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Institute for Rock Magnetism

Wild goats depicted in the Aberdeen Bestiary, ca 1200.

The Rock-Magnetic Bestiary

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Our proto-database of mineral magnetic data is now online at www.geo.umn.edu/orgs/irm/bestiary

Eventually, of course, there will be a rock-magnetic database. For more than 40 years, paleomagnetic data have been systematically compiled, tabulated, and made available to the geophysical community, starting with the Irving/McElhinny paleopole lists in the Geophysical Journal. The value of these tabulations was compounded when they were transplanted to the easily-manipulable format of an electronic database in 1990. There are now seven geomagnetism-related databases maintained by the International Association of Geomagnetism and Aeronomy (IAGA): paleomagnetic directions and poles; archeomagnetic directions; magnetostratigraphy; paleointensity; paleosecular variation recorded in lavas; secular variation from lake sediments; and polarity transition records.

A rock-magnetic database will ultimately serve a variety of purposes. We anticipate that the most common use will be as a standard for comparison in interpreting data for natural materials, in terms of their magnetic mineralogy and size distribution. For this purpose it is most useful to include detailed experimental results (e.g., complete hysteresis loops, low-temperature remanence unblocking curves, etc) for discrete size fractions of the most important minerals. Another expected use will be to provide experimental data for comparison with theoretical predictions or numerical models.

There are various reasons why a rock-magnetic database has been slower to develop than other geomagnetic databases, and we will briefly discuss them below. For the present, we are taking the first step in that direction by assembling what we have dubbed the *Rock-Magnetic Bestiary* (*RMB*).

Bestiaries and Late Medieval Science

A popular literary form of medieval Europe, bestiaries were collections of fables and allegories, most often lavishly illustrated, featuring animals, plants, or even stones. Medieval scholarship, of course, did not make the same rigorous distinctions we make today between the scientific and theological aspects of the universe, and the bestiaries mixed moral instructions and religious doctrine with compilations of descriptive information about the natural world. The "scientific" information in the bestiaries represents a database of sorts, with a strong emphasis on practical knowledge. It is the descriptive aspect that we emulate in the *RMB.*

All bestiaries are considered to be the descendents of a 4th-Century Greek text known as the *Physiologus* ("the Naturalist"). This probably originated in Alexandria, and it draws on older sources such as Pliny's *Natural History*, and tales from India and northern Africa. Neither the original nor any early Greek copies survive; the oldest extant copies are translations from the 4th and 5th Centuries in Syrian, Armenian and Latin. The latter translations made their way through Europe and evolved into what are now called bestiaries in about the 12th Century, adding animals such as the hedgehog to the original cast of lions and elephants. A beautiful example from England *ca* 1200 is the *Aberdeen Bestiary*, which has been made available for on-line viewing, with translation and commentary, at http://www.clues.abdn.ac.uk:8080/besttest/alt/comment/aberbest.html.

Among many other things, the *Aberdeen Bestiary* contains basic

Bestiary... *continued on p. 7*

Source: The Academic Bestiary, *by Richard Armour, 1974, Morrow & Co., New York.*

***"The Full Professor** (Ad ultimum)*
The most impressive of all the kinds of Professors is the Full Professor. It is not apparent at first glance precisely what it is full of, but there is an obvious fullness. When it is not sitting on a Committee, the Full Professor is usually to be found in its orifice, which is its nesting place except that it is not supposed to sleep there and does so only briefly and while pretending to be actively doing something, such as thinking."

Current Abstracts

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 abstracts are culled from* INSPEC *(© Institution of Electrical Engineers),* Geophysical Abstracts in Press *(© American Geophysical Union), and* The Earth and Planetary Express *(© Elsevier Science Publishers, B.V.), after which they are subjected to Procrustean editing and condensation 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 5200 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

Alteration, Diagenesis and Remagnetization

Kovalenko, D. V., and Zlobin, V. L., 2000, **Comparison of petromagnetic characteristics of remagnetized and nonremagnetized volanic-sedimentary sequences of Kamchatka and the Koryak area**: *Izvestiya, Physics of the Solid Earth, v. 36*, no. 11, p. 965-79.
Petromagnetic studies indicate that the magnetic minerals of these sequences consist of magnetite formed during spinodal decomposition of titanomagnetites. The decomposition being very fine, its products are unrecognizable in microprobe examination, and the magnetic grains appear as homogeneous titanomagnetites. The comparable concentrations of Ti-free grains in remagnetized and nonremagnetized tuffs of the Kamchatka-Olyutorskii arc indicate that the processes resulting in higher magnetite concentrations are unlikely to have been responsible for the overprinting of some sequences of this arc. Petromagnetic comparison of remagnetized and nonremagnetized sequences of the Kamchatka-Olyutorskii arc shows that thermoviscous remagnetization of island-arc rocks is most probable.

Anisotropy

Borradaile, G. J., and Gauthier, D., 2001, **AMS-detection of inverse fabrics without AARM, in ophiolite dikes**: *Geophysical Research Letters, v. 28*, no. 18, p. 3517-20.
"Inverse" fabric contributions from SD magnetite complicate interpretation of magmatic flow from AMS in the S Troodos ophiolite dike swarm. Flow directions and magma chamber dimensions may only be inferred correctly if magnetic fabrics correspond to the orientation distribution of minerals. Magnetite shape-fabrics were isolated by anisotropy of anhysteretic remanence but AMS ambiguously merges magnetite and silicate fabrics. However, with the retrospective benefit of AARM, in this area, we recommend avoiding SD complications by excluding magnetite-rich samples for which the bulk low-field susceptibility >27,500 µSI. Magma-flow was steeply upwards to the SW proximal to an axial magma chamber.

Lee, T.-Q., and Angelier, J., 2000, **Tectonic significance of magnetic susceptibility fabrics in Plio-Quaternary mudstones of southwestern foothills, Taiwan**: *Earth, Planets and Space, v. 52*, no. 8, p. 527-38.
AMS in three turbiditic sequences shows five types of fabrics in more than 3000 samples collected from 352 sites, with 251 sites allowing determination of a magnetic lineation. NNE-SSW trends are predominant, and minor N-S and NE-SW trends are present. Magnetic lineations are widespread in the lower section where folds are tight, and scarce in the youngest sediments where folds are gentle. We suggest a tectonic origin for most magnetic lineations, superimposed on the initial compaction flattening. This is confirmed by tectonic studies based on structural analysis and paleostress tensor reconstructions. The tectonic studies reveal a major WNW-ESE compression, which provide orientations of compressive tectonic regimes consistent with the magnetic lineations.

Carriers and Origins of NRM

Crouzet, C., Rochette, P., and Menard, G., 2001, **Experimental evaluation of thermal recording of successive polarities during uplift of metasediments**: *Geophysical Journal International, v. 145*, no. 3, p. 771-85.
A post-tectonic NRM carried by pyrrhotite in the Dauphinoise Zone has recorded a sequence of magnetic polarities during slow cooling. Laboratory experiments show that the pyrrhotite grains are SD-sized and that they are able to record successive independent pTRMs. The NRM contains several anti-parallel components, and the authors attempt to retrieve the temperature at which each reversal occurs during the post-metamorphic cooling.

McEnroe, S. A., Robinson, P., and Panish, P. T., 2001, **Aeromagnetic anomalies, magnetic petrology, and rock magnetism of hemo-ilmenite- and magnetite-rich cumulate rocks from the Sokndal Region, South Rogaland, Norway**: *American Mineralogist, v. 86*, p. 1447-1468.
Aeromagnetic maps of the Egersund igneous province show a spectacular range of positive and negative magnetic anomalies with a contrast up to 15 600 nT. The positive anomalies are over rocks dominated by MD magnetite, the negative ones over rocks dominated by hemo-ilmenite and/or by silicates containing fine-grained oxide exsolution lamellae. Early magmatic rocks are dominated by hemo-ilmenite with minor end-member magnetite, followed by more reduced oxides dominated by titanomagnetite with minor near end-member ilmenite. What is not fully understood is the property of ilmenite with hematite exsolution lamellae, or, even more striking, hematite with ilmenite lamellae, to produce strong remanent magnetization of high coercivity and with a Néel temperature equal to or above the Curie temperature of magnetite. This property makes the rhombohedral oxides an important candidate to explain some high-amplitude deep-crustal anomalies on earth, or strong remanent magnetization on other planets.

Environmental Magnetism

Mishima, T., Torii, M., Fukusawa, H., Ono, Y., Fang, X.-M., Pan, B.-T., and Li, J.-J., 2001, **Magnetic grain-size distribution of the enhanced component in the loess-palaeosol sequences in the western Loess Plateau of China**: *Geophysical Journal International, v. 145*, no. 2, p. 499-504.
Samples from the Beiyuan section show evidence of two magnetic components: a constant background and an enhanced component. The magnetic properties of the enhanced component suggest strong grain-size control, which is in contrast with variable grain-size distribution in loess-palaeosol from the central Loess Plateau. Chemically formed magnetic grains do not fulfill the require-

ments in the case of the western Loess Plateau because they may show shifts in the grain-size distribution. The difference in climate between the western and central Loess Plateau may lead to different origins and different preservation conditions of the pedogenic magnetite.

Sagnotti, L., Macri, P., Camerlenghi, A., and Rebesco, M., 2001, **Environmental magnetism of Antarctic Late Pleistocene sediments and interhemispheric correlation of climatic events**: *Earth and Planetary Science Letters, v. 192*, no. 1, p. 65-80.
Sharp coercivity minima observed in fine-grained sediments from the continental rise of the western Antarctic Peninsula correlate to the major rapid cooling events of the northern Atlantic (Heinrich layers). The authors interpret this environmental magnetic signal in terms of variations in deep sea diagenetic processes of sulfide formation, which reflect changes in the input of detrital organic matter controlled by sea-ice extent. With the inherent uncertainties in age controls, the sedimentary paleoclimatic markers of the two hemispheres are almost contemporaneous, but interhemispheric time lags or leads of the order of 1-2 kyr are also compatible with the data.

Extraterrestrial Magnetism

Dunlop, D. J., and Kletetschka, G., 2001, **Multidomain hematite: A source of planetary magnetic anomalies?**: *Geophysical Research Letters, v. 28*, no. 17, p. 3345-8.
TRM in hematite is larger than TRM in magnetite for grain sizes ≥10 mu m. The authors show that hematite's weak spontaneous magnetization M_s causes its strong TRM, since the self-demagnetizing field H_d opposing large domain wall displacements is proportional to M_s. In hematite, H_d is comparable to the Earth's magnetic field but in magnetite, H_d is 1000 times larger. As a result, Earth's field TRM of MD hematite (≈0.3 Am^2/kg) outweighs TRM and induced magnetization of MD magnetite (≈0.01-0.02 Am^2/kg) and rivals TRM of single-domain and PSD magnetite as a source of magnetic anomalies on Earth and perhaps on Mars.

Shaw, J., Hill, M. J., and Openshaw, S. J., 2001, **Investigating the ancient Martian magnetic field using microwaves**: *Earth and Planetary Science Letters, v. 190*, no. 3, p. 103-9.
The new microwave palaeointensity technique has been used to investigate samples from the Martian meteorite Nakhla. Assuming that a part of the magnetic remanence is of thermal origin and originating on Mars the two samples studied yield estimates of 4 µT for the Martian magnetic field at 1.35 Ga.

Instruments and Measurement Techniques

Borradaile, G. J., Lagroix, F., and Trimble, D., 2001, **Improved isolation of archeomagnetic signals by combined low temperature and alternating field demagnetization**: *Geophysical Journal International, v. 147*, no. 1, p. 176-82.
AF demagnetization of the magnetite-bearing claystone foundations of a Saxon or late medieval lime kiln in Lincolnshire, England, fail to isolate stable characteristic remanences, or remanences compatible with possible contemporary geomagnetic field orientations. Consolidation of the material prevented thermal demagnetization. When LTD precedes AF demagnetization, however, the vector plots show a stable characteristic (primary) component. Magnetic anisotropy measurements show that the LTD did not significantly disturb the mineral fabric of the claystone, that the mineral fabric did not deflect the palaeofield, and that AF demagnetization did not induce a field-impressed anisotropy during the experiments. We conclude that LTD preceding AF demagnetization improves the isolation of a characteristic remanence, which here favours a late medieval age for the kiln foundation.

Fleet, E. F., Chatraphorn, S., Wellstood, F. C., and Eylem, C., 2001, **Determination of magnetic properties using a room-temperature scanning SQUID microscope**: *IEEE Transactions on Applied Superconductivity, v. 11*, no. 1, p. 1180-3.
We have used a YBCO dc SQUID at 77 K to image room-temperature magnetic thin film samples, including Fe_3O_4, rare earth magnets and CMR materials. We typically saturate the magnetization of the sample in fields up to 8.5 Tesla, and then image the remanent (zero applied field) state. We have developed several analytical techniques that yield quantification of magnetic properties, including magnetization, total dipole moment, and the demagnetizing field.

Magnetic Field Records and Paleointensity Methods

Carvallo, C., and Dunlop, D. J., 2001, **Archeomagnetism of potsherds from Grand Banks, Ontario: a test of low paleointensities in Ontario around A.D. 1000**: *Earth and Planetary Science Letters, v. 186*, no. 3, p. 437-50.
24 pottery fragments with ages in the range A.D. 990-1160 give a paleofield intensity of 42.0±7.4 µT, and a virtual axial dipole moment of $7.0\pm1.3*10^{22}$ Am^2, in agreement with the low VADMs given by contemporary materials from the southwestern USA. Hysteresis measurements indicate that the NRM is carried by PSD magnetite grains, and measurements after heating to various temperatures reveal only slight mineralogical changes.

Guyodo, Y., Acton, G. D., Brachfeld, S., and Channell, J. E. T., 2001, **A sedimentary paleomagnetic record of the Matuyama chron from the Western Antarctic margin (ODP Site 1101)**: *Earth and Planetary Science Letters, v. 191*, no. 1, p. 61-74.
The bulk magnetic parameters vary by more than a factor of 20 over the entire time interval, but by less than a factor of 6 over the 0.7-1.1 Ma interval, which was selected for paleointensity determinations based on NRM/ARM. Direct comparison of the Site 1101 paleointensity record with other curves for the same time interval suggests a geomagnetic origin for features present in the record. A more quantitative comparison by means of a jackknife test, performed on nine records of relative paleointensity over the 0.95-1.1 Ma interval, yielded no outlier for the period considered, confirming the geomagnetic character of the records. The authors have constructed a low-resolution stack revealing some of the characteristic paleointensity features of the Jaramillo subchron.

Kent, D. V., and Carlut, J., 2001, **A negative test of orbital control of geomagnetic reversals and excursions**: *Geophysical Research Letters, v. 28*, no. 18, p. 3561-4.
A 41 kyr periodic component has been reported in some sedimentary paleointensity records, allowing speculation that there may be some component of orbital control of geomagnetic field generation such as by obliquity modulation. However, no discernable tendency is found for astronomically-dated geomagnetic reversals in the Plio-Pleistocene (0 to 5.3 Ma) or excursions in the Brunhes (0 to 0.78 Ma) to occur at a consistent amplitude or phase of obliquity cyclicity, nor of orbital eccentricity. An implication is that paleointensity lows which are characteristically associated with these features are not distributed in a systematic way relative to obliquity and eccentricity, supporting the idea that orbital forcing does not power the geodynamo.

Pan, Y. X., Zhu, R. X., Shaw, J., Liu, Q. S., and Guo, B., 2001, **Can relative paleointensities be determined from the normalized magnetization of the wind-blown loess of China?**: *Journal of Geophysical Research, v. 106*, no. B9, p. 19221-32.
The authors examine the Malan loess (L_1), the last glacial sediments, in the Lingtai section to determine whether loess is able to reliably record relative paleointensity. Both normalization and the pseudo-Thellier method were used. Rock magnetic properties show uniform magnetic mineralogy and grain size. Normalized remanences derived from L_1 show highs for 72-66 ka and 62-51 ka, and lows near 63 ka, 42 ka and 20-10 ka. Comparable results are obtained using different normalization parameters. However, comparisons of the normalized magnetization with contemporaneous marine records show some dissimilarities. In particular, the intensity low at 20-10 ka, corresponding to the last glacial maximum, is not compatible with the Sint-800 composite record.

Magnetic Microscopy and Spectroscopy

El-Jaick, L. J., Acosta-Avalos, D., de Souza Esquivel, D. M., Wajnberg, E., and Linhares, M. P., 2001, **Electron paramagnetic resonance study of honeybee apis mellifera abdomens**: *European Biophysics Journal, v. 29*, no. 8, p. 579-86.
At least four iron structures are identified: isolated Fe^{3+} ions, amorphous FeOOH, isolated magnetite nanoparticles of about $3*10^2$ nm^3 and 10^3 nm^3 volumes, depending on the hydration degree of the sample, and aggregates of these particles. A low-temperature transition (52-91 K) was observed and the temperature dependence of

abstracts... *continued on p. 4*

the magnetic anisotropy constant of those particles was determined. These results imply that biomineralized magnetites are distinct from inorganic particles and the parameters presented are relevant for the refinement of magnetoreception models in honeybees.

Mizoguchi, M., 2001, **Charge and orbital ordering structure of Fe_3O_4 in the low-temperature phase as deduced from NMR study**: *Journal of the Physical Society of Japan, v. 70*, no. 8, p. 2333-44.
The hyperfine fields of Fe ions in Fe_3O_4 have been investigated for a spherically shaped specimen at 4.2 K using NMR. The numbers of inequivalent sites on A- and B-sites are determined to be just eight and sixteen, respectively. The anisotropy in the hyperfine fields of A-sites reveals that one of the mirror symmetries in the high-temperature phase remains incomplete. A charge and orbital ordering structure is constructed by freezing the charge density waves at the lattice points of Fe ions. Two mechanisms are postulated to stabilize orbital ordering at the time of freezing. One is the repulsive Coulomb force between the electron clouds of the nearest-neighbor Fe ions and the other is the formation of bonding and anti-bonding orbitals between these Fe ions.

Nikolaev, V. I., Shipilin, A. M., and Zakharova, I. N., 2001, **On estimating nanoparticle size with the help of the Mössbauer effect**: *Physics of The Solid State, v. 43*, no. 8, p. 1515-17.
A method for estimating nanoparticle size by determining the distribution function p(Hn) of hyperfine magnetic fields from data on the Mössbauer spectrum of ^{57}Fe nuclei is described. The idea of the method stems from the fact that, owing to the breaking of exchange bonds for surface atoms, their contribution to the total area bounded by the p(Hn) curve can be singled out. The potentialities of the method are illustrated using the data obtained in experiments with nanoparticles of magnetite.

Schmidt, O., Fazan, T. A., Morais, J., and Fecher, G. H., 2001, **Microanalysis of the surfaces of natural iron-based minerals by means of synchrotron radiation based experimental techniques**: *Surface Science, v. 482-485*, p. 568-73.
We investigated the surfaces of natural iron-based minerals, magnetite, hematite, goethite, pyrite, pyrrhotite, chalcopyrite, bornite and vivianite, using synchrotron radiation based techniques. Most iron chalcogenides are very suitable for photoemission microscopy studies due to their low resistivity, which prevents from surface charging. The local compositions were studied employing photoemission microscopy in combination with X-ray absorption spectroscopy. Imaging of the sample in the near-edge region of the absorption edges was used to visualise the spatial distributions of the chemical phases on the surface. Distributions of trace elements are imaged with high chemical and lateral resolution.

Takele, S., and Hearne, G. R., 2001, **Magnetic-electronic pressure studies of natural iron-bearing minerals and materials using ^{57}Fe Mössbauer spectroscopy in a diamond anvil cell**: *Nuclear Instruments & Methods in Physics Research, Section B, v. 183*, no. 3, p. 413-18.
We have measured ^{57}Fe Mössbauer spectra of natural materials at variable high pressures and cryogenic temperatures in a diamond anvil cell (DAC). Satisfactory spectra were obtained for an ilmenite sample in 12 h at temperatures where the sample is paramagnetic and in 20-30 h below the spin-ordering temperature of 60 K where resonance intensity is reduced due to magnetically split spectral components. Sufficiently high count-rates are obtained by using both the 14.4 keV resonant gamma -ray and associated 1.8 keV escape peak events. By using conventional commercially available Mössbauer apparatus, magnetic-electronic properties of iron-bearing minerals and materials with an iron content greater than 20% may be investigated to pressures in excess of 10 GPa encompassing many minerals of the earth's interior.

Valckenborg, R. M. E., Pel, L., and Kopinga, K., 2001, **NMR relaxation and diffusion measurements on iron(111)-doped Kaolin clay**: *Journal of Magnetic Resonance, v. 151*, no. 2, p. 291-7.
For kaolin clay samples mixed with Fe_2O_3 powder, the NMR relaxation a nearly mono-exponential decay, leading to the conclusion that the pore size distribution of the clay samples is narrow and/or that the pores are interconnected very well. The NMR diffusion measurements revealed that the Fe_2O_3 causes internal magnetic field gradients that largely exceed the maximum external gradient that could be applied by NMR apparatus (0.3 T/m). Probably an intermediate or a localization regime is induced by the large internal gradients, which are estimated to be on the order of 1 to 10 T/m in the pore volume and may exceed 1000 T/m at the pore surface.

Modeling and Theory

Antonov, V. N., Harmon, B. N., Antropov, V. P., Perlov, A. Y., and Yaresko, A. N., 2001, **Electronic structure and magneto -optical Kerr effect of Fe_3O_4 and Mg^{2+}- or Al^{3+}-substituted Fe_3O_4**: *Physical Review B, v. 64*, no. 13, p. 1-12.
The optical and magneto -optical spectra of charge-ordered magnetite (Fe_3O_4) below the Verwey transition and Mg^{2+}- and Al^{3+}-substituted Fe_3O_4 are investigated theoretically from first principles, using the fully relativistic Dirac linear muffin-tin orbital band structure method. The electronic structure is obtained with the local spin-density approximation (LSDA), as well as with the so-called LSDA+U approach for which the charge ordering is found to be a stable solution with an energy gap value of 0.19 eV (the experimental value is 0.14 eV) in contrast to a metallic state given by LSDA. The origin of the Kerr rotation realized in the compounds is examined.

Iglesias, O., Labarta, A., and Ritort, F., 2001, **Monte Carlo study of the finite-size effects on the magnetization of maghemite small particles**: *Journal of Applied Physics, v. 89*, no. 11, pt.1, p. 7597-9.
Monte Carlo simulations for a single spherical particle of $\gamma-Fe_2O_3$ show that for the smallest sizes, thermal demagnetization of the surface completely dominates the magnetization while the behavior of the core is similar to that of the periodic boundary case, independently of D. The change in shape of the hysteresis loops with D demonstrates that the reversal mode is strongly influenced by the presence of broken links and disorder at the surface.

Néel Symposium (EGS 2000) Volume

Dunlop, D., and Prévot, M., 2001, **Preface to the Néel Symposium Volume**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 1.

Prévot, M., and Dunlop, D., 2001, **Louis Néel: 40 years of magnetism**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 3-6.

Prévot, M., and Dunlop, D., 2001, **Louis Néel: quarante ans de magnetisme**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 7-10.

Pike, C. R., Roberts, A. P., Dekkers, M. J., and Verosub, K. L., 2001, **An investigation of multi-domain hysteresis mechanisms using FORC diagrams**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 11-25.
In Néel's classical one-dimensional domain wall (DW) pinning model, a pinning function represents the interactions of a DW with the surrounding medium. Bertotti et al. have modelled this pinning function as a random Wiener-Levy process, where particle boundaries are neglected, and predict a FORC diagram that consists of perfectly vertical contours, decreasing with increasing microcoercivity. This prediction is consistent with our experimental results for transformer steel and for annealed MD magnetite grains, but not for unannealed grains. We extend the DW pinning model to include particle boundaries and an Ornstein-Uhlenbeck random process, but this still does not account for the behaviour of the unannealed MD grains. We conclude that MD hysteresis is more complicated than the classical one-dimensional pinning model, possibly due to factors including DW interactions, DW nucleation and annihilation, and DW curvature.

Jackson, M., and Worm, H.-U., 2001, **Anomalous unblocking temperatures, viscosity and frequency-dependent susceptibility in the chemically-remagnetized Trenton limestone**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 27-42.
New blocking-unblocking models (for maghemite and for magnetite controlled by magnetocrystalline rather than shape anisotropy) fail to account for the observed high T_{UB}'s of the viscous overprint, leading to the conclusion that the T_{UB} anomaly is probably attributable to MD carriers, despite evidence for a dominant SP-SSD assemblage . A possible alternative explanation is an increase in coercivity due to maghemitization of SD particles after acquisition of the viscous

overprint, causing a significant increase in their unblocking temperatures. New frequency-dependent susceptibility measurements at low temperatures allow us to isolate the t-T behavior of particles at the SP-SSD threshold, and we find that these do in fact closely follow the predictions of Néel theory, as formulated in the models of Pullaiah et al. and Walton-Middleton-Schmidt.

Dunlop, D. J., and Özdemir, Ö., 2001, **Beyond Néel's theories: thermal demagnetization of narrow-band partial thermoremanent magnetizations**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 43-57.
pTRM was imparted over a narrow temperature interval, T=370-350°C, to a suite of crushed and annealed natural magnetite samples, ranging from ~1 to 125-150µm (small PSD to MD). In this way, effectively a single blocking temperature, T_B, of pTRM was activated. Stepwise thermal demagnetization did not erase the pTRMs sharply at T_B, as for SD grains. Demagnetization began well below 350°C and continued above 370°C, with a median unblocking temperature, T_{UB}, close to 360°C. The largest grains deviated most from SD behavior. Their pTRM demagnetized over the entire interval from room temperature to the Curie point, in accordance with predictions for MD grains. In terms of the unblocking temperature distribution $f(T_{UB})$ or slope dM/dT of the thermal demagnetization curve, SD grains have a sharp spectrum, $T_{UB}=T_B$; MD grains were observed to have a broad, roughly symmetrical spectrum centered on T_B; and intermediate size grains in the PSD range had non-Gaussian spectra, combining a central peak near T_B with broad tails above and below T_B. Practical implications of these observations are that Thellier's law of reciprocity ($T_{UB}=T_B$) will be increasingly violated as grain size increases in the PSD range. The low-T_{UB} part of $f(T_{UB})$ produces anomalously large demagnetization of NRM in low-temperature heating steps of Thellier-type paleointensity determinations and a sagging shape of the Arai plot. The high-T_{UB} part of $f(T_{UB})$ results in undemagnetized remanence at and above T_B in thermal demagnetization. Among pretreatments designed to make remanence more SD-like in subsequent thermal cleaning, AF pre-cleaning sharpened $f(T_{UB})$ more effectively than LTD for the 20µm sample.

Shcherbakov, V. P., Shcherbakova, V. V., Vinogradov, Y. K., and Heider, F., 2001, **Thermal stability of pTRMs created from different magnetic states**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 59-73.
Violation of Thellier's laws of pTRM independence and additivity for PSD and especially for MD samples leads to inequality of T_b and T_{ub}. A direct check involves pTRM acquisition by cooling a sample in zero field from T_C to T_1 before applying the pTRM field. An alternative method begins with AF demagnetization, followed by heating to T_1, avoiding the undesirable heating of samples to T_C. The tail[$pTRM_{AF}(300, T_r)$] is usually much shorter than that of $pTRM_a(300, T_r)$ and of smaller magnitudes by a factor of about 3. Thus, this test is suitable mainly for the pre-selection of MD samples having relatively large tails of $pTRM_{AF}(300, T_r)$. For PSD grains, the tails of $pTRM_{AF}(300, T_r)$ are often too small to distinguish them from the single-domain (SD) ones. A detailed study of properties of different pTRMs created from AF-demagnetized, thermodemagnetized and zero-field cooled states has been undertaken. Physically the dependence of values of both pTRMs and their tails on the initial magnetic state of a sample is explained by the phenomenon of metastability.

Prévot, M., Hoffman, K. A., Goguitchaichvili, A., Doukhan, J.-C., Shcherbakov, V., and Bina, M., 2001, **The mechanism of self-reversal of thermoremanence in natural hemoilmenite crystals: new experimental data and model**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 75-92.
Magnetic force microscopy on self-reversing hemoilmenite ($Fe_{2-y}Ti_yO_3$) grains from Pinatubo indicates the presence of MD magnetic structures in coexisting strongly and weakly magnetic crystallographic regions having compositions of y≈0.54 and 0.53, respectively. Continuous thermal demagnetization shows that the magnitude of a normal TRM (nTRM) component, observed at temperatures above the Curie point of the self-reversing phase, is much too large to be carried by a phase that is entirely cation-disordered. We argue that the so-called nTRM-carrying x-phase is itself partially cation-ordered, and, thus, ferrimagnetic, as postulated first by Ishikawa and Syono.We propose a "nanophase" self-reversal model for the ilmenite-hematite solid solution series in which the rTRM and nTRM components are carried by the cores and margins, respectively, of the tiny, partially cation-ordered nano-sized domains observed by TEM. Due to the kinetics of the ordering process, the cation distributions in the cores and margins must be antiphase, which causes their magnetic moments to be oppositely aligned. Since the margins are slightly more Fe-rich, they acquire a magnetic remanence first (nTRM). Then, upon further cooling, the superexchange interactions force the core material be oppositely aligned (producing a rTRM). Upon stepwise thermal demagnetization, the self-reversed remanence measured at room temperature is not destroyed until the unblocking temperature of the disordered Fe-enriched aureole (approximately 410°C) is reached. Mineralogical considerations and magnetic evidence from previous works suggest that this model is generally valid for self-reversed dacitic pumice, in particular the Mt. Haruna dacite and the 1985 Nevado del Ruiz dacitic andesite.

de Boer, C. B., Dekkers, M. J., and van Hoof, T. A. M., 2001, **Rock-magnetic properties of TRM carrying baked and molten rocks straddling burnt coal seams**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 93-108.
The subsurface spontaneous combustion of coal seams in Xinjiang (NW China) during Pleistocene to recent times produced large areas of thermally altered sedimentary rocks with large magnetic moments. The NRM and TRM intensities and low-field susceptibilities of such rocks range from 0.1 to 10 A/m and 100 x 10^{-4} to 1000 x 10^{-4} SI, respectively, two to three orders of magnitude higher than in their sedimentary protoliths. The dominant magnetic carriers include relatively pure magnetite, maghemite and hematite as well as more complex spinel phases, occurring mainly as fine PSD particles. Conspicuous is the presence of pure metallic iron (α-Fe) in some samples. This highly magnetic phase is inferred to appear as more or less elongated SP and SD inclusions in host silicate phases, which prevent them from oxidizing. The SD α-Fe particles can carry a highly stable remanence, having remanent coercivities ranging 70-140 mT. The ARM and IRM stability of all burnt rock samples is relatively high; MDFs, $B_{(1/2)A}$ and $B_{(1/2)I}$, respectively, are 25-46 and ~20-30 mT for spinel-bearing samples, 34-36 and 47-53 mT for maghemite-hematite-bearing samples, and 48-89 and 64-84 mT for metallic iron-bearing samples. Consequently, burnt rocks are high-quality geomagnetic field recorders. Their very nature makes them useful for paleointensity determinations, although age determination is a limiting factor.

Rochette, P., Vadeboin, F., and Clochard, L., 2001, **Rock magnetic applications of Halbach cylinders**: *Physics of The Earth and Planetary Interiors, v. 126*, no. 1-2, p. 109-117.
Permanent magnet field sources made of NdFeB, in particular the Halbach cylinders, have not previously been used by rock magneticists. Here, their use is explored for determining saturation IRM (SIRM) and S ratio. An original "one-step" scheme is presented to obtain both parameters in one measurement and one operation of IRM acquisition using two crossed Halbach cylinders with 1.0 and 0.3 T fields. The first tests performed demonstrate the ability of Halbach cylinders to derive SIRM and S values over a wide range of coercivities using both the standard and the one-step schemes, although further improvements are needed in field homogeneity to achieve better precision. Other possible applications of Halbach cylinders are reviewed.

Reviews

Petrova, G. N., Pechersky, D. M., and Khramov, A. N., 2000, **Paleomagnetology is the science of the 20th century**: *Izvestiya, Physics of the Solid Earth, v. 36*, no. 9, p. 777-98.
This paper is devoted to the historical development of paleomagnetology, the state of the art of studies on the fine structure and long-period variations in the geomagnetic field, and their comparison with surface processes such as variations in the climate, the organic world, and movements of the continental plates.

Synthesis and Properties of Magnetic Minerals

Gun'ko, Y. K., Pillai, S. C., and McInerney, D., 2001, **Magnetic nanoparticles and nanoparticle assemblies from**

abstracts... *continued on p. 6*

metallorganic precursors: *Journal of Materials Science: Materials in Electronics, v. 12*, no. 4, p. 299-302.
Magnetic nanoparticles of γ-Fe_2O_3,Fe_2O_3 / SiO_2 composite and magnetite (Fe_3O_4) have been prepared using novel metallorganic precursors ($Fe[NC(C_6H_4)C(NSiMe_3)_2]_2Cl$, $Fe_2[O_2Si(C_6H_5)_2]_3$ and $[Fe(OBut)_3Na(THF)]_2$) by hydrolysis, sol-gel condensation and further ultrasound and thermal treatment of the samples. The nanoparticles have been investigated by X-ray powder diffraction, TEM, SEM and AFM.

Kucza, W., 2001, **Electrostatically driven charge-ordering in magnetite below the Verwey temperature**: *Solid State Communications, v. 118*, no. 8, p. 401-5.
The work describes the stability of different charge models for magnetite, Fe_3O_4, below the Verwey temperature (T_V). Thirty-seven configurations allowed by the Anderson condition are analysed by means of Madelung calculations, including models proposed by Verwey, Mizoguchi and Zuo. A new approach based on summation over cubic cells is applied that ensured rapid convergence of lattice sums. The lowest Madelung energy has been found for the model in which coupled chains of Fe^{2+} and Fe^{3+} ions form structures parallel to the c-axis. These structures are similar to double helices having a period of twice the cubic lattice constant. Thus it has been shown, contrary to previous studies, that the Coulomb energy alone is sufficient to stabilize the charge order involving doubling of the c-axis.

Sinha, A., Chakraborty, J., Kumar Das, S., Das, S., Rao, V., and Ramachandrarao, P., 2001, **Oriented arrays of nanocrystalline magnetite in polymer matrix produced by biomimetic synthesis**: *Materials Transactions, v. 42*, no. 8, p. 1672-5.
Synthesis of nano sized magnetite particles has been carried out following a polymer matrix mediated process. The synthesis route, being akin to bio mineralization, yields elongated magnetite particles of uniform size and morphology. The produced particles were oriented perpendicularly with respect to polymeric tubules and showed a tendency of array formation as happens in magnetotactic bacteria.

Xuehong, L., Junjie, Z., Wei, Z., and Hong-Yuan, C., 2001, **Synthesis of amorphous Fe_2O_3 nanoparticles by microwave irradiation**: *Materials Letters, v. 50*, no. 5, p. 341-6.
Amorphous Fe_2O_3 nanoparticles of about 3-5 nm in size have been synthesized by microwave irradiation heating of an aqueous solution, containing ferric chloride, polyethylene glycol-2000 and urea. The Fe_2O_3 nanoparticles were characterized by the techniques of TEM, XRD, DSC, TGA and magnetization measurements.

Zhang, L., Papaefthymiou, G. C., and Ying, J. Y., 2001, **Synthesis and properties of γ-Fe_2O_3 nanoclusters within mesoporous aluminosilicate matrices**: *Journal of Physical Chemistry B, v. 105*, no. 31, p. 7414-23.
Iron oxide nanoclusters were synthesized within mesoporous MCM-41 aluminosilicate matrices via evaporation-condensation of volatile $Fe(CO)_5$. The well-defined hexagonally packed cylindrical pore structure of MCM-41 led to the derivation of γ-Fe_2O_3 particles with spherical and elongated morphologies. Magnetization studies and Mössbauer spectroscopy indicated that the γ-Fe_2O_3 /MCM-41 nanocomposites exhibited interesting superparamagnetic behavior. A blue shift in the absorption edge relative to bulk iron oxide was noted in the UV-Vis spectra. Strain at the particle-support interface and quantum confinement effects played a critical role in determining the overall magnetic and optical behavior of the γ-Fe_2O_3 / MCM-41 nanocomposites. The iron oxide nanoclusters within the MCM-41 matrix showed high thermal stability and increased magnetization when calcined at high temperatures.

Request for Proposals: *IRM* Visiting Fellowships

Fellowship period:
March-August, 2002
Proposal deadline:
Dec 14, 2001
Forms available on our web site:
www.geo.umn.edu/orgs/irm

Applications are invited for IRM Visiting Fellowships during the interval from March through August, 2002. Visiting Fellowships provide access to the entire set of IRM instruments (as needed), for periods up to ten days. Visiting Fellows are also eligible for reimbursement of travel expenses (up to a maximum of $750; lodging and meal costs excluded). Application forms are available through our web site, and must be submitted by December 14, 2001 to be considered for the 2002 spring-summer interval.

Proposal Preparation Guidelines

1. *Proposal Length*: Do not exceed a total of three pages for the text, figures, and references in your project description. Be concise. Excessive proposal length is a good way to antagonize the members of our Review and Advisory Committee (RAC).

2. *Subject Areas*: Topics for research are open to any field of study involving fine particle magnetism, but preference will be given to projects relating magnetism to geological or environmental studies, or to fundamental physical studies that are of potential relevance to the geosciences. In the latter case, you should give a brief indication of the relevance.

3. *Justification*: Briefly explain the overall importance of your project, and why it is important for you to carry out detailed studies at the IRM. In general, projects that require only widely-available equipment (such as paleomagnetic or low-field susceptibility instruments) will be given lower priority than those that require a variety of more specialized rock-magnetic instruments (e.g., low-temperature, high-field susceptometers, domain imaging, Mössbauer spectroscopy).

4. *Work Plans*: Outline the experiments to be carried out or data to be acquired during your visit.

For less intensive or more preliminary studies we encourage you to consider an informal visit. These allow access to two or three instruments, for periods up to 3 days and are scheduled through the lab manager. Email us for more information and to arrange a visit. It is best to send a short (2 or 3 sentence) description of what you propose to do along with dates you would be interested in visiting.

...Bestiary
continued from p. 1

descriptions of, and practical uses for, various rocks and minerals, including lodestone, which "…is found in the land of the cave-dwellers and in India. It has a metallic colour and attracts iron. Its virtue is that if a man wants to know if his wife is chaste or not, he should place the stone under her head when she is asleep; if she is chaste, she will embrace him warmly; otherwise, she will fall from the bed as if struck by a hand; this happens because of the odour of the stone. If a thief should enter a house to rob it, and should place in different parts of the house a live coal and on top of it powdered lodestone, so that it gives off smoke to the four corners of the house, it will seem to those who are in the house that the house is collapsing; as a result, they will flee and the thief can rob the place. Lodestone produces harmony between man and woman; it bestows grace, eloquence, skill in argument. If it is given in the form of a drink, it purges dropsy. Its powder, put on a fire, quenches it." (For the record, we do not condone using lodestone to assist in criminal activity.)

The fabled mineral *adamant* was closely associated in former times with the lodestone, either synonymously (e.g. Gilbert, who asserted that the French "aimant" was a corruption of adamant), or antithetically, as a diamond-like substance which neutralized the lodestone with superior powers. In the *Aberdeen Bestiary*, "Adamant is a small and unsightly stone, with a dusky colour and the brightness of crystal, and is about the size of an Abelline nut. It yields to no other matter, not iron, nor indeed fire, and it never grows hot; for this reason its name, translated from Greek, means 'invincible force'. While adamant remains unconquered by iron, however, and scorns fire, it can be broken by the fresh blood of a goat, softened by heat and thus crushed with repeated blows of iron. Engravers use fragments of it for engraving and cutting gemstones. Adamant is at odds with the magnet stone in so much as, placed near iron, it will not suffer the metal to be drawn to the magnet; if the adamant is removed, however, the magnet seizes hold and bears away the metal. They say also that it resembles amber, repelling poisons, banishing vain fears, resisting evil spells."

Bestiaries were one manifestation of the slow re-emergence of scholarly activity in Europe during the first centuries of the 2nd millennium. Universities were established in Paris (1150), Oxford (1167) and Cambridge (1200). The mathematics and science of antiquity had been preserved and expanded in the Islamic world and elsewhere, and Latin translations (from Arabic) of Euclid's *Elements* and Ptolemy's *Almagest*, as well as Al-Khwarizmi's *Algebra* appeared in the 12th Century. Leonardo of Pisa ("Fibonacci"), in his *Liber Abaci* (1202), illustrated the power of algebraic methods and Hindu-Arabic numerals, but also made significant original contributions to mathematics, particularly in number theory.

Such original contributions were exceptional in an age of rediscovery. The celebrated *Epistola de Magnete* of Petrus Peregrinus (Pierre de Maricourt), written in August, 1269, represents another outstanding example. In fact it represents an advance beyond the *Aberdeen Bestiary's* account of magnetism 70 years earlier, that is in some ways greater than the subsequent 762-year advancement from the *Epistola* to the *Rock-Magnetic Bestiary*. It is such a significant advance not because of the improvement in the quantity or quality of the knowledge contained (although these were substantial), but because it exemplifies a fundamental change in the approach to scientific knowledge. In fact the *Epistola* is often described as the first scientific treatise ever written.

Maricourt's contemporary Roger Bacon, who has been described as "a historically precocious expression of the empirical spirit of experimental science," himself referred to Maricourt as *magister experimentorum*: "though others strive blinkingly to see, as a bat in the twilight, the light of the sun, he himself contemplates it in its full splendor, [because] he is a master of experiment: and therefore he knows by experiment natural history, and physic, and alchemy, and all things in the heavens and beneath them." Unlike the bestiaries, the *Epistola* contains descriptions based (mostly) on direct, deliberate observation (a model that we carefully emulate in the *RMB*). More than three centuries before Gilbert, Peregrinus mapped out the orientations assumed by small elongate pieces of iron placed on the surface of spherical lodestones, describing magnetic meridians and poles. He observed that magnetic poles are of two types, and that opposites attract whereas like poles repel one another. He further noted that when a magnet is broken or cut into pieces, each still has two opposite poles.

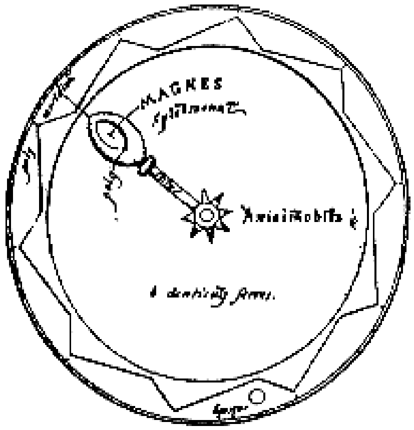
Peregrinus ascribed the meridional alignment of the compass needle to extraterrestrial causes: "Wherever one may be, he may see with his own eyes this movement of the stone according to the place of its meridian circle. But all meridian circles meet in the poles, wherefore the poles of the magnet receive their virtue from the poles of the universe." He further proposes that a spherical lodestone, mounted like a globe (with its polar axis aligned with that of the celestial sphere and so that the stone is free to pivot on that axis) will be observed to rotate, clocklike, one revolution per day, in order to keep in perfect longitudinal alignment with the universe. "If the stone move according to the motion of the heavens, you will rejoice in having discovered so wonderful a secret. But if it moves not, impute the failure rather to your own unskilfulness than to any fault in nature."

Maricourt was an engineer in the army of Charles of Anjou, which was engaged in a seige of Lucera at the time he wrote the *Epistola*. Naturally his interests, like those of the bestiary authors, were strongly attuned to practical applications. He spent three years constructing an Archimedean burning mirror, described by Bacon in his *Opus Tertium*, and he substantially improved on contemporary designs for the mariners compass by adding a graded circular scale around the perimeter and a sighting arm for reading bearings.

One of the more interesting (albeit chimerical) inventions of Peregrinus is described in Chapter 3 of the *Epistola*: "The Art of Making a Wheel of Perpetual Motion." "In this chapter I will make known to you the construction of a wheel which in a remarkable manner moves continuously. I have seen many

Bestiary... *continued on p. 8*

Stained glass window in Bapst Library, Boston College, showing Roger Bacon (1220-1292) and depicting his research interests in mathematics, optics, alchemy, and astronomy. Al Hazan refers to ibn-al-Haitham (ca. 965-1039), known to the west as Alhazen, and author of an influential work on optics, in which (among other things) he estimated the thickness of the atmosphere from the duration of twilight. Bacon also highly esteemed the work of Petrus Peregrinus De Maharn-Curia (of whom no portraits appear to exist). http://www.bc.edu/bc_org/avp/ulib/bap/walk.html



The Peregrinus Perpetual Motion Magnetic Wheel

people vainly busy themselves… in their efforts to construct such a wheel. But… by means of the virtue or power of the lodestone all difficulty can be overcome. Within let there be iron nails or teeth of equal weight fastened to the periphery of the wheel in a slanting direction… Fasten the middle of the axis about which the wheel revolves so that the axis may always remain immovable. Add thereto a silver bar, and at its extremity affix a lodestone… let the north pole be then turned towards the teeth or cogs of the wheel somewhat slantingly so that the virtue of the stone may not flow diametrically into the iron teeth, but at a certain angle; consequently when one of the teeth comes near the north pole and owing to the impetus of the wheel passes it, it then approaches the south pole from which it is rather driven away than attracted." An animation of the Peregrinus wheel may be seen at http://jnaudin.free.fr/html/peregrin.htm.

An interesting speculative footnote concerns the recipient of the *Epistola*, addressed by Peregrinus as Sigerus, who, like Peregrinus, is known to have been a soldier and a landowner in Picardy. S. P. Thompson suggests that this was the same Siger who wrote a treatise *De Anima intellectiva*, and who was placed by Dante next to Thomas Aquinas and the Venerable Bede in *Paradiso*. Dante's teacher Brunetto Latini (who wrote an encyclopaedia, *Li Livres dou Trésor*, that includes descriptions of the lodestone and the mariner's compass) did not fare as well, consigned by Dante to the burning plains in the seventh circle of the *Inferno*.

The castle of Lucera, built by Frederick II in 1233. It was as a soldier engaged in the siege of Lucera in 1269 that Petrus Peregrinus wrote his famous Epistola de Magnete. source: http://rubens.anu.edu.au/htdocs/laserdisk/0026/2616.JPG

Bestiary versus Database

Bestiaries are fascinating and beautiful, but our reasons for producing a rock-magnetic bestiary, rather than a rock-magnetic database, are more practical than aesthetic.

First, the term database implies a comprehensive completeness, which would require more time and effort than we are currently able to devote to the project. Exclusion of certain results from a database can provoke controversy, as has recently occurred in connection with the Global Paleomagnetic Database [McElhinny, *EOS 82(39)*, 436]. Our immediate goal is not to bring together an exhaustive set of published rock-magnetic data, but rather to assemble data for a relatively small number of well-characterized specimens, for use as a tool in the interpretation of data for natural samples.

Further, databases must support certain kinds of functionality. A user has to be able to query the database to extract and manipulate relevant subsets of the data, and obtain various reports and other formatted output. A bestiary, in contrast, needs only be browsable, and is therefore somewhat easier to set up. Our initial objective is simply to make available a reference data set for pure materials that may be components in natural assemblages. We consider it essential for this purpose to provide detailed raw data (e.g., complete hysteresis loops, low-temperature remanence unblocking curves, etc), rather than simple summary parameters (such as H_C, M_R/M_S, δ_{FC}/δ_{ZFC}, etc).

Finally, the structure of a database should be optimized to accommodate the levels of complexity in the data and the sorts of manipulations required. On the one hand, mineral magnetic data are remarkably simple. With few exceptions (such as Mössbauer spectroscopy and magnetic microscopy), there is just one dependent variable of interest: magnetic moment (normalized by mass or volume). On the other hand, there is a very large number of independent variables, which include both material characteristics (composition, particle size, defect concentration, internal stress state, stoichiometry, concentration/interaction, anisotropy…) and experimental conditions (applied DC field, temperature, heating/cooling rate, applied AC field frequency and amplitude, applied stress, time, orientation…). Significant complexity arises from the fact that M usually depends not only on this entire set of independent variables, but also on the initial state of the sample, which is related to its thermomagnetic history. For example, pTRM unblocking temperature spectra differ, depending on whether the pTRM is imprinted by (a) cooling from the Curie point in zero field to temperature T1, switching on an applied field, cooling further to T2, switching off the field, and finally cooling to room-temperature in zero field, or (b) warming from room temperature to T1 in zero field, and then turning on the field and cooling, continuing as in case (a). The development of a true rock-magnetic database must wait until we are able to determine how much of this complexity should be built into its structure, and how to do so.

What is in the *RMB*

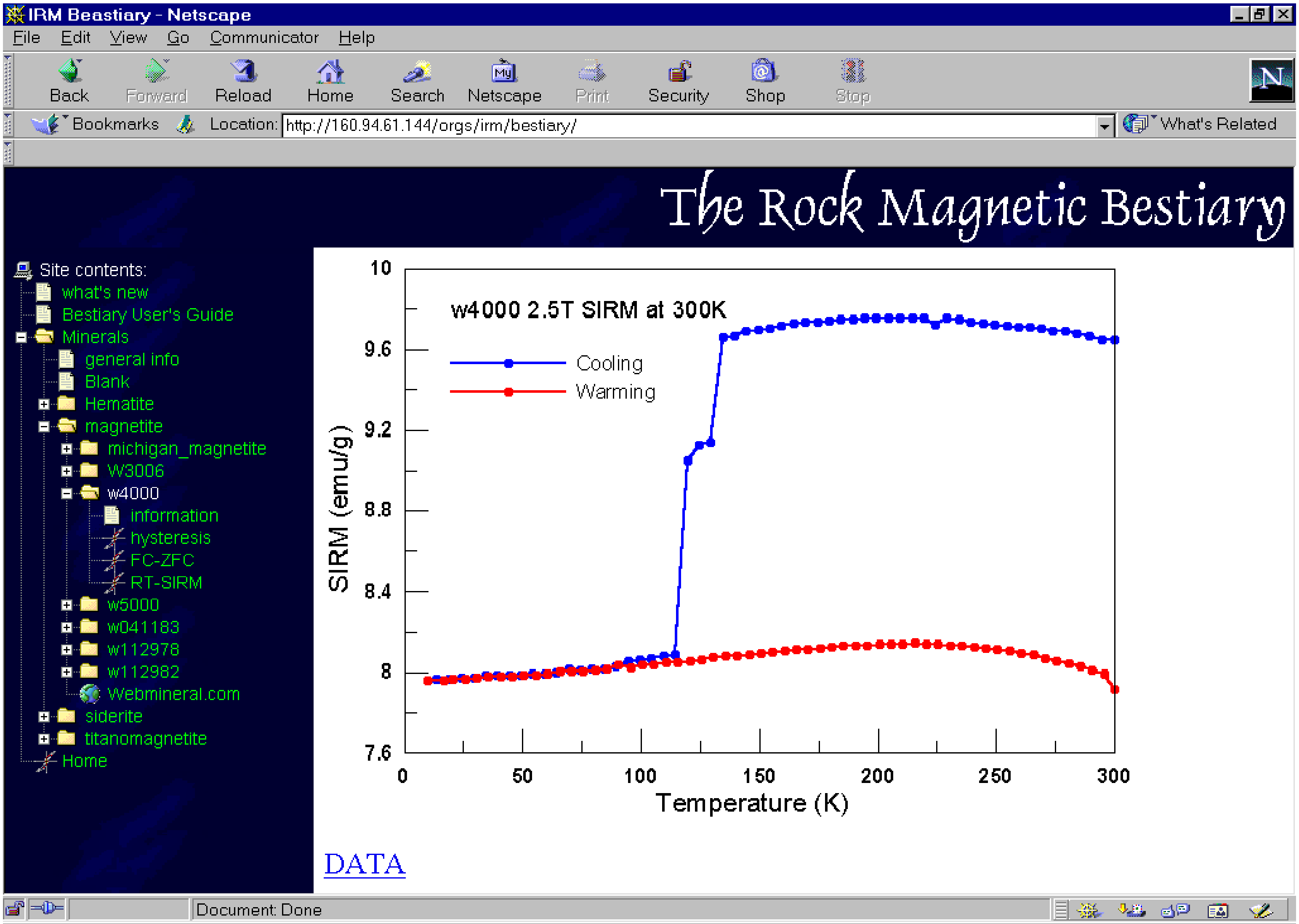
Initially we are including data primarily for synthetic minerals, and a few carefully selected natural materials. Natural and synthetic iron oxides have a variety of commercial applications, notably in magnetic recording and data storage; as coatings; and as pigments in paints, building materials, plastics and toners. Iron oxide pigments are readily available commercially - major producers are Bayer (Bayferrox), Columbian Chemicals (Mapico), and Pfizer. Annual production of iron oxides amounts to half a million tons globally.

Commercially-available iron oxides include both natural and synthetic materials. Natural goethites, hematites and magnetites are processed ("beneficiated") to remove impurities, and ground and separated into size fractions. Although maghemite occurs naturally, all commercially-available maghemite is synthetic, and an increasing share of the goethite, hematite and magnetite sold is also synthesized, which enables tighter control of composition, particle size and shape. Synthesis is primarily by three techniques: thermal decomposition of iron salts (e.g., $FeSO_4$, a by-product of steel manufacturing) to produce hematite; precipitation (the Penniman-Zoph process) of various compositions; and reduction of organic materials by Fe. An interesting class of iron oxide pigments is the "transparent" or low-opacity pigments produced by precipitation of extremely fine particle sizes (<100 nm).

Characteristics such as composition, particle size and shape are important in controlling the color or other properties required in these applications, and they are fairly carefully controlled for each pigment or other product. Of course these are also exactly the characteristics that are most important in controlling magnetic properties, and therefore commercial pigments are excellent standards for magnetic property characterization. We have started with a suite of sized magnetite, maghemite, hematite and goethite powders from Pfizer and from Wright Industries.

In addition to synthetics from commercial sources, we have collected and included data from synthetic materials produced specifically for research purposes. The "Purdue titanomagnetites" are single-crystal samples with compositions TM0, TM05, TM19, TM28, TM41 and TM55; they have been cut and ground down to spherical specimens of 1-2 mm diameter.

Among the natural materials



currently (or soon to be) included is the "Michigan magnetite," obtained from Wards Scientific and crushed to mm-sized pieces. Several specimens of the Tiva Canyon Tuff from Yucca Mountain, obtained from Joe Rosenbaum (USGS) and Horst-Ulrich Worm (Magnon International) are notable for their very narrow grain-size distributions spanning the superparamagnetic - stable single-domain size range.

For each sample in the *Bestiary*, we provide (or will eventually provide) extensive data sets covering all of the characterization protocols most commonly used at *IRM*. These include various flavors of low-temperature remanence (FC: field-cooled in 2.5 T from 300 to 20 K, then measured in zero-field while warming back to 300 K; ZFC: zero-field-cooled from 300 to 20 K, then magnetized isothermally in 2.5 T and measured in zero-field from 20 to 300 K; RTSIRM: isothermally magnetized in 2.5 T at 300 K and measured in zero field while cycling 300->20->300 K); AC susceptibility at various frequencies and amplitudes between room temperature and 20 K; room-temperature hysteresis; high-temperature susceptibility and strong-field thermomagnetic curves; Mössbauer spectrum at 300 K; and room-temperature IRM acquisition and demagnetization curves.

In addition, the *RMB* provides links to relevant external sites for each mineral type. These contain information on crystallography, x-ray diffraction, and basic physical properties such as density and hardness.

How the *RMB* Works

The *RMB* is designed to provide information in 3 forms. For every sample we will make available a plot of the data measured, the numerical data in text format, and any information we have about the mineral and actual sample measured. The data will be divided into broad areas, such as minerals, rocks, and sediments; other categories will be added (meteorites, vegetables, etc) as they become necessary. Within these you have the ability to "drill" down to specific mineral, rock, or sediment types, and further to individual samples. Then for each sample there is an information sheet and a list of data that have been collected and included in the *RMB*. The information sheet contains particulars about the sample such as chemical formula, source, room-temperature susceptibility, ARM, known transitions, Curie point(s), etc. We also provide a list of references to publications describing previous work done on the samples.

To make the *RMB* widely available and browsable we have rolled it into a web page using a collapsible tree menu javascript (modified from one originally written by Morten Wang). Before getting started there are a few things you need to be aware of. Although most web browsers these days recognize most javascripts, there might be a few out there that do not. If you have one of these and want to use the *RMB*, you will need to update to a javascript-capable browser such as Netscape version 3+, Opera v.5+, or Explorer v.4+.

Above is a screen capture of the *RMB* opened to a plot. To the left is the navigation panel, containing a tree menu that functions much the same way as the

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** The trademark name "Windows" is used for description only; it is not required and no endorsement is implied.*

Bestiary... *continued on p. 10*

Synthetic Iron Oxides in the Bestiary of Magnetic Minerals

Magnetite (Fe_3O_4)

Producer	*Product#*	*nominal size (µm)*
Wright	3006	2.50
Wright	4000	0.05
Wright	5000	0.75
Wright	41183	14.00
Wright	112978	0.50
Wright	112982	35.00
Pfizer	4232	0.45 (acicular)

Hematite (α-Fe_2O_3)

Producer	*Product#*	*nominal size (µm)*
Pfizer	R1299	0.15
Pfizer	R5098	0.50
Pfizer	R6097	
Pfizer	R8098	0.90
Pfizer	R9998	2.50
Baker	12024	
Harcros	R2899R	
Space Products	287925	

Maghemite (γ-Fe_2O_3)

Producer	*Product#*	*nominal size (µm)*
Wright	4200	0.05

Goethite (α-FeOOH)

Producer	*Product#*	*nominal size (µm)*
Pfizer	YLO1888	0.35
Pfizer	YLO3289	0.50
Pfizer	YLO5087	0.90
Pfizer	Y8089	

Windows™ "file explorer".* Each folder can be opened and closed by clicking on the + or - sign, or on the text itself. Plots and information pages will be opened in the viewing window to the right. Each time you click on a different entry from the list, the corresponding plot will replace the one in the viewing window. The plots are relatively low-resolution .gif images that look fine on the screen, but when printed they are a bit fuzzy. This was a compromise to speed up browsing. The images themselves are of a fixed size, generally ~ 640 x 440 pixels. The *bestiary* is optimized for a screen resolution of 1024 x 768 pixels - if you are using a lower resolution, you might have to scroll back and forth to see the entire image. The graphs and info sheets can be printed by clicking on them to activate the viewing window, then choosing print from the file menu on your browser.

Below each plot there is a link to download the data and other information extracted from the measurement. The data files use comma-separated variables (.csv) and text in double quotes. Depending on how file extension associations are set up in your browser, it will open the file in one of two ways (we hope this is all). When you click on the link it will either (a) open the text file in the display window, in which case you can highlight everything, copy, and paste it into a spreadsheet, or (b) prompt you to save it, or open it in wordpad, or whatever program you have associated with .dat files. The graphs and info sheets can be printed by clicking on them to activate the viewing window, then choosing print from the file menu on your browser. In addition to all of this, there are links to relevant external data that will open in a new browser window. As data are added to the *RMB*, the function and structure might change. We will keep track of these changes and data uploads on the What's New page.

Looking Ahead

Eventually, as we have said, there will be a rock-magnetic database. The *Bestiary* is still small enough to browse through, but as it grows that method of data access will become increasingly cumbersome, and it will become essential to provide standard database functionality. Meanwhile, however, we will continue expanding and developing the *RMB*, primarily as a tool for qualitative interpretation or quantitative modeling of the mixed assemblages in natural samples.

One approach to quantitative modeling that may benefit substantially from the availability of the *Bestiary* data is an "unmixing" technique based on work of Thompson [1986] and recently elaborated by Carter-Stiglitz et al [2001]. Under the assumption that a measured data set (comprising, e.g., hysteresis loops at various temperatures) represents a weighted sum of the corresponding data for discrete sizes of particular minerals, it is possible to determine the proportions of these components in the mixture. Data sets from the *RMB* can be used as basis functions in a least-squares inversion, solving for the mass of each basis component in a natural sample.

Once we have finished measuring and uploading the samples that we have at our disposal, we will be interested in obtaining additional synthetic materials and well-characterized natural samples, and/or data for such samples. If you would like to contribute to the *Bestiary*, please contact us. We would also appreciate hearing your reactions to the structure and content of the *Bestiary*, and your suggestions for its evolution into a database.

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Néel, Louis

b. Nov 22, 1904, Lyon
d. Nov 17, 2000, Brive-Correze

No name is more synonymous with magnetism than that of Néel, because no individual has been more important to the field. We use “Néel temperature” to designate the transition (on cooling) from a paramagnetic to an antiferromagnetic state; “Néel theory” to describe the evolution of the net moment of assemblages of SD particles as a function of time and temperature; “Néel diagrams” to understand important magnetization processes; “Néel walls” and “Néel caps” to indicate particular micromagnetic structures. In the 1930’s Néel originated the concept of magnetic sublattices, the basis for the antiferromagnetism and ferrimagnetism of all important natural magnets. For this discovery he was awarded the 1970 Nobel Prize in physics (shared with Hannes Alfvén).

1970 Nobel Prize citation, Louis Néel: "for fundamental work and discoveries concerning antiferromagnetism and ferrimagnetism which have led to important applications in solid state physics"

For more information:

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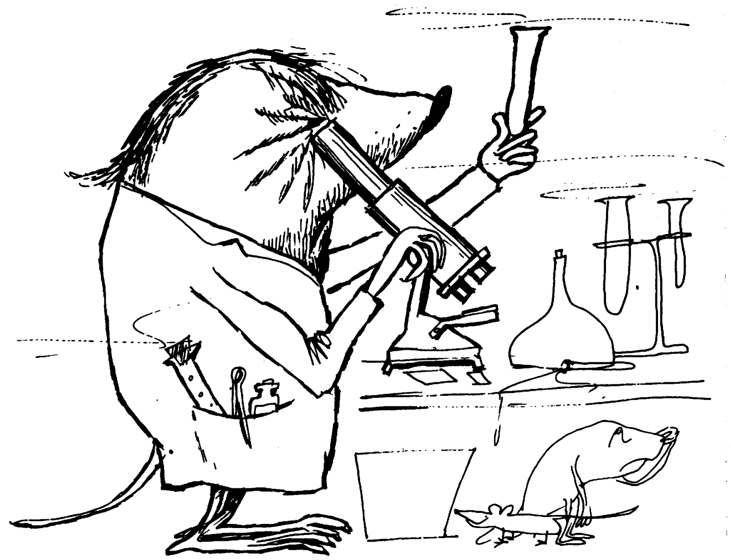
source: ***A Bestiary by Toulouse-Lautrec***, *The Art Institute of Chicago, 1954.*



Source: The Academic Bestiary, by Richard Armour, 1974, Morrow & Co., New York. (with minor editorial modifications)

The Scientist *(Res non posse creari de nilo)*[*]

There are two major types of scientist, the Pure Scientist and the Applied (and presumably Impure) Scientist. The Pure Scientist must not think any bad thoughts or have any naughty ideas, because these are made into Rules which the Applied Scientist has to carry out.[†]

Scientists are not all alike. For instance there is the Physicist. But for the Physicist there would have been no such inventions as the electric light, the short circuit and electrocution. The Chemist can change just about anything into something else. Because it has to handle so many things in the Lab, such as test tubes, flasks, beakers and Bunsen burners (used for burning Bunsens), and because it gets into just about everything, including trouble if it mixes the wrong chemicals and causes an explosion,[‡] *the Chemist is akin to an octopus.*

The Scientist may also be a Biologist, specializing[§] *in such things as cells, organisms, and sex. The first two it looks at through a microscope. While the Biologist is only interested in living things, the Geologist concentrates on rocks, which have been dead as long as anyone can remember. In fact the Geologist tells students exactly how many billion years old the Earth is, and the Students, though unconvinced, dutifully write this down. Nothing, they believe, could be that old, not even the Geology Professor.*

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[*]*Matter cannot be created from nothing. Discovery of this astonishing fact was a great breakthrough for the Scientist. It came about in answer to the question, “What is the matter?”*

[†]*It carries them out of Academe and leaves them with Industry and others to dispose of.*

[‡]*The only thing more dangerous, in Academe, is mixing metaphors.*

[§]*There is nothing special about Specialization. Only through Specialization can a Professor get to know so much about so little as eventually to achieve the Academians’s goal of knowing everything about nothing worth knowing anything about.*

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

The *IRM* staff consists of **Subir Banerjee**, Professor/Director; **Bruce Moskowitz**, Associate Professor/ Associate Director; **Jim Marvin**, Senior Scientist; **Mike Jackson**, Senior Scientist and Facility Manager, and **Peat Solheid**, Scientist.

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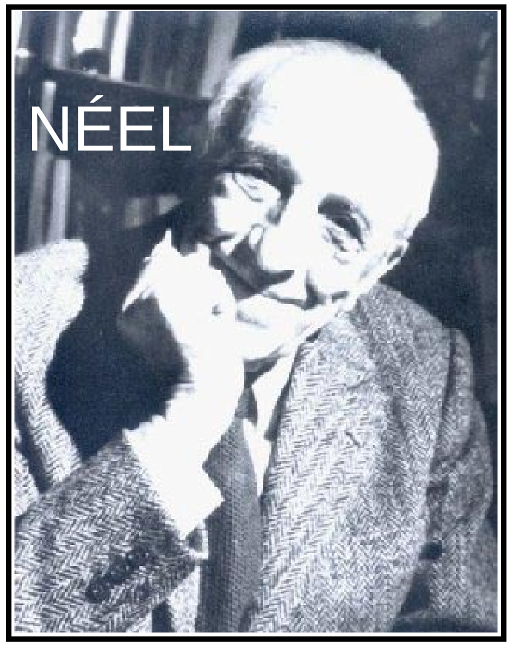

$$\tau(V, M_s, H_k, T) = \tau_0 \exp\left(\frac{VM_S(T)H_K(T)}{2kT}\right)$$

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