holocene age (TV, FS, FL, FG layers + other proximal deposits) collected on the flank of the volcano and fallout ashes representing recent explosive activity, including products ejected during the year 2001-2002.

The work can be divided in two tasks:

- characterize the complete magnetic mineral assemblage of different tephra layers representing the old/historical eruptions as well as the recent ones.
- comparison between the evolution of the four events of the Biancavilla eruption (Y1) (Del Carlo et al. 2004) and the evolution of the recent explosive activity observed during the interval 27/10/2002-30/12/2002 (Andronico et al. 2008).

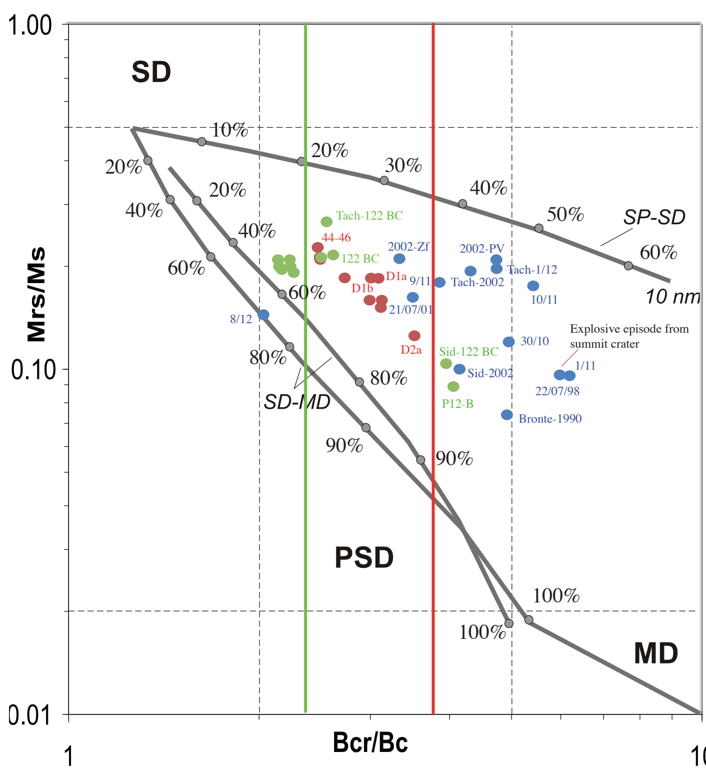


Figure 1: Day-Dunlop Plot for the ash samples from Etna. Red dots refer to the samples from Core ET97-70; green dots to the late Holocene historical eruptions and the blue dots to the fallout from recent activity.

To better discriminate the magnetic properties of the explosive disintegration of newly erupted magma, the two end members of the juvenile ash, tachylite fragments (microlite-rich) and sideromelane (glassy), were separated from recent ashes (2002 eruption) and from the old FG tephra (122 BC Plinian eruption). The combination between a mixture of coarser-hotter tachylite (juvenile component) and finer-glassy sideromelane should play a role on the magnetic properties, so one of the aim of this project is to identify a magnetic signature of these end-members of groundmass cristallization.

## Methods

A full set of rock magnetic experiments was carried out to determine the magnetic mineralogy and domain-state of the ashes. I performed FORCs (First-Order Reversal Curves), hysteresis loops and backfields at room temperature with the VSMs and low temperature (LT) measurements with the MPMS. LT experiments were carried out by measuring the magnetic remanence by heating the samples from 10 K to room temperature after cooling in a 2.5 T field (field cooled remanence, FC), as well as after cooling in zero field but applying a saturation isothermal remanent magnetization (SIRM) of 2.5 T at 10 K (zero-field cooled remanence, ZFC). A room temperature (RT) 2.5 T SIRM was also applied and the remanence measured upon cooling to 10 K and warming back to room temperature (RTSIRM). AC susceptibility as a function of temperature and frequency (3-5 steps at 1, 10, 100 Hz or 1, 5, 32, 178, 1000 Hz) was also measured on the MPMS on selected specimens from the three different groups of samples. Susceptibility measurements at different field amplitudes were carried out on samples belonging to the Y1 tephra of the Biancavilla Eruption. One sample from this eruption together a recent sample was investigated by Mossbauer measurements at room and low (20 K) temperatures.

## Results

The samples are characterized by coercivity of the remanence (Bcr) to coercivity (Bc) ratios ranging from 2 to 6, defining three main groups according to the position in the Day-Dunlop plot (Fig. 1). These groups represent magnetic grain sizes dominated by PSD grain-size with variable contribution of larger (MD) and smaller (SD/SP) grains corresponding to the old, historical and recent activity (Fig. 1). The historical tephra exhibit a quite well defined population whereas scattered data characterize the young ashes. The two glassy sideromelane samples from recent and 122 BC eruption show consistent values in the Day plot with lower Mr/Mrs values with respect to the Tachylites (Fig. 1). The latter point out to an increasing contribution of finer grains that contrasts with the coarser grain-size of this juvenile fraction. The data from the old Y1 tephra show an alignment indicating a trend in the grain-size. The susceptibility profile of the 28 samples representing this tephra exhibits a magnetic signature characterized by four peaks representing the two couples of plinian eruptions (D1a-D2a/D1b-D2b; Fig. 2) of the stratigraphic Unit D recognized in the field

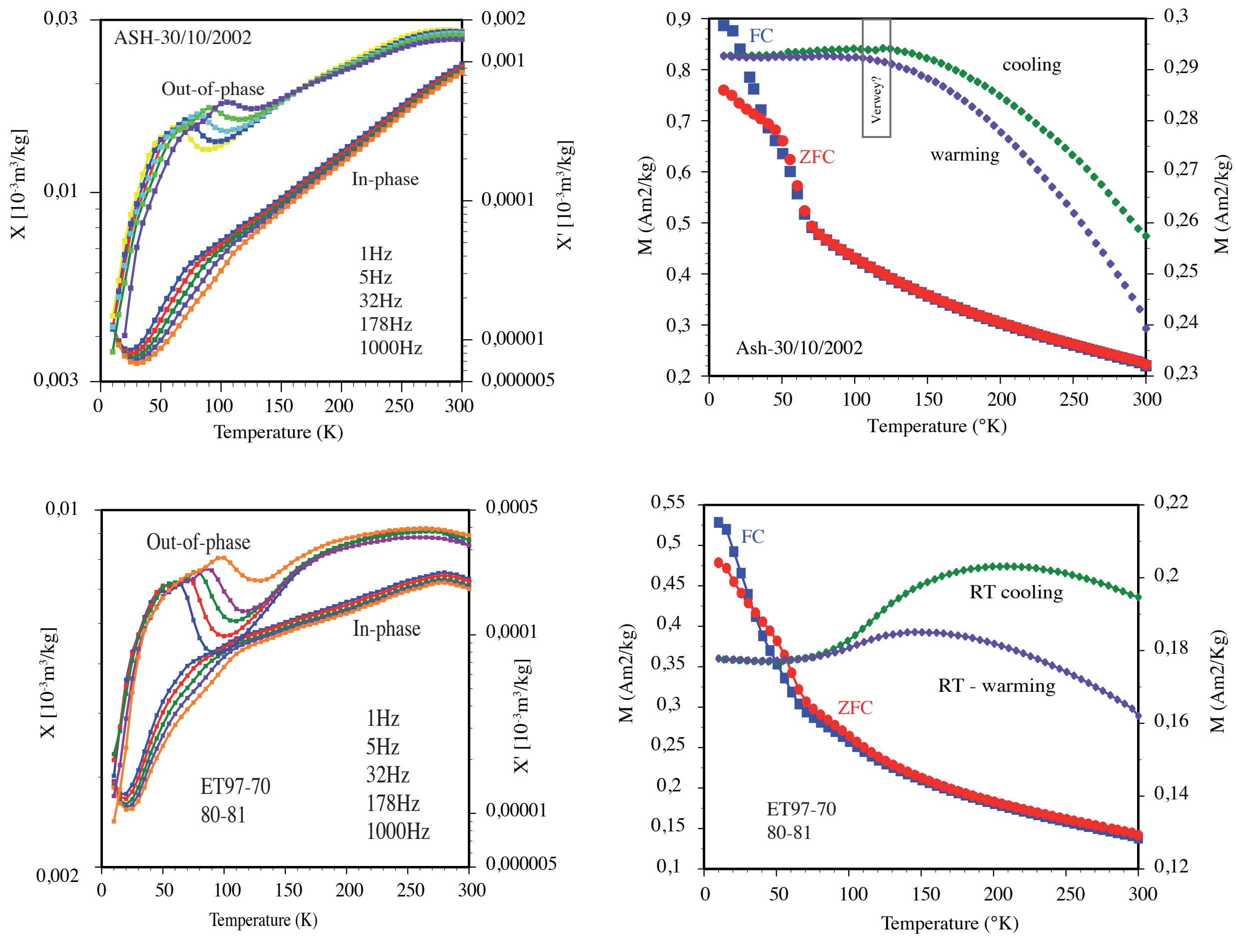


Figure 2: Low temperature magnetic measurements for two samples from old (ET97-70/80-81) and recent (30-10-2002) Etna ashes. Left: In-phase and out-of-phase susceptibility as a function of frequency and temperature. Right: Field Cooled (ZF), Zero Field Cooled (ZFC) and measurements of room temperature remanence (RTSIRM) during cooling and warming.

by Coltelli et al. (2000). The highest peak occurs for the D2a eruption (Fig. 2) that according to the Day Plot seems also characterized by larger grain-size in Day Plot of (Fig. 1). On the contrary, the samples from the final stage of the eruption (D1b-D2b) indicate an increasing contribution of smaller grain sizes. These samples also exhibit a decreasing trend in the difference between the susceptibility values measured at low (10 A/m) and high field (400 A/m) that could be an indication of a minor Ti-content. The presence of the titanium seems common to most of the studied samples with thermomagnetic curves dominated by Curie temperatures <300°C. Magnetite or Ti-poor titanomagnetite (Tc ~540-570°C) was well identified only in a few historical tephras (TV, FS, FL), suggesting minor or missing Ti-substitution for this class of samples.

Low temperature measurements of in-phase and out-of-phase susceptibility show a common behavior for most of the samples that point out to a significant decrease of the susceptibility during the cooling from 300 to 10 K (Fig. 2). The out-of-phase susceptibility shows two peaks both depending from the frequency. The in-phase susceptibility shows a similar trend with more pronounced low T frequency dependence and temperature-dependence susceptibility. This behavior is typical of titanomagnetite grains with significant content in titanium (~60% titanium substitution, TM60; Moskowitz et al. 1998). Low temperature experiments carried out on 5 samples (one from the Y1 tephra, one from the plinian 122 BC eruption and three from the recent ashes) show that FC curves have higher magnetization than the ZFC curves and their ratio gives a consistent $R_{LT}$ values around 1.1 that represent a further indication of the presence of PSD grain size (Smirnov, 2009). A significant drop observed between 10 and 70 K could be indicative of the presence of SP grains and/or to surface oxidation of the magnetite grains. The Vervey transition appears suppressed in the FC-ZFC measurements, whereas a weak indication seems visible in the RTSIRM curves of the recent ash (Fig. 2). The feeble indication of the presence of the Verwey transition represents a confirmation that titanomagnetite is the main magnetic carrier for most of the samples.

The young ashes (including the tachylites) show wasp-waisted hysteresis loops (Fig. 3) that can depend on two magnetic components with contrasting coercivities or grain sizes. Among the old tephras, only the samples from the plinian FG tephra exhibit similar wasp-waisted loops (Fig. 3). FORC diagrams carried out on a significant number of samples display similar features: distributions are not distinct from the origin with a spreading especially along the negative values of Bu indicating the presence of interacting MD grains with a contribution of SP materials. A ridge up to 0.2 T along the Bc axes oc-

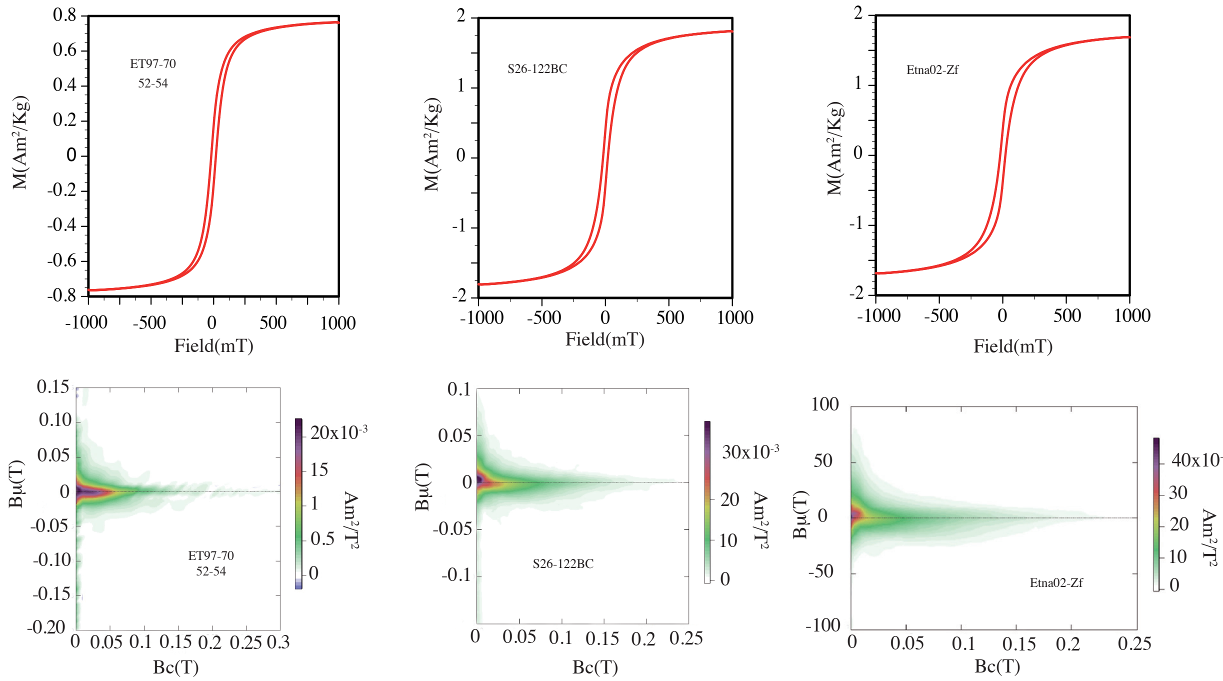


Figure 3: Hysteresis loops and FORC diagrams for three samples representative of the old, historical and recent activity of the Etna volcano.

curs in most of the samples with increasing values in the recent ashes indicating a contribution of a harder magnetic fraction. Similar shape characterizes the FORC of the tachylites whereas the sideromelane do not exceed Bc value of 0.12 T suggesting a minor contribution of the hard fraction for the glassy samples. However the presence of a harder magnetic fraction was not confirmed by Mossbauer data that do not show any feature compatible with antiferromagnetic minerals. Some difference in coercivities is also observed between the tachylites and the sideromelane with the former characterized by values even above 0.2 T whereas the sideromelane do not exceed 0.12 T.

The obtained data indicate that the magnetic properties of volcanic ash is dominated by the (titano)magnetite that usually is among the accessory minerals that constitute the volcanic products. The most explosive volcanic explosions are characterized by the most intensive fragmentation and it could be responsible of the observed differences in grain size. The magnetic properties may be also affected by low temperature modification such as oxidation or exsolution due to the breakdown of the solid solution between ulvospinel ($Fe_2TiO_4$) and magnetite ($Fe_3O_4$) that may be also responsible for increasing coercivity observed in the FORC diagram of several samples.

## References

Andronico D., Branca S., Calvari S., Burton M.R., Caltabiano T., Corsaro R.A., Del Carlo P., Garfì G., Lodato L., Miraglia L., Murè F., Neri M., Pecora E., Pompilio M., Salerno G., Spampinato L. (2005), A multi-disciplinary study of the 2002–03 Etna eruption: insights for a complex plumbing system. Bull. Volcanol., 67, pp. 314-330.

Andronico D., Scollo S., Cristaldi A., Caruso S. (2008), The 2002–03 Etna explosive activity: tephra dispersal and features of the deposit. J. Geophys. Res., 113, p. B04209, 10.1029/2007JB00

Andronico D., Cristaldi A., Del Carlo P. & Taddeucci J. (2009), Shifting styles of basaltic explosive activity during the 2002–03 eruption of Mt. Etna, Italy. J. of Volcan. and Geoth. Res. 180, 110–122.

Coltelli M., Del Carlo P., Vezzoli L. (2000), Stratigraphic constrains for explosive activity in the last 100 ka at Etna volcano, Italy. Int. Jour. of Earth Sci., 89, 665-677.

Del Carlo P., Vezzoli L., Coltelli M. (2004), Last 100 ka tephrostratigraphic record of Mount Etna. In Mt Etna: volcano laboratory. Geophysical Monograph Series 143, 77–89.

Dellino P., Kyriakopoulos K., (2003), Phreatomagmatic ash from the ongoing eruption of Etna reaching the Greek island of Cefalonia. J. Volcanol. Geotherm. Res., 126, pp. 341-345.

Moskowitz B. M., Jackson M., Kissel C. (1998), Low-temperature magnetic behaviour of titanomagnetites Earth Planet. Sci. Lett., 157 (1998), pp. 141-149

Scollo S., Del Carlo P., Coltelli M. (2007), Tephra fallout of 2001 Etna flank eruption: analysis of the deposit and plume dispersion. J. Volcanol. Geotherm. Res., 160, pp. 147-164.

Smirnov A. V. (2009). Grain size dependence of low-temperature remanent magnetization in natural and synthetic magnetite: experimental study. Earth Planets Space 61, 119–124. doi: 10.1186/BF03352891

# Current Articles

A list of current research articles dealing with various topics in the physics and chemistry of magnetism is a regular feature of the IRM Quarterly. Articles published in familiar geology and geophysics journals are included; special emphasis is given to current articles from physics, chemistry, and materials-science journals. Most are taken from ISI Web of Knowledge, after which they are subjected to Procrustean culling for this newsletter. An extensive reference list of articles (primarily about rock magnetism, the physics and chemistry of magnetism, and some paleomagnetism) is continually updated at the IRM. This list, with more than 10,000 references, is available free of charge. Your contributions both to the list and to the Current Articles section of the IRM Quarterly are always welcome.

### Archaeomagnetism


Calvo-Rathert, M., J. M. Contreras, A. Carrancho, P. Camps, A. Goguitchaichvili, and M. J. Hill (2019), Reproducibility of archaeointensity determinations with a multimethod approach on archaeological material reproductions, Geophysical Journal International, 218(3), 1719-1738.

Dmitrijeva, M., C. L. Ciobanu, K. J. Ehrig, N. J. Cook, A. V. Metcalfe, M. R. Verdugo-Ihl, and J. McPhie (2019), Mineralization-alteration footprints in the Olympic Dam IOCG district, South Australia: The Acropolis prospect, Journal of Geochemical Exploration, 205.

Frances-Negro, M., A. Carrancho, A. Perez-Romero, J. L. Arsuaga, J. M. Carretero, and E. Iriarte (2019), Storage or cooking pots? Inferring pottery use through archaeomagnetic assessment of palaeotemperatures, Journal of Archaeological Science, 110.

Goguitchaichvili, A., C. Greco, R. G. Ruiz, L. P. Domingorena, R. Cejudo, J. Morales, C. Gogorza, C. Scattolin, and M. Tarrago (2019), First archaeointensity reference paleosecular variation curve for South America and its implications for geomagnetism and archaeology, Quaternary Research, 92(1), 81-97.

Oxman, B. I., M. Pirola, S. Bustos, M. R. Morales, P. Tchilinguirian, and M. J. Orgeira (2019), Environmental trends between 2400 and 1200 BP in Barrancas, Argentinean Puna: Impacts on local resource variability and socioeconomic organization, Geoarchaeology-an International Journal.

Scardia, G., F. Parenti, D. P. Miggins, A. Gerdes, A. G. M. Araujo, and W. A. Neves (2019), Chronologic constraints on hominin dispersal outside Africa since 2.48 Ma from the Zarqa Valley, Jordan, Quaternary Science Reviews, 219, 1-19.

Zhang, W. L., M. D. Yan, X. M. Fang, D. W. Zhang, T. Zhang, J. B. Zan, and C. H. Song (2019), High-resolution paleomagnetic constraint on the oldest hominoid- fossil-bearing sequence in the Xiaolongtan Basin, southeast margin of the Tibetan Plateau and its geologic implications, Global and Planetary Change, 182.


### Environmental magnetism and Climate


Ayoubi, S., and V. Adman (2019), Iron Mineralogy and Magnetic Susceptibility of Soils Developed on Various Rocks in Western Iran, Clays and Clay Minerals, 67(3), 217-227.

Badesab, F., et al. (2019), Magnetic Mineralogical Approach for the Exploration of Gas Hydrates in the Bay of Bengal, Journal of Geophysical Research-Solid Earth, 124(5), 4428-4451.

Bradak, B., Y. Seto, D. Csonka, T. Vegh, and J. Szeberenyi (2019), The hematite-goethite enhancement model of loess and an 'irregular' case from Paks, Hungary, Journal of Quaternary Science, 34(4-5), 299-308.

Calderon-Garciduenas, L., González-Maciel, A., Mukherjee P.S., Reynoso-Robles, R., Pérez-Guillé, B., Gayosso-Chávez, C., Torres-Jardón, R., Cross, J., Ahmed, I.A. and Maher, B.A. (2019). Combustion- and Friction-Derived Magnetic Air Pollution Nanoparticles in Human Hearts. Environmental Research, doi.org/10.1016/j.envres.2019.108567

Cervi, E. C., B. Maher, P. C. Poliseli, I. G. de Souza, and A. C. S. da Costa (2019), Magnetic susceptibility as a pedogenic proxy for grouping of geochemical transects in landscapes, Journal of Applied Geophysics, 169, 109-117.

Chen, J. S., X. M. Liu, and X. J. Liu (2019), Sedimentary dynamics and climatic implications of Cretaceous loess-like red beds in the Lanzhou basin, Northwest China, Journal of Asian Earth Sciences, 180.

Cooper, R. E., and T. J. DiChristina (2019), Fe(III) Oxide Reduction by Anaerobic Biofilm Formation-DeficientS-Ribosylhomocysteine Lyase (LuxS) Mutant of Shewanella oneidensis, Geomicrobiology Journal, 36(7), 639-650.

Durn, G., S. D. Skapin, N. Vdovic, T. Rennert, F. Ottner, S. Ruzicic, N. Cukrov, and I. Sondi (2019), Impact of iron oxides and soil organic matter on the surface physicochemical properties and aggregation of Terra Rossa and Calcocambisol subsoil horizons from Istria (Croatia), Catena, 183.

Dytlow, S., A. Winkler, B. Gorka-Kostrubiec, and L. Sagnotti (2019), Magnetic, geochemical and granulometric properties of street dust from Warsaw (Poland), Journal of Applied Geophysics, 169, 58-73.

Gao, X. B., et al. (2019), New High-Temperature Dependence of Magnetic Susceptibility-Based Climofunction for Quantifying Paleoprecipitation From Chinese Loess, Geochemistry Geophysics Geosystems, 20(8), 4273-4291.

Gawali, P. B., P. T. Hanamgond, B. V. Lakshmi, and M. Herlekar (2019), Applicability of Magnetic and Geochemical Characterization Techniques to Assess the Evolution of Estuarine Systems: A Case Study of Gad River Estuary Sediments, Maharashtra, Journal of the Geological Society of India, 94(3), 267-274.

Gonet, T. & Maher, B.A. (2019). Airborne, vehicle-derived Fe-bearing nanoparticles in the urban environment – A review. Environmental Science & Technology, 53, 17, 9970-9991. https://doi.org/10.1021/acs.est.9b01505

Guan, C., H. Chang, M. D. Yan, L. Y. Li, M. M. Xia, J. B. Zan, and S. C. Liu (2019), Rock magnetic constraints for the Mid-Miocene Climatic Optimum from a high-resolution sedimentary sequence of the northwestern Qaidam Basin, NE Tibetan Plateau, Palaeogeography Palaeoclimatology Palaeoecology, 532.

Hang, T., V. Gurbich, D. Subetto, V. Strakhovenko, M. Potakhin, N. Belkina, and M. Zobkov (2019), A local clay-varve chronology of Onega Ice Lake, NW Russia, Quaternary International, 524, 13-23.

Kadoya, S., and D. C. Catling (2019), Constraints on hydrogen levels in the Archean atmosphere based on detrital magnetite, Geochimica Et Cosmochimica Acta, 262, 207-219.

Koshnaw, R. I., B. K. Horton, D. F. Stockli, D. E. Barber, and M. Y. Tamar-Agha (2019), Sediment routing in the Zagros foreland basin: Drainage reorganization and a shift from axial to transverse sediment dispersal in the Kurdistan region of Iraq, Basin Research.

Lanci, L., et al. (2019), Magnetic properties of early Pliocene sediments from IODP Site U1467 (Maldives platform) reveal changes in the monsoon system, Palaeogeography Palaeoclimatology Palaeoecology, 533.

Lin, Z., L. Yi, H. F. Wang, X. G. Deng, J. C. Yang, T. F. Fu, H. J. Yu, Q. Xie, and C. L. Deng (2019), Rock magnetism of deep-sea sediments at Caiwei Guyot, Magellan seamounts of Northwest Pacific and its significance to abyssal environmental changes, Chinese Journal of Geophysics-Chinese Edition, 62(8), 3067-3077.

Lone, A. M., H. Achyuthan, R. A. Shah, S. J. Sangode, P. Kumar, S. Chopra, and R. Sharma (2019), Paleoenvironmental shifts spanning the last similar to 6000 years and recent anthropogenic controls inferred from a high-altitude temperate lake: Anchar Lake, NW Himalaya, Holocene.

Lu, S., W. X. Han, T. Zhang, F. Q. Han, S. C. Lu, X. H. Ma, and Z. G. Zhang (2019), Rock magnetic characteristics and magnetic susceptibility change mechanism of the loess since 8. 5 ka in the southern margin of Tarim Basin, Chinese Journal of Geophysics-Chinese Edition, 62(8), 3053-3066.

Maher, B.A. (2019). Airborne magnetite and iron-rich pollution nanoparticles: potential neurotoxicants and environmental risk factors for neurodegenerative disease, including Alzheimer's disease. J. Alzheimer's Disease. 71, doi:10.3233/JAD-190204

Marques, R., J. C. Waerenborgh, L. C. J. Pereira, B. J. C. Vieira, M. I. Prudencio, F. Ruiz, M. Abad, T. Izquierdo, and F. Rocha (2019), Development of a buried paleosol on silica-undersaturated mafic lava (Fogo Island, Cape Verde): An Fe speciation study using Mossbauer spectroscopy and magnetization, Catena, 182.

Mayr, C., P. Stojakowits, B. Lempe, M. Blaauw, V. Diersche, M. Grohganz, M. L. Correa, C. Ohlendorf, P. Reimer, and B. Zolitschk (2019), High-resolution geochemical record of environmental changes during MIS 3 from the northern Alps (Nesseltalgraben, Germany), Quaternary Science Reviews, 218, 122-136.

Nordsvan, A. R., M. Barham, G. Cox, U. Kirscher, and R. N. Mitchell (2019), Major shoreline retreat and sediment starvation following Snowball Earth, Terra Nova.

Ohneiser, C., and C. Tapia (2019), Diagenesis of magnetic minerals at the Southwest Pacific DSDP Site 277, New Zealand Journal of Geology and Geophysics.

Oliva-Urcia, B., and A. Moreno (2019), Discerning the major environmental processes that influence the magnetic properties in three northern Iberia mountain lakes, Catena, 182.

Ortega-Guerrero, B., M. A. Albarran-Santos, M. Caballero, I. Reyes-Corona, B. Gutierrez-Mendez, and L. Caballero-Garcia (2018), Paleoambiental reconstruction of the Xochimilco sub-basin, central Mexico, between 18000 and 5000 years cal before present, Revista Mexicana De Ciencias Geologicas, 35(3), 254-267.

Prezzi, C. B., M. J. Orgeira, A. M. J. Coronato, D. R. A. Quiroga, J. F. Ponce, P. A. N. Demarco, and P. Palermo (2019), Geophysical methods applied to Quaternary studies in glacial environments: Rio Valdez outcrop, Tierra del Fuego, Argentina, Quaternary International, 525, 114-125.

Reilly, B. T., et al. (2019), Holocene break-up and reestablishment of the Petermann Ice Tongue, Northwest Greenland, Quaternary Science Reviews, 218, 322-342.

Schindler, M., S. Michel, D. Batcheldor, and M. F. Hochella (2019), A nanoscale study of the formation of Fe-(hydr) oxides in a volcanic regolith: Implications for the understanding of soil forming processes on Earth and Mars, Geochimica Et Cosmochimica Acta, 264, 43-66.

Sepulveda, L. D., K. L. Lecomte, A. I. Pasquini, E. G. Mansilla, and M. A. E. Chaparro (2019), Geochemical and magnetic properties of sediments as pollution indicators. Case study: rio Suquia, Cordoba, Argentinas, Revista Mexicana De Ciencias Geologicas, 36(2), 183-194.

Su, Q. D., J. Nie, Z. Luo, M. S. Li, R. Heermance, and C. Garzione (2019), Detection of Strong Precession Cycles from the Late Pliocene Sedimentary Records of Northeastern Tibetan Plateau, Geochemistry Geophysics Geosystems, 20(8), 3901-3912.

Tommasi, P., et al. (2019), Evaluation of disturbance induced on soft offshore sediments by two types of gravity piston coring techniques, Marine Geology, 417.

Vankova, L., et al. (2019), Integrated stratigraphy and palaeoenvironment of the Berriasian peri-reefal limestones at Stramberk (Outer Western Carpathians, Czech Republic), Palaeogeography Palaeoclimatology Palaeoecology, 532.

Vilela, E. F., A. V. Inda, and Y. L. Zinn (2019), Soil genesis, mineralogy and chemical composition in a steatite outcrop under tropical humid climate in Brazil, Catena, 183.

Voelz, J. L., N. W. Johnson, C. L. Chun, W. A. Arnold, and R. L. Penn (2019), Quantitative Dissolution of Environmentally Accessible Iron Residing in Iron-Rich Minerals: A Review, Acs Earth and Space Chemistry, 3(8), 1371-1392.

Vologina, E. G., M. Sturm, A. S. Astakhov, and X. F. Shi (2019), Anthropogenic traces in bottom sediments of Chukchi Sea, Quaternary International, 524, 86-92.

Wang H., Maher, B.A., Ahmed, I.A.M. & Davison, B. (2019), Efficient removal of ultrafine particles from diesel exhaust by selected tree species: implications for roadside planting for improving the quality of urban air, Environmental Science & Technology, DOI: 10.1021/acs.est.8b06629.

Wang, H. Y., Y. Cheng, Y. Luo, C. N. Zhang, L. Deng, X. Y. Yang, and H. Y. Liu (2019), Variations in erosion intensity and soil maturity as revealed by mineral magnetism of sediments from an alpine lake in monsoon-dominated central east China and their implications for environmental changes over the past 5500 years, Holocene.

Wang, L. B., J. Jia, H. Zhao, H. Liu, Y. W. Duan, H. C. Xie, D. D. Zhang, and F. H. Chen (2019), Optical dating of Holocene paleosol development and climate changes in the Yili Basin, arid central Asia, Holocene, 29(6), 1068-1077.

Wang, L. S., S. Y. Hu, G. Yu, X. H. Wang, Q. Wang, Z. H. Zhang, M. M. Ma, B. L. Cui, and X. B. Liu (2019), Multiproxy studies of lake sediments during mid-Holocene in Zhengzhou region of the Henan Province, central China, and the implications for reconstructing the paleoenvironments, Quaternary International, 521, 104-110.

Wu, L., R. J. Wang, W. Krijgsman, Z. H. Chen, W. S. Xiao, S. L. Ge, and J. W. Wu (2019), Deciphering Color Reflectance Data of a 520-kyr Sediment Core From the Southern Ocean: Method Application and Paleoenvironmental Implications, Geochemistry Geophysics Geosystems, 20(6), 2808-2826.

Xuea, P. F., L. Chang, S. S. Wang, S. F. Liu, J. H. Li, X. F. Shi, S. Khokiattiwong, and N. Kornkanitnan (2019), Magnetic mineral tracing of sediment provenance in the central Bengal Fan, Marine Geology, 415.

Yang, D., M. N. Wang, H. L. Lu, Z. H. Ding, J. C. Liu, and C. L. Yan (2019), Magnetic properties and correlation with heavy metals in mangrove sediments, the case study on the coast of Fujian, China, Marine Pollution Bulletin, 146, 865-873.

Ye, S. S., W. Zhong, Z. Q. Wei, S. T. Shang, X. W. Tang, C. Zhu, J. B. Xue, J. Ouyang, and J. Y. Pan (2019), Environmental magnetic record of a similar to 3000-years subalpine peat core from the western Nanling Mountains, South China, Journal of Paleolimnology, 62(3), 229-244.

Zhang, L., H. L. Dong, R. K. Kukkadapu, Q. S. Jin, and L. Kovarik (2019), Electron transfer between sorbed Fe(II) and structural Fe(III) in smectites and its effect on nitrate-dependent iron oxidation by Pseudogulbenkiania sp. strain 2002, Geochimica Et Cosmochimica Acta, 265, 132-147.

#### Extraterrestrial Planetary, and impact Magnetism


Bryson, J. F. J., J. A. Neufeld, and F. Nimmo (2019), Constraints on asteroid magnetic field evolution and the radii of meteorite parent bodies from thermal modelling, Earth and Planetary Science Letters, 521, 68-78.

Bryson, J. F. J., B. P. Weiss, B. Getzin, J. N. H. Abrahams, F. Nimmo, and A. Scholl (2019), Paleomagnetic Evidence for a Partially Differentiated Ordinary Chondrite Parent Asteroid, Journal of Geophysical Research-Planets, 124(7), 1880-1898.

Davidson, J., C. M. O. Alexander, R. M. Stroud, H. Busemann, and L. R. Nittler (2019), Mineralogy and petrology of Dominion Range 08006: A very primitive CO3 carbonaceous chondrite, Geochimica Et Cosmochimica Acta, 265, 259-278.

Dixit, A., R. P. Tripathi, and N. Bhandari Glassy magnetic cronstedtite signatures in Mukundpura CM2 chondrite based on magnetic and Mossbauer studies, Meteoritics & Planetary Science.

Dobrica, E., R. C. Ogliore, C. Engrand, K. Nagashima, and A. J. Brearley Mineralogy and oxygen isotope systematics of magnetite grains and a magnetite-dolomite assemblage in hydrated fine-grained Antarctic micrometeorites, Meteoritics & Planetary Science.

Garenne, A., P. Beck, G. Montes-Hernandez, L. Bonal, E. Quirico, O. Proux, and J. L. Hazemann The iron record of asteroidal processes in carbonaceous chondrites, Meteoritics & Planetary Science.

Garrick-Bethell, I., A. R. Poppe, and S. Fatemi (2019), The Lunar Paleo-Magnetosphere: Implications for the Accumulation of Polar Volatile Deposits, Geophysical Research Letters, 46(11), 5778-5787.

Gattacceca, J., W. Zylberman, A. B. Coulter, F. Demory, Y. Quesnel, P. Rochette, G. R. Osinski, and B. Edwige (2019), Paleomagnetism and rock magnetism of East and West Clearwater Lake impact structures, Canadian Journal of Earth Sciences, 56(9), 983-993.

Goodrich, C. A., et al. The first samples from Almahata Sitta showing contacts between ureilitic and chondritic lithologies: Implications for the structure and composition of asteroid 2008 TC3, Meteoritics & Planetary Science.

Kadlag, Y., H. Becker, and A. Harbott Cr isotopes in physically separated components of the Allende CV3 and Murchison CM2 chondrites: Implications for isotopic heterogeneity in the solar nebula and parent body processes, Meteoritics & Planetary Science.

Nekvasil, H., N. J. DiFrancesco, A. D. Rogers, A. E. Coraor, and P. L. King (2019), Vapor-Deposited Minerals Contributed to the Martian Surface During Magmatic Degassing, Journal of Geophysical Research-Planets, 124(6), 1592-1617.

Oliveira, J. S., L. L. Hood, and B. Langlais Constraining the Early History of Mercury and Its Core Dynamo by Studying the Crustal Magnetic Field, Journal of Geophysical Research-Planets.

O'Rourke, J. G., J. Buz, R. R. Fu, and R. J. Lillis (2019), Detectability of Remanent Magnetism in the Crust of Venus, Geophysical Research Letters, 46(11), 5768-5777.

Pourkhorsandi, H., et al. (2019), Meteorites from the Lut Desert (Iran), Meteoritics & Planetary Science, 54(8), 1737-1763.

Schrader, D. L., and T. J. Zega (2019), Petrographic and compositional indicators of formation and alteration conditions from LL chondrite sulfides, Geochimica Et Cosmochimica Acta, 264, 165-179.


#### Fundamental Rock and Mineral Magnetism


Almqvist, B. S. G., A. Bjork, H. B. Mattsson, D. Hedlund, K. Gunnarsson, A. Malehmir, K. Hogdahl, E. Backstrom, and P. Marsden (2019), Magnetic characterisation of magnetite and hematite from the Blotberget apatite - iron oxide deposits (Bergslagen), south-central Sweden, Canadian Journal of Earth Sciences, 56(9), 948-957.

Aubourg, C., M. Jackson, M. Ducoux, and M. Mansour (2019), Magnetite-out and pyrrhotite-in temperatures in shales and slates, Terra Nova.

Belgrano, T. M., L. W. Diamond, Y. Vogt, A. R. Biedermann, S. A. Gilgen, and K. Al-Tobi (2019), A revised map of volcanic units in the Oman ophiolite: insights into the architecture of an oceanic proto-arc volcanic sequence, Solid Earth, 10(4), 1181-1217.

Bialo, I., A. Kozlowski, M. Wack, A. Wlodek, L. Gondek, Z. Kakol, R. Hochleitner, A. Zywczak, V. Chlan, and S. A. Gilder (2019), The influence of strain on the Verwey transition as a function of dopant concentration: towards a geobarometer for magnetite-bearing rocks, Geophysical Journal International, 219(1), 148-158.

Dunlop, D. J., O. Ozdemir, and S. Xu (2019), Magnetic hysteresis of 0.6-110 μm magnetites across the Verwey transition, Canadian Journal of Earth Sciences, 56(9), 958-972.

Hikosaka, K., R. Sinmyo, K. Hirose, T. Ishii, and Y. Ohishi (2019), The stability of $Fe_5O_6$ and $Fe_4O_5$, at high pressure and temperature, American Mineralogist, 104(9), 1356-1359.

Jacomo, M. H., R. I. F. Trindade, M. French, E. Lucas-Oliveira, E. T. Montrazi, and T. J. Bonagamba (2019), Nuclear magnetic resonance characterization of porosity-preserving microcrystalline quartz coatings in Fontainebleau sandstones, Aapg Bulletin, 103(9), 2117-2137.

Li, J. C., T. Zhao, Z. B. Liu, Y. Lin, H. S. Shao, G. L. Yuan, and Y. Song (2019), The processes and influencing factors of serpentinization and associated magnetite mineralization of ultramafic rocks from Angwu area, North Tibet, Acta Petrologica Sinica, 35(7), 2158-2172.

Musgrave, R. J., M. Kars, and M. E. Vega (2019), Progressive and Punctuated Magnetic Mineral Diagenesis: The Rock Magnetic Record of Multiple Fluid Inputs and Progressive Pyritization in a Volcano-Bounded Basin, IODP Site U1437, Izu Rear Arc, Journal of Geophysical Research-Solid Earth, 124(6), 5357-5378.

Nagy, L., W. Williams, L. Tauxe, and A. R. Muxworthy (2019), From Nano to Micro: Evolution of Magnetic Domain Structures in Multidomain Magnetite, Geochemistry Geophysics Geosystems, 20(6), 2907-2918.

Roberts, A. P., P. X. Hu, R. J. Harrison, D. Heslop, A. R. Muxworthy, H. Oda, T. Sato, L. Tauxe, and X. Zhao (2019), Domain State Diagnosis in Rock Magnetism: Evaluation of Potential Alternatives to the Day Diagram, Journal of Geophysical Research-Solid Earth, 124(6), 5286-5314.

Steullet, A. K., R. D. Elmore, M. Hamilton, and G. Heij (2019), Remagnetization of Marcellus Formation in the Plateau Province of the Appalachian Basin, Frontiers in Earth Science, 7.

Volk, M. W. R., M. Eitel, and M. Jackson (2019), AF demagnetization and ARM acquisition at elevated temperatures in natural titanomagnetite bearing rocks, Geophysical Journal International, 219(1), 290-296.

Webber, J. R., L. L. Brown, and M. L. Williams (2019), Petrophysical constraints on magnetic anomalies associated with metamorphic reactions in northern Saskatchewan, Canada, Canadian Journal of Earth Sciences, 56(9), 895-911.

Zhang, M., X. H. Han, and Y. X. Pan (2019), Rock magnetism of the banded iron formation in Barberton greenstone belt, South Africa, Acta Petrologica Sinica, 35(7), 2206-2218.

### Geomagnetism, Paleointensity and Records of the Geomagnetic Field

Brandt, D., et al. (2019), New Late Pennsylvanian Paleomagnetic Results From Parana Basin (Southern Brazil): Is the Recent Giant Gaussian Process Model Valid for the Kiaman Superchron?, Journal of Geophysical Research-Solid Earth, 124(7), 6223-6242.

Grappone, J. M., A. J. Biggin, and M. J. Hill (2019), Solving the mystery of the 1960 Hawaiian lava flow: implications for estimating Earth's magnetic field, Geophysical Journal International, 218(3), 1796-1806.

Hong, H. B., L. Chang, A. Hayashida, A. P. Roberts, D. Heslop, G. A. Paterson, K. Kodama, and L. Tauxe (2019), Paleomagnetic Recording Efficiency of Sedimentary Magnetic Mineral Inclusions: Implications for Relative Paleointensity Determinations, Journal of Geophysical Research-Solid Earth, 124(7), 6267-6279.

Korte, M., and M. Mandea (2019), Geomagnetism: From Alexander von Humboldt to Current Challenges, Geochemistry Geophysics Geosystems, 20(8), 3801-3820.

Rodriguez-Trejo, A., L. M. Alva-Valdivia, M. Perrin, G. Herve, and N. Lopez-Valdes (2019), Analysis of geomagnetic secular variation for the last 1.5 Ma recorded by volcanic rocks of the Trans Mexican Volcanic Belt: new data from Sierra de Chichinautzin, Mexico, Geophysical Journal International, 219(1), 594-606.

Sheng, M., X. S. Wang, M. J. Dekkers, Y. Chen, G. Q. Chu, L. Tang, J. L. Pei, and Z. Y. Yang (2019), Paleomagnetic Secular Variation and Relative Paleointensity During the Holocene in South China-Huguangyan Maar Lake Revisited, Geochemistry Geophysics Geosystems, 20(6), 2681-2697.

Shin, J. Y., Y. Yu, and W. Kim (2019), Wavelet-based verification of a relative paleointensity record from the North Pacific, Earth Planets and Space, 71(1).

Sprain, C. J., A. J. Biggin, C. J. Davies, R. K. Bono, and D. G. Meduri (2019), An assessment of long duration geodynamo simulations using new paleomagnetic modeling criteria (Q(PM)), Earth and Planetary Science Letters, 526.

Wang, S. S., L. Chang, P. F. Xue, S. F. Liu, X. F. Shi, S. Khokiattiwong, N. Kornkanitnan, and J. X. Liu (2019), Paleomagnetic Secular Variations During the Past 40,000 Years From the Bay of Bengal, Geochemistry Geophysics Geosystems, 20(6), 2559-2571.

### Instrumentation, techniques and databases

de Groot, B. M., and L. V. de Groot (2019), A low-cost device for measuring local magnetic anomalies in volcanic terrain, Geoscientific Instrumentation Methods and Data Systems, 8(2), 217-225.

Demory, F., et al. (2019), A New High-Resolution Magnetic Scanner for Sedimentary Sections, Geochemistry Geophysics Geosystems, 20(7), 3186-3200.

Huang, C. G., J. S. Gu, F. B. Zong, W. M. Zhang, and Z. Wei (2019), Design of helium optical-pumping magnetometer probe and digital loop electronics circuit, Chinese Journal of Geophysics-Chinese Edition, 62(10), 3675-3685.

Liu, K., T. Y. Hao, B. H. Wen, and H. Yang Modified reduction to the pole using the estimated total magnetisation direction and variable geomagnetic inclination: application to the Sichuan Basin, Exploration Geophysics.

Tonti-Filippini, J. A. D., and M. C. Brown (2019), The Iceland Palaeomagnetism Database (ICEPMAG), Earth Planets and Space, 71.

### Magnetic Fabrics and Anisotropy

Amor, K., S. P. Hesselbo, D. Porcelli, A. Price, N. Saunders, M. Sykes, J. Stevanovic, and C. MacNiocaill (2019), The Mesoproterozoic Stac Fada proximal ejecta blanket, NW Scotland: constraints on crater location from field observations, anisotropy of magnetic susceptibility, petrography and geochemistry, Journal of the Geological Society, 176(5), 830-846.

Heinrich, F. C., V. Schmidt, M. Schramm, and M. Mertineit (2019), Anisotropy of magnetic susceptibility in salt rocks from the German Zechstein Basin, Sondershausen mine, Geophysical Journal International, 219(1), 690-712.

Hirt, A. M., and A. R. Biedermann (2019), Preferred orientation of ferromagnetic phases in rock-forming minerals: insights from magnetic anisotropy of single crystals, Canadian Journal of Earth Sciences, 56(9), 994-1001.

Kuehn, R., A. M. Hirt, A. R. Biedermann, and B. Leiss (2019), Quantitative comparison of microfabric and magnetic fabric in black shales from the Appalachian plateau (western Pennsylvania, USA), Tectonophysics, 765, 161-171.

Marcen, M., T. Roman-Berdiel, A. M. Casas-Sainz, R. Soto, B. Oliva-Urcia, and J. Castro (2019), Strain variations in a seismogenic normal fault (Baza Sub-basin, Betic Chain): Insights from magnetic fabrics (AMS), Tectonophysics, 765, 64-82.

Nagaraju, E., and V. Parashuramulu (2019), AMS studies on a 450 km long 2216 Ma dyke from Dharwar craton, India: Implications to magma flow, Geoscience Frontiers, 10(5), 1931-1939.

Nke, B. E. B., T. Njanko, and J. Tchakounte (2019), CPO and kinematic analysis of the Bitou S-tectonites (Central Cameroon shear zone): AMS and EBSD investigations, Journal of Earth System Science, 128(8).

Raeisi, D., H. Mirnejad, and M. Sheibi (2019), Emplacement mechanism of the Tafresh granitoids, central part of the Urumieh-Dokhtar Magmatic Arc, Iran: evidence from magnetic fabrics, Geological Magazine, 156(9), 1510-1526.

Yan, Y. G., L. W. Chen, B. C. Huang, Z. Y. Yi, and J. Zhao (2019), Magnetic fabric constraint on tectonic setting of Paleoproterozoic dyke swarms in the North China Craton, China, Precambrian Research, 329, 247-261.

### Paleomagnetism

Alva-Valdivia, L. M., A. Agarwal, B. Garcia-Amador, W. Morales-Barrera, K. K. Agarwal, S. Rodriguez, and J. A. Gonzalez-Rangel (2019), Paleomagnetism and tectonics from the late Pliocene to late Pleistocene in the Xalapa monogenetic volcanic field, Veracruz, Mexico, Geological Society of America Bulletin, 131(9-10), 1581-1590.

Boschman, L. M., E. van der Wiel, K. E. Flores, C. G. Langereis, and D. J. J. van Hinsbergen (2019), The Caribbean and Farallon Plates Connected: Constraints From Stratigraphy and Paleomagnetism of the Nicoya Peninsula, Costa Rica, Journal of Geophysical Research-Solid Earth, 124(7), 6243-6266.

Cole, R. P., C. Ohneiser, J. D. L. White, D. B. Townsend, and G. S. Leonard (2019), Paleomagnetic evidence for cold emplacement of eruption-fed density current deposits beneath an ancient summit glacier, Tongariro volcano, New Zealand, Earth and Planetary Science Letters, 522, 155-165.

Elming, S. A., P. Layer, and U. Soderlund (2019), Cooling history and age of magnetization of a deep intrusion: A new 1.7 Ga key pole and Svecofennian-post Svecofennian APWP for Baltica, Precambrian Research, 329, 182-194.

Evans, M. E., and A. R. Muxworthy (2019), Vaalbara Palaeomagnetism, Canadian Journal of Earth Sciences, 56(9),

912-916.
Hansma, J., and E. Tohver (2019), Paleomagnetism of Oligocene Hot Spot Volcanics in Central Queensland, Australia, Journal of Geophysical Research-Solid Earth, 124(7), 6280-6296.
Huang, W. T., M. J. Jackson, M. J. Dekkers, Y. Zhang, B. Zhang, Z. J. Guo, and G. Dupont-Nivet (2019), Challenges in isolating primary remanent magnetization from Tethyan carbonate rocks on the Tibetan Plateau: Insight from remagnetized Upper Triassic limestones in the eastern Qiangtang block, Earth and Planetary Science Letters, 523.
Kawasaki, K. (2019), Paleomagnetism of the Mn wad deposit at Niimi hot springs, Hokkaido, Japan, Canadian Journal of Earth Sciences, 56(9), 973-982.
Kirscher, U., Y. Liu, Z. X. Li, R. N. Mitchell, S. A. Pisarevsky, S. W. Denyszyn, and A. Nordsvan (2019), Paleomagnetism of the Hart Dolerite (Kimberley, Western Australia) - A two-stage assembly of the supercontinent Nuna?, Precambrian Research, 329, 170-181.
Konstantinov, K. M., M. D. Tomshin, I. K. Konstantinov, and A. A. Yakovlev (2019), Paleomagnetism of Middle Paleozoic Basites on the Southeastern Flank of the Vilyui Paleorift, Doklady Earth Sciences, 486(2), 695-698.
Larrea, P., C. Siebe, E. Juarez-Arriaga, S. Salinas, H. Ibarra, and H. Bohnel (2019), The similar to AD 500-700 (Late Classic) El Astillero and El Pedregal volcanoes (Michoacan, Mexico): a new monogenetic cluster in the making?, Bulletin of Volcanology, 81(10).
Liu, Y. B., Z. X. Li, S. Pisarevsky, U. Kirscher, R. N. Mitchell, and J. C. Stark (2019), Palaeomagnetism of the 1.89 Ga Boonadgin dykes of the Yilgarn Craton: Possible connection with India, Precambrian Research, 329, 211-223.
Mattei, M., A. L. Visconti, F. Cifelli, R. Nozaem, A. Winkler, and L. Sagnotti (2019), Clockwise paleomagnetic rotations in northeastern Iran: Major implications on recent geodynamic evolution of outer sectors of the Arabia-Eurasia collision zone, Gondwana Research, 71, 194-209.
Narasimhan, C. L., B. R. Arora, and S. K. Patil (2019), Rock magnetic and palaeomagnetic studies on the alkaline complexes of western Rajasthan, India, Journal of Earth System Science, 128(8).
Perez-Rodriguez, N., J. Morales, A. Goguitchaichvili, and F. Garcia-Tenorio (2019), A comprehensive paleomagnetic study from the last Plinian eruptions of Popocatepetl volcano: absolute chronology of lavas and estimation of emplacement temperatures of PDCs, Earth Planets and Space, 71.
Pivarunas, A. F., and J. G. Meert (2019), Protracted magmatism and magnetization around the McClure Mountain alkaline igneous complex, Lithosphere, 11(5), 590-602.
Qiao, Q. Q., J. D. A. Piper, B. C. Huang, M. J. Wu, S. B. Liao, and S. Q. Fan (2019), Neotectonic Deformation in the Southwestern Tian Shan, Western China: Evidence From Paleomagnetic Study of Quaternary Sediments From the Mingyaole Anticline, Tectonics, 38(7), 2540-2554.
Salminen, J., R. Klein, and S. Mertanen (2019), New rock magnetic and paleomagnetic results for the 1.64 Ga Suomenniemi dyke swarm, SE Finland, Precambrian Research, 329, 195-210.
Salminen, J., E. P. Oliveira, E. J. Piispa, A. V. Smirnov, and R. I. F. Trindade (2019), Revisiting the paleomagnetism of the Neoarchean Uaua mafic dyke swarm, Brazil: Implications for Archean supercratons, Precambrian Research, 329, 108-123.
Satolli, S., S. Agostini, and F. Calamita (2019), Behaviour of minor arcuate shapes hosted in curved fold-and-thrust belts: an example from the Northern Apennines (Italy), Geological Magazine, 156(9), 1547-1564.
Swanson-Hysell, N. L., L. M. Fairchild, and S. P. Slotznick (2019), Primary and Secondary Red Bed Magnetization Constrained by Fluvial Intraclasts, Journal of Geophysical Research-Solid Earth, 124(5), 4276-4289.
Symons, D. T. A., and K. Kawasaki (2019), Paleomagnetism of the native copper mineralization, Keweenaw Peninsula, Michigan, Canadian Journal of Earth Sciences, 56(9), 932-947.
Tetley, M. G., S. E. Williams, M. Gurnis, N. Flament, and R. D. Muller (2019), Constraining Absolute Plate Motions Since the Triassic, Journal of Geophysical Research-Solid Earth, 124(7), 7231-7258.
Torsvik, T. H., B. Steinberger, G. E. Shephard, P. V. Doubrovine, C. Gaina, M. Domeier, C. P. Conrad, and W. W. Sager (2019), Pacific-Panthalassic Reconstructions: Overview, Errata and the Way Forward, Geochemistry Geophysics Geosystems, 20(7), 3659-3689.
Westerweel, J., P. Roperch, A. Licht, G. Dupont-Nivet, Z. Win, F. Poblete, G. Ruffet, H. H. Swe, M. K. Thi, and D. W. Aung (2019), Burma Terrane part of the Trans-Tethyan arc during collision with India according to palaeomagnetic data, Nature Geoscience, 12(10), 863-+.
Xian, H. B., S. H. Zhang, H. Y. Li, Q. S. Xiao, L. X. Chang, T. S. Yang, and H. C. Wu (2019), How Did South China Connect to and Separate From Gondwana? New Paleomagnetic Constraints From the Middle Devonian Red Beds in South China, Geophysical Research Letters, 46(13), 7371-7378.
Yan, Y. G., Q. Zhao, D. H. Zhang, P. Charusiri, B. C. Huang, and P. Z. Zhang (2019), Palaeomagnetism of Late Triassic volcanic rocks from the western margin of Khorat Basin, Thailand and its implication for ambiguous inclination shallowing in Mesozoic sediments of Indochina, Geophysical Journal International, 219(2), 897-910.

### Stratigraphy

Bucher, J., et al. (2019), U-PB geochronology and magnetostratigraphy of a north Patagonian synorogenic Miocene succession: Tectono-stratigraphic implications for the foreland system configuration, Tectonophysics, 766, 81-93.
Crouzet, C., et al. (2019), Palaeomagnetism for chronologies of recent alpine lake sediments: successes and limits, Journal of Paleolimnology, 62(3), 259-278.
Deino, A. L., M. J. Sier, D. Garello, B. Keller, J. Kingston, J. Scott, G. Dupont-Nivet, and A. Cohen (2019), Chronostratigraphy of the Baringo-Tugen-Barsemoi (HSPDP-BTB13-1A) core-Ar-40/Ar-39 dating, magnetostratigraphy, tephrostratigraphy, sequence stratigraphy and Bayesian age modeling, Palaeogeography Palaeoclimatology Palaeoecology, 532.
Erbajeva, M. A., A. A. Shchetnikov, A. Y. Kazansky, G. G. Matasova, F. I. Khenzykhenova, I. A. Filinov, O. D. T. Namzalova, and I. O. Nechaev (2019), The New Pleistocene Ulan-Zhalga Key Section in Western Transbaikalia, Doklady Earth Sciences, 488(1), 1035-1038.
Harning, D. J., T. Thordarson, A. Geirsdottir, S. Olafsdottir, and G. H. Miller (2019), Marker tephra in Haukadalsvatn lake sediment: A key to the Holocene tephra stratigraphy of northwest Iceland, Quaternary Science Reviews, 219, 154-170.
Llanos, M. P. I., D. A. Kietzmann, M. K. Martinez, and D. Minisini (2019), Magnetostratigraphy of a Middle Jurassic delta system (Lajas Formation), Portada Covunco section, southern Neuquen Basin, Argentina, Journal of South American Earth Sciences, 94.
Mana, S., S. Hemming, D. V. Kent, and C. J. Lepre (2019),

Temporal and Stratigraphic Framework for Paleoanthropology Sites Within East-Central Area 130, Koobi Fora, Kenya, Frontiers in Earth Science, 7.

Puspoki, Z., et al. (2019), High-resolution stratigraphy of a Quaternary fluvial deposit based on magnetic susceptibility variations (Jaszsag Basin, Hungary), Boreas.

Wiers, S., I. Snowball, M. O'Regan, and B. Almqvist (2019), Late Pleistocene Chronology of Sediments From the Yermak Plateau and Uncertainty in Dating Based on Geomagnetic Excursions, Geochemistry Geophysics Geosystems, 20(7), 3289-3310.

Zhang, B. S., Y. S. Wei, E. Garzanti, C. S. Wang, X. Chen, W. Y. Pan, and Q. S. Liu (2019), Sedimentologic and stratigraphic constraints on the orientation of the Late Triassic northern Indian passive continental margin, Palaeogeography Palaeoclimatology Palaeoecology, 533.

***cont'd. from pg. 1...***

and cooled through $T_V$ in an applied field (FC). To minimize energy, the monoclinic c-axis forms in each particle along the cube edge closest to the applied field (Abe et al., 1976; Moskowitz et al., 1993; Carter-Stiglitz et al., 2002). When the field is removed after further cooling, the moment of each particle rotates from the applied field direction into alignment with this easy axis. The remanence thus acquired by such a population is exactly the same as that which would be acquired by isothermal magnetization of randomly-oriented SD particles having cubic anisotropy and easy axes along <100>, so the expectation is $M_{FC}$=0.832* low-T $M_{RS}$ (Gans, 1932; Wohlfarth & Tonge, 1957; Jackson, 2007). Conversely, random c-axis selection during ZFC yields an isotropic population of monoclinic grains which, when magnetized isothermally in a strong field, acquires a low-T SIRM equal to 0.5*$M_{RS}$, the same as the room-T SIRM acquired by a population of randomly oriented uniaxial SD particles (Stoner & Wohlfarth (1948). The theoretically expected ratio of intensities $M_{FC}$/ $M_{ZFC}$ for these ideal SD magnetite populations at low temperature is therefore 0.832/0.5=1.664. This ratio was termed $R_{LT}$ by Smirnov (2009) who reported values of 1.12 for synthetic magnetite with the smallest mean grain size of 150 nm (range 30-600 nm).

*Multi-Domain Case*

In contrast to the SD case, a ZFC low-T SIRM has a higher intensity than a FC remanence.

When MD magnetite cools through $T_V$, the resulting magnetic state is complicated by the presence of both domain walls and transformational twins. Kasama et al. (2010) indicate 24 possible orientational variants, each having the monoclinic c-axis aligned along one of the cubic <100> axes and the monoclinic a-axis along one of the cubic face diagonals perpendicular to c. Twin domains with any of these orientations are separated by twin walls from other twin domains of differing orientation. Various configurations are possible; for example a twin wall may separate domains with different hard (a) axis orientations but identical easy axes, or the wall may be a boundary where two c-axes intersect at right angles. Because of the intense magnetocrystalline anisotropy of the monoclinic phase, the latter type of twin wall is also necessarily a 90° domain wall. Such twin configurations and the resultant immobile domain walls exert strong controls on the low-T magnetitc properties of magnetite.

Carter-Stiglitz et al. (2006) and Kosterov and Fabian (2008) proposed that the elevated remanence in the ZFC state arises from the twin boundaries which serve to pin domain walls and produce an effectively smaller magnetic grain size, and Kasama et al. (2013) directly demonstrated that by low-temperature magnetic imaging. In the FC case, the formation of twins is suppressed (particularly those with c-axes at a high angle to the cooling field) because of the field-induced easy axis selection (described above), resulting in an overall softer magnetization. The 180° domain walls that form in this case are more easily moved than the 90° twin boundaries/ domain walls that form in the ZFC case.

## The nuance

Although FC remanence higher than ZFC is indicative of the presence of SD grains in some quantity, it cannot exclude the occurrence of Vortex, PSD or MD grains in the same specimens. Notably, because SD grains have higher remanence ratios ($M_{RS}$/$M_S$) than MD grains they will dominate the remanence even if present in smaller quantities and regardless of their origin (e.g. primary magmatic versus secondary chemical). Therefore, even when FC magnetizations are larger than the ZFC counterparts, their separation may actually be too small to represent pure dominance of SD grains. For example the results presented by Smirnov (2009) are particularly well-suited to demonstrate this effect: the observation of SD-like behavior in grain size ranges that are actually dominated by MD particles. Pan et al. (2005) and Moskowitz et al. (2008) report separations of FC-ZFC curves in certain sediment samples containing magnetotactic bacteria (MTB), that are below the values determined for pure MTB contribution, indicating that a significant fraction of the remanence is carried by larger inorganic grains or maghemitized ones.

Effects of non-stoichiometry are investigated by Carter-Stiglitz et al. (2004). Note also that $M_{FC}$/$M_{ZFC}$ ratios may be reduced below the expected value for Stoner-Wohlfarth populations by the presence of other magnetic phases that contribute equally to the FC and ZFC magnetizations (Moskowitz et al., 1993), or they may be increased by phases like goethite with even larger values of $M_{FC}$/$M_{ZFC}$ (unrelated to the Verwey transition).

These behaviours significantly complicate interpretation of paleomagnetic data, for example, in which stability of the remanence, and thus grain size information, is of the essence. Caution must be exercised when stating that a magnetization is carried by SD grains on the basis of FC>ZFC remanences alone.

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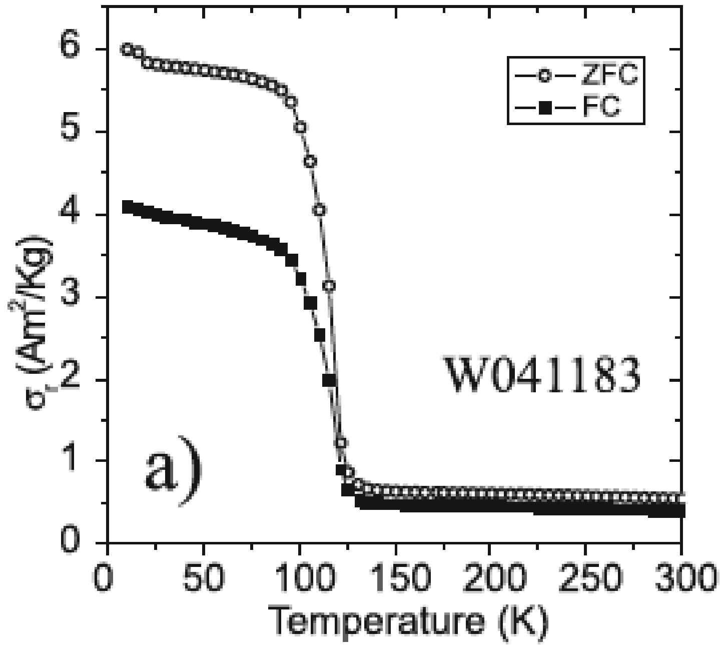



FC-ZFC curves for a Wright Industries multi-domain magnetite sample of 30-40 μm grains. From Carter-Stiglitz et al. (2006)

References:

Abe, K., Y. Miyamoto, and S. Chikazumi (1976), Magnetocrystalline anisotropy of low-temperature phase of magnetite, J. Phys. Soc. Jpn., 41(6), 1894-1902.

Bilardello, D., and M. Jackson (2013), What do the Mumpsies do? IRMQ 23 (3), Fall 2013.

Bowles, J., Jackson, M., and S. Banerjee (2010), Interpretation of Low-Temperature Data Part II: The Hematite Morin Transition. IRMQ 20:1 (Spring 2010).

Bowles, J., Jackson, M., and S. Banerjee (2012), Interpretation of Low-Temperature Data Part VI: The MagnetiteVerwey Transition (Part C): Low-Temperature Demagnetization of Stoichiometric Magnetite. IRMQ 22:2 (Summer 2012).

Carter-Stiglitz, B. S., M. J. Jackson, and B. M. Moskowitz (2002), Verwey transition in stable single-domain magnetite, Geophys. Res. Lett., 29(0), 10.1029/2001GL014197.

Carter-Stiglitz, B. S., B. M. Moskowitz, and M. J. Jackson (2004), More on the low-temperature magnetism of stable single domain magnetite: reversibility, and non-stoichiometry, Geophys. Res. Lett., 31(L06606), doi:10.1029/2003GL019155.

Carter-Stiglitz, B. S., B. Moskowitz, P. Solheid, T. S. Berquó, M. Jackson, and A. Kosterov (2006), Low-temperature magnetic behavior of multi-domain titanomagnetites: TM0, TM16, and TM35, J. Geophys. Res. B: Solid Earth, 111(B12S05), doi:10.1029/2006JB004561.

Dunlop, D.J., and Ö. Özdemir (1997), Rock Magnetism: Fundamentals and frontiers, Cambridge University Press, New York, 573pp.

Gans, R. (1932), Über das magnetische Verhalten isotroper Ferromagnetika, Annalen der Physik, 407(1), 28-44, doi: 10.1002/andp.19324070103.

Guyodo, Y., A. Mostrom, R. L. Penn, and S. K. Banerjee (2003), From Nanodots to Nanorods: Oriented Aggregation and Magnetic Evolution of Nanocrystalline Goethite, Geophys. Res. Lett., 30(10), doi:10.1029/2003GL017021.

Jackson, M. (2007), Isothermal Remanent Magnetization, in Encyclopedia of Geomagnetism and Paleomagnetism, edited by D. Gubbins and E. Herrero-Bervera, Encyclopedia of Earth Sciences, vol., pp. 589-594, Springer, Dordrecht.

Jackson, M., Bowles, J., and S. Banerjee (2011b), Interpretation of Low-Temperature Data Part 5: The Magnetite Verwey Transition (Part B): Field-Cooling Effects on Stoichiometric Magnetite Below Tv, IRMQ 21:4 (Winter 2011).

Jackson, M., Moskowitz, B., and J. Bowles (2011a), Interpretation of Low Temperature Data Part III: The Magnetite Verwey Transition (Part A), IRMQ 20:4 (Winter 2010-2011).

Kasama, T., N.S. Church, J.M. Feinberg, R.E. Dunin-Borkowski, and R.J. Harrison (2010), Direct observation of ferrimagnetic/ ferroelastic domain interactions in magnetite below the Verwey transition, Earth Planet. Sci. Lett., 297, 10-17.

Kasama, T., R. J. Harrison, N. S. Church, M. Nagao, J. M. Feinberg, and R. E. Dunin-Borkowski (2013), Ferrimagnetic/ferroelastic domain interactions in magnetite below the Verwey transition. Part 1: Electron Holography and Lorentz Microscopy, Phase Transitions: A Multinational Journal, doi: 10.1080/01411594.2012.695373.

Kosterov, A., and K. Fabian (2008), Twinning control of magnetic properties of multidomain magnetite below the Verwey transition revealed by measurements on individual particles, Geophys. J. Int., 174(1), 93-106.

Moskowitz, B.M., Bazylinski, D.A., Egli, R., Frankel, R.B., Edwards, K.J., 2008. Magnetic properties of marine magnetotactic bacteria in a seasonally stratified coastal pond (Salt Pond, MA, USA), Geophys. J. Int. (2008) 174, 75–92, doi: 10.1111/j.1365-246X.2008.03789.x.

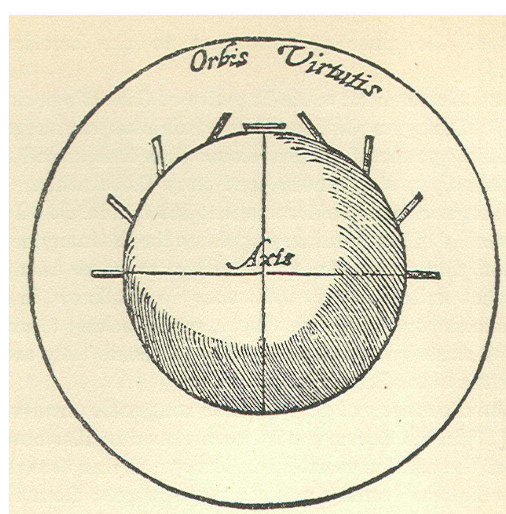
Moskowitz, B. M., R. Frankel, and D. Bazylinski (1993), Rock magnetic criteria for the detection of biogenic magnetite, Earth Planet. Sci. Lett., 120, 283–300.

Pan, Y., Petersen, N., Davila, A.F., Zhang, L, Winklhofer, M., Liu, Q., Hanzlik, M. & Zhu, R., 2005a. The detection of bacterial magnetite in recent sediments of Lake Chiemsee (southern Germany), Earth planet. Sci. Lett., 232, 109–123.

Rochette, P., Fillion, G., and M. J. Dekkers (2011) Interpretation of LowTemperature Data Part 4: The Low-Temperature Magnetic Transition of Monoclinic Pyrrhotite. IRMQ 21:1 (Spring 2011).

Smirnov, A. (2009), Grain size dependence of low-temperature remanent magnetization in natural and synthetic magnetite: Experimental study, Earth Planets Space, 61, 119–124.

Wohlfarth, E. P., and D. G. Tonge (1957), The remanent magnetization of single-domain ferromagnetic particles, Phil. Mag., 2, 1333–1344.



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