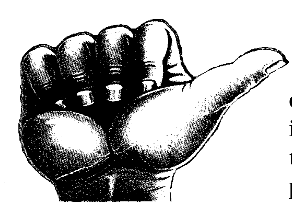
Inside…

The IRM Quarterly

WINTER 1996-97, VOL. 6, NO. 4 INSTITUTE FOR ROCK MAGNETISM

You will generally need between 50 and 200 mg of material…

Sample Preparation Specifications



Mike Jackson
IRM

The Return of the Hitchhiker's Guide to the IRM covers sample specifications for various sorts of magnetic measurements using IRM instruments.

There are, alas, always limitations on what you can measure. Limits are imposed by many constraining factors, not least of which are human physical and psychological endurance (anecdotes available on request). Here, however, we will humanely focus our attention on instrumental limits and the constraints they place on samples, primarily in terms of mass, volume, and/or magnetic moment. Armed with this knowledge, you can avoid sample-related problems and delays during your *IRM* visit, and get straight to the business of testing your mettle.

SI UNITS FOR STRAWS

The arrangement of choice for many measurements at or below room temperature is based on pharmaceutical "gel-cap" capsules and beverage straws (provoking no end of wisecracks from the folks down in the U of M storehouse). These materials are cheap, widely available, magnetically clean, reasonably "wieldy," and very close to the optimum size for several instruments. A #4 gel cap is (approximately) a cylinder of length 12 mm and diameter 5 mm, and thus it contains a volume a bit more than $2x10^{-7}$ m^3. Sediments, rock powders, or rock chips can be quickly and easily packed into gel caps for measurement on the LakeShore (low-field) and MPMS (high-field) susceptometers and on our two VSMs. When packed to a bulk density of 1500 kg/m^3, gel-cap specimens have a maximum mass of 200-300 mg; smaller samples are accommodated if necessary (see below) by packing partially full gel caps with "fiberfrax", a relatively nonmagnetic material. The drinking straws serve to mount the gel caps in the sample space of these instruments.

Additional constraints are imposed by the dynamic ranges of the instruments. The MPMS can routinely measure magnetic moments between about 10^{-10} and 10^{-3} Am^2 (10^{-7} and 1 emu); the upper limit corresponds to the room-temperature saturation moment of about 10 mg of magnetite. Samples with very high ferromagnetic concentration therefore generally have to be diluted or diminished, especially for measurement in applied fields (e.g., hysteresis). The MicroVSM range extends from 10^{-9} to 10^{-2} Am^2 (10^{-6} to 10 erg/Gauss), and high-side magnetic constraints are only important for magnetic extracts or pure magnetic mineral samples.

The LakeShore has no practical magnetic upper limit, with a range extending to 1 Am^2 for equivalent magnetic moment, or on the order of 10^5 SI volume-normalized susceptibility units ($\approx 10^4$ emu/G·cm^3) for a gel-cap specimen. The lower moment limit of the LakeShore corresponds to a volume susceptibility of about 10^{-6} SI.

Instrument sensitivity in each case sets a lower limit on sample magnetic content. However, well before the instrument noise level is reached, the signal from the sample holders becomes significant. An empty gelcap in a straw has a readily measurable diamagnetic moment susceptibility of the order 10^{-7} Am^2/T (10^{-13} m^3). Minor ferrimagnetic contamination typically contributes about 5 x 10^{-8} Am^2 to the saturation moment and 10^{-9} Am^2 to the saturation remanence. These values are equivalent to less than 1 μg of magnetite. For very weak samples additional steps are necessary to cancel the contribution of the cap/straw assemblage.

A final consideration when dealing with gelcaps is sample shape anisotropy. For strongly magnetic samples the demagnetizing factors due to the elongate shape have an effect on measured properties. For the standard mounting arrangement, MPMS and LakeShore measurements are made parallel to the gelcap long axis, but MicroVSM measurements are made in a perpendicular direction.

Gelcaps and straws (along with appropriate witticisms) will be provided on your arrival at *IRM*.

FISSION CHIPS

Small rock chips, obtained by splitting, cutting, or crushing larger samples, are optimal for MicroMag (AGFM) measurements. Samples are mounted directly on the piezo-electric probe, affixed by a bit of petroleum jelly or vacuum grease. The most stringent limitation for this instrument is sample mass, which should be no greater than 50 mg for proper operation of the high-

Sample Prep Specs
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Visiting Fellows' Reports

The *IRM* is in the grip of a classic Minnesota winter, and the last "interglacial" is only a dim memory. Xiaomin Fang investigated sedimentary magnetic records of the last interglacial, with detailed hysteresis and low-temperature remanence measurements on Chinese loess and paleosol samples. Bodo Katz was plagued by poltergeists in his MicroMag measurements of remagnetized carbonates, but persisted and ultimately prevailed. His work is leading to an improved understanding of the role of clay diagenesis in remagnetization.

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Remagnetization and Diagenesis of Clays

Although I brought samples for several projects to the IRM, my main objective was to resolve the magnetic characteristics of Upper Jurassic/ Lower Cretaceous hemipelagic limestones from the Vocontian Trough in SE-France. I am attempting to test for a possible connection between clay diagenesis and the origin of pervasive chemical remanent magnetizations. Previous studies have identified clay diagenetic trends with burial as well as with proximity to the Alps in the eastern part of the basin. Prior to my visit to the IRM I had found that a primary magnetization was only present in the westernmost part of the basin where little clay mineral diagenesis had occurred. In the central part of the basin the older units, which no longer contain any smectite, are characterized by a CRM with northerly declinations and moderate down inclinations. A fold test reveals that the CRM is pre-folding whereas the results of a conglomerate test and the lack of reversed polarities within the section indicate that the magnetization is secondary. The demagnetization behavior as well as IRM acquisition and thermal decay of the IRM suggest that the CRM resides in magnetite. The CRM is poorly defined or absent in younger units in the central area which still contain abundant smectite. In order to explain the observed differences between primary, weakly defined and prefolding CRM which parallel the continuous alteration of the smectite, I attempt to contrast results from hysteresis experiments, heating of low temperature SIRM and pARM spectra. I furthermore intend to test whether rock-magnetic characteristics commonly associated with remagnetizations (wasp-waisted hysteresis, high Hcr/Hc ratios, characteristic ARM/SIRM ratios and others) can be confirmed by this study. Ultimately, I will try to characterize the process (or processes) which is (are) responsible for the creation of the CRM (e.g., alteration, precipitation, dissolution).

Despite all these ambitious objectives, I had to realize that the rock-magnetic reality is somewhat harsh to paleomagnetists with extremely weak samples. One of the more severe limitations arose from the fact that hysteresis-data acquired on the MicroMag frequently exhibited viscous behavior during measurement of Hcr. This complication was partly overcome by using large averaging times or by utilizing 1-inch cores on the VSM. Preliminary evaluation of the hysteresis data suggests possible systematic variations with the 3 types of magnetization encountered. However, the loops do not exhibit any wasp-waistedness or other characteristics commonly associated with remagnetizations. Thermal demagnetization of a low temperature SIRM basically confirms the presence of magnetite (Verwey-transition, remanence at 300K) and abundance of SP-grains. I will evaluate any systematic variation in the low temperature demagnetization pattern as well as the pARM spectra and combine the results from Minnesota with previously acquired information on magnetic susceptibility, NRM, saturation remanence, maximum blocking temperature and so on. I am particularly curious about those parameters which are being used by my friends at the IRM to indicate changes in relative abundance of SP, SD and MD (ferrimagnetic susceptibility/saturation magnetization, ARM/SIRM, and Hcr/Hc, respectively). I would like to toast the *IRM* crew with a little "Friday afternoon tea".

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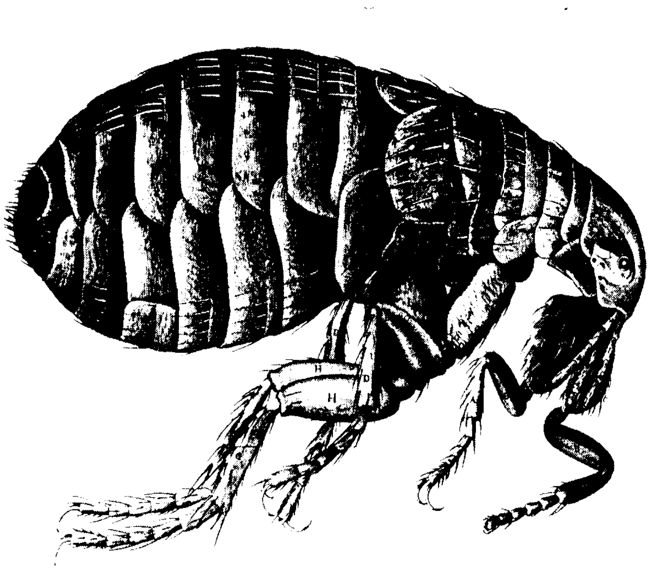
Rock magnetic studies of a high resolution loess-paleosol sequence at Jiuzhoutai of Lanzhou, western China

My objectives at the *IRM* were to obtain more conclusive evidence that the variable magnetic susceptibility signatures we have previously obtained for the last interglacial from the Jiuzhoutai section are pedogenic in origin and reflect actual climatic changes. Quantification of ultrafine magnetic mineral variations in soil horizons and loess sections is the key to my work, since these ultrafine magnetic grains have been proposed to be dominantly produced by in-situ pedogenic processes and to contribute largely to the enhancement of magnetic susceptibility. Two kinds of individual techniques and / or approaches have been employed. One is to use the method of thermal demagnetization of low-temperature saturation remanence to identify magnetic minerals and the particle size distribution of superparamagnetic (SP) fractions. The other is to use hysteresis properties of loess-paleosol sequence to achieve the same purposes. The ratios χ_f/J_S, ARM/J_{RS}, and H_{CR}/H_C serve as proxies for SP, SD and MD grains, respectively, since the normalization of the ferrimagnetic susceptibility (χ_f) and anhysteretic remanence magnetization (ARM) by saturation

VF Reports *continued on page 7…*



Robert Hooke's engraving of a flea, from Micrographia, *1665. In this work Hooke gave the first description of the cellular structure of plant material (coining the term "cell"), and also described petrified wood and other fossils.*

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 3700 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

Anisotropy

Aubourg, C., H. Bakhtari, and P. Rochette
Anisotropy of magnetic susceptibility of magnetically oriented rock powders, *Geophys. Res. Lett.*, *23* (15), 1977-1980, 1996.
AMS measurements on magnetically-oriented rock powders provide estimates of the anisotropy of the constituent magnetic particles. Powdered basalts containing PSD titanomagnetites have prolate anisotropy with $L \approx 1.16$. In metasediment samples, the magnetic foliation is constant ($F \approx 1.3$) and is controlled by Fe-bearing phyllosilicates; the magnetic lineation is variable and dependent on the ferromagnetic mineralogy ($L \approx 2$ in pyrrhotite-bearing samples and $L \leq 1.1$ in magnetite-bearing samples).

Lehman, B., *et al.*
Magnetic mineralogy changes in the Pleistocene marine sequence of Montalto di Castro (central Italy) and influences on the magnetic anisotropy, *Geophys. J. Int.*, *127* (2), 529-541, 1996.
Magnetic mineralogy and sedimentary facies show strong variations over a 40-m interval. A new best-fit method allows estimation of the relative contributions of various minerals to the isothermal remanence. The variable magnetic mineralogy produces strong changes in AMS, including an interval of unexpectedly weak anisotropy, interpreted as arising from interference between an inverse fabric due to goethite and a normal fabric.

Stephenson, A., and D. K. Potter
Towards a quantitative description of field-impressed anisotropy of susceptibility, *Geophys. J. Int.*, *126* (2), 505-512, 1996.
A simplified model of domain rearrangement in multidomain particles following the application of alternating (AF) or direct (DC) field is used to quantify the dependence of AMS on magnetic history. Changes in mean susceptibility are accommodated in the model through interactions between domains. Four model parameters are required to describe the AF-dependence of AMS; for the DC field-dependence two of these parameters are allowed to change systematically with field strength. Good fits are obtained for new experimental results for samples containing sized magnetite particles from 0.7 to 58 µm.

Chemical Alteration and Remagnetization

Brothers, L. A., M. H. Engel, and R. D. Elmore
The late diagenetic conversion of pyrite to magnetite by organically complexed ferric iron, *Chem. Geol.*, *130*, 1-15, 1996.
Late diagenetic replacement of pyrite by magnetite was simulated in laboratory experiments involving organically complexed ferric iron. Aqueous solutions of ferric-ligand complexes and pyrite were heated at 60°C for 60 days at low partial pressures of oxygen, with or without bentonite. For pH>8.5 a ferrous hydroxide precipitate was obtained, which on heating at 90°C produced magnetite. Ferric complexes of oxalate, salicylate, and acetylacetonate all resulted in pyrite dissolution and magnetite formation. Bentonite acted to adsorb dissolved species and also underwent direct dissolution. A continuing supply of molecular oxygen (more available in near-surface settings) would result in formation of hematite, whereas at greater depths (or tighter porosity) the redox gradation halts at magnetite.

Katz, B., *et al.*
Paleomagnetism of the Jurassic Asphaltkalk deposits, Holzen, northern Germany, *Geophys. J. Int.*, *127* (2), 305-310, 1996.
A stable natural remanence is found in bitumen-impregnated Asphaltkalk deposits, but not in other limestones of the same age, suggesting a connection between the hydrocarbons and the magnetization. The stable remanence fails the fold test and is thus secondary, and the corresponding pole position indicates a late Cretaceous-early Tertiary age. AF and thermal demagnetization of the NRM and of strong-field IRM, as well as hysteresis properties, are consistent with magnetite as the principal remanence carrier.

Magnetic Mineral Properties

Dekkers, M. J., and M. A. A. Schoonen
Magnetic properties of hydrothermally synthesized greigite (Fe_3S_4). I. Rock magnetic parameters at room temperature, *Geophys. J. Int.*, *126* (2), 360-368, 1996.
Scanning electron microscopy indicates a grain-size range up to 400 nm for hydrothermally synthesized greigite. Specific room-temperature saturation magnetization J_S ranges from 3-29 Am²/kg, indicating variable purity, and J_{RS}/J_S ratios of 0.3 to 0.4 are consistent with the fine sizes observed with SEM. Coercivities (B_C 13-43 mT; B_{CR} 37-73 mT) are the highest obtained to date for synthetic greigite and are comparable to natural greigite values. Greigite hysteresis parameters overlap those of magnetite to a large degree, but a diagnostic property of greigite is its high J_{RS}/χ_{in} ratio; the range for the hydrothermal greigite is 40-75 kA/m.

Hodych, J. P.
Inferring domain state from magnetic hysteresis in high coercivity dolerites bearing magnetite with ilmenite lamellae, *Earth Planet. Sci. Lett.*, *142*, 523-533, 1996.
Precambrian dolerite dikes carry a primary remanence in grains of magnetite subdivided by ilmenite lamellae. $H_C \propto J_{RS}/J_S$, with a

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proportionality constant appropriate for PSD magnetite with one or two domain walls per particle. A cooling cycle to 77 K causes large demagnetization of J_{RS} in most samples. Most samples also show a large decrease in H_C on cooling to 140 K, suggesting magnetostrictive control of coercivity. Only the three dolerites with H_C>30 kA/m show little change in H_C on cooling, suggesting SD particles with shape anisotropy.

Kozlowski, A., *et al*.
Heat capacity of $Fe_{3-a}M_aO_4$ (M=Zn, Ti, 0≤a≤0.04), *Phys. Rev. B*, *54* (17), 12,093-12,098, 1996.
Systematic studies of the specific-heat anomaly and of entropy changes at the Verwey transition in the $Fe_{3-x}Ti_xO_4$ and $Fe_{3-x}Zn_yO_4$ series show only one well-defined phase transition. In the composition range 0≤x,y≤0.012 the transition is of first order, with extremely sharp spikes in specific heat at T_V. For 0.012<x,y≤0.04 the transition is of second or higher order, with broadened specific heat anomalies near T_V. Increases in x result in a decrease in the transition temperature and in the entropy of the transition.

Mitsek, A. I.
Electron structure and magnetic properties of magnetite, *Ukrainian J. Phys.*, *41*, 91-98, 1996.
The many electron operator spinors (MEOS) method is used for calculation of electron structure and of chemical bond fluctuations in ferrites. Near the “electronic ordering” point $T \approx T_V$ expansion of the donor level changes the activation energy of charge carriers, resistivity, and Hall constant. The covalent 3d-holes polarization and defreezing of orbital moment explain nonintegral atomic magnetic moment and the T-dependence of magnetic anisotropy constants in the rhombic and cubic phases.

Murad, E.
Magnetic properties of microcrystalline iron (III) oxides and related materials as reflected in their Mössbauer spectra, *Phys. Chem. Mineral.*, *23*, 248-262, 1996.
The magnetic properties of fine-particle iron oxides deviate from those of the bulk material, leading to radical changes in their Mössbauer spectra. Diverse models to account for such changes are discussed in this paper, including superparamagnetism, collective magnetic excitations, anomalous recoil-free fractions, superferromagnetism, spin canting and speromagnetism, reduced hyperfine field supertransfer, and Néel temperature reductions and distributions.

Torii, M., *et al.*
Magnetic discrimination of pyrrhotite- and greigite-bearing sediment samples, *Geophys. Res. Lett.*, *23* (14), 1813-1816, 1996.
Low-temperature rock-magnetic measurements successfully distinguish pyrrhotite and greigite in shallow marine sediments from southwestern Taiwan. To check for mineral alteration and estimate the true unblocking temperature (T_B) spectra, saturation IRMs were imparted at each temperature step during thermal demagnetization. Pyrrhotite-bearing samples produced unambiguous T_B spectra, but greigite-bearing samples underwent considerable alteration and decrease in magnetization. Such alteration is a practical and important clue for identifying greigite.

Microscopy

Foss, S., *et al.*
Localized micromagnetic perturbation of domain walls in magnetite using a magnetic force microscope, *Appl. Phys. Lett.*, *69* (22), 3426-3428, 1996.
Opposite polarity MFM profiles of domain walls in magnetite are obtained when the MFM tip is magnetized in opposite directions, perpendicular to the sample surface. The field due to the tip locally magnetizes the domain walls, and the difference between opposite polarity profiles provides a qualitative measure of the resulting reversible changes in domain wall structure.

Ocean Crust & Sediments

Johnson, H. P., D. Van Patten, and W. W. Sager
Age dependent variation in the magnetization of seamounts, *J. Geophys. Res. B*, *101* (B6), 13,701-13,714, 1996.
As with normal upper oceanic crust, the external layers of Pacific seamounts initially have a high magnetization that decays rapidly, by a factor of 5 in less than 0.5 Myr, and low-temperature oxidation of titanomagnetite is assumed to be responsible for this decay. Cretaceous-age seamounts have average magnetizations twice as high as Tertiary seamounts, similar to the ratio for seafloor basalts. The elevated Cretaceous magnetizations may be due to high paleointensity, large-scale geochemical variations, or systematic acquisition of a secondary magnetization during the Cretaceous Normal Superchron.

Schwartz, M., *et al.*
Early sediment diagenesis on the Blake/Bahama outer ridge (N. Atlantic Ocean) and its effects on sediment magnetism, *J. Geophys. Res. B*, in press, 1996.
Magnetic and geochemical studies have identified two current redox boundaries (Mn^{+4}/Mn^{+2} and Fe^{+3}/Fe^{+2}) in surficial carbonate-rich sediments over much of the Blake/Bahama outer ridge. Sediment magnetic intensities associated with these redox boundaries are higher than in deeper, carbonate-poor layers, due to two factors: magnetic mineral authigenesis and the presence of abundant bacterial magnetosomes in the shallower sediments. The NRM is strongly correlated with the clastic fraction and relatively unaffected by diagenesis and by the presence/absence of bacterial magnetite.

Tivey, M. A.
Vertical magnetic structure of ocean crust determined from near-bottom magnetic field measurements, *J. Geophys. Res. B*, *101* (B9), 20,275-20,296, 1996.
The first attempt to measure the vertical magnetic structure of oceanic crust exposed at a sharp scarp face using near-bottom magnetic measurements is reported along with the theoretical basis for data reduction and analysis. A large amplitude anomaly is consistently found at the intrusive / extrusive transition, indicating that the lavas are more strongly magnetized; these constitute the main magnetic source for magnetic anomalies in oceanic crust less than 2 m.y. in age.

Paleoclimate

Leventer, A., *et al.*
Productivity cycles of 200-300 years in the Antarctic Peninsula region: Understanding linkages among the sun, atmosphere, oceans, sea ice, and biota, *Geol. Soc. Am. Bull.*, *108* (12), 1626-1644, 1996.
A new multiproxy record (magnetic susceptibility and granulometry, bed thickness, particle size, organic carbon, bulk density, and microfossil assemblages) for the past 3700 yr shows significant short-term cycles (≈200 yr) and longer-term variations (≈2500 yr) that are most likely related to global climate fluctuations. Susceptibility variations are controlled primarily by dilution of detrital magnetic minerals with biogenic silica. Low-susceptibility layers also contain relatively high organic carbon, and magnetite dissolution may therefore enhance the susceptibility variation. The 200-yr cyclicity is also noted in other paleoclimate records around the world, suggesting a global forcing mechanism, possibly solar variability.

Rosenbaum, J. G., et al.
Record of middle Pleistocene climate change from Buck Lake, Cascade Range, southern Oregon - Evidence from sediment magnetism, trace-element geochemistry, and pollen, *Geol. Soc. Am. Bull.*, *108* (10), 1328-1341, 1996.
Four susceptibility zones were identified in 24 m of lacustrine sediments spanning most of the Brunhes chron. Two high-susceptibility zones contain abundant Fe oxides and pollen indicative of cold, dry environments; the lower-susceptibility layers contain warm-

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climate pollen. Pollen changes are preceded by abrupt changes in magnetic properties, indicating that land-surface processes responded more quickly to climate change than did vegetation changes. Magnetic properties have been affected by dissolution of Fe oxides, by variation in heavy mineral content, and by variation in abundance of volcanic rock fragments, the latter two factors being controlled primarily by changes in peak runoff.

Yamazaki, T., and N. Ioka
Environmental rock magnetism of pelagic clay: implications for Asian eolian input to the North Pacific since the Pliocene, *Paleoceanogr.*, in press, 1996.
Magnetic susceptibility and S-ratio in 5 pelagic clay cores have decreased since about 2.5 Ma, the time of onset of the Northern Hemisphere glaciation and Chinese loess deposition. Mössbauer and TEM observations suggest the presence of biogenic magnetite and detrital hematite and magnetite. The geographic distribution of S-ratios from box-core surface sediments shows a low in the central North Pacific, suggesting that S-ratio can be used as a proxy of Asian eolian dust content. Subtle 400-kyr S-ratio fluctuations are superimposed on the decreasing trend since 2.5 Ma.

Paleointensity

Constable, C., and L. Tauxe
Towards absolute calibration of sedimentary paleointensity records, *Earth Planet. Sci. Lett.*, *143*, 269-274, 1996.
Twelve pelagic sediment records of paleointensity spanning the Matuyama-Brunhes boundary were normalized to make the minimum intensity during the reversal correspond to an assumed geographically-invariant non-axial-dipole field intensity of 7.5 µT. The cores are distributed in latitude from 0° to 50°, and the latitudinal dependence of the time-averaged calibrated paleointensites is consistent with that expected for a geocentric axial dipole.

Guyodo, Y., and J.-P. Valet
Relative variations in geomagnetic intensity from sedimentary records: the past 200,000 years, *Earth Planet. Sci. Lett.*, *143*, 23-36, 1996.
Eighteen published marine-sediment paleointensity records have been compiled, adjusted to a common time scale, and stacked together to obtain a synthetic paleointensity curve and to estimate its statistical significance. Paleointensity features of 10-kyr duration appear to be resolvable between 120 and 200 ka. Comparison with the Lac du Bouchet and Labrador Sea records indicate an offset of 7 kyr between the ^{14}C and $\partial^{18}O$ ages.

Laj, C., A. Mazaud, and J.-C. Duplessy
Geomagnetic intensity and ^{14}C abundance in the atmosphere and ocean during the past 50 kyr, *Geophys. Res. Lett.*, *23* (16), 2045-2048, 1996.
A new sedimentary paleointensity record has been combined with published volcanic data to examine the affects of geomagnetic field variations on ^{14}C production in the past. The results indicate that changes in field intensity account for at least 80% of the $\partial^{14}C$ shift documented by published U-Th data. Model simulations show that variation due to changes in oceanic circulation are within the uncertainty of the geomagnetic correction. Radiocarbon ages have to be shifted by 2 to 3.5 kyr towards older ages during the 20-40 ka interval.

Schneider, D. A., and G. A. Mello
A high-resolution marine sedimentary record of geomagnetic intensity during the Brunhes Chron, *Earth Planet. Sci. Lett.*, *144*, 297-314, 1996.
Four cores in the Sulu Sea with sedimentation rates of about 10 cm/ky provide a high-resolution susceptibility-normalized paleointensity record for the Brunhes, supported by detailed studies on discrete samples covering the last 130 ky. A number of short-duration paleointensity decreases appear to be useful stratigraphic markers. The average geomagnetic dipole moment during the Brunhes may have been considerably lower than the present value.

Physics

Sedlar, M., I. Paulicka, and M. Sayer
Optical fiber magnetic field sensors with ceramic magnetostrictive jackets, *Appl. Optics*, *35* (27), 5340-5344, 1996.
Optical fibers coated by magnetostrictive ceramic films, including magnetite, gamma-Fe_2O_3, nickel ferrite, and Co-doped Ni ferrite (NCF2), exhibit excellent linearity and good sensitivity. Best performance was achieved with a 2-µm thick NCF2 jacket, with a minimum detectable field of $3.2 * 10^{-3}$ A/m. It is proposed that magnetic fields as low as $2.6 * 10^{-7}$ A/m may be measurable with a 10-µm thick NCF2 jacket.

Remanence

Borradaile, G. J.
Experimental stress remagnetization of magnetite, *Tectonophys.*, *261* (4), 229-248, 1996.
A secondary component of remanence was acquired during experimental deformation by synthetic specimens containing chemically-precipitated 3-µm magnetite particles dispersed in a matrix of calcite and Portland cement. Initial ARMs with various orientations were consistently overprinted with low-coercivity (<15 mT) and sometimes high-coercivity (>60 mT) components parallel to the 30-µT field in the deformation vessel. The remagnetization is attributed to locking in of domain wall displacements by deformation microstructures. In nature, differential stresses exceeding 25 MPa could partially remagnetize rocks containing magnetite with low dislocation densities.

Chauvin, A., H. Perroud, and M. L. Bazhenkov
Anomalous low paleomagnetic inclinations from Oligocene-Lower Miocene red beds of the south-west Tien Shan, central Asia, *Geophys. J. Int.*, *126* (2), 303-313, 1996.
The characteristic component of the NRM in samples from 19 sites resides in hematite and passes both the fold and reversal tests. The mean declination (3°) indicates no tectonic rotation with respect to Eurasia, in accord with geological data. However, the mean inclination (30°) is about 30° shallower than expected. The authors argue that large-scale northward transport of the area can be ruled out, and that the shallow inclinations are due to inaccurate recording of the field orientation.

Shcherbakova, V. V., *et al.*
On the effect of low-temperature demagnetization on TRMs and pTRMs, *Geophys. J. Int.*, *127* (2), 379-386, 1996.
Liquid nitrogen LTD experiments with MD and PSD samples carrying TRM and pTRM demonstrate good agreement between commonly used indicators of domain structure (such as I_{RS}/I_S and H_{CR}/H_C) and more sophisticated ones, such as LTD response and the thermomagnetic criterion based on Thellier's law of pTRM independence. There is no observable tendency for MD or PSD samples to display SD-like pTRM(T) curves after LTD.

Reversals

Layer, P. W., A. Kröner, and M. McWilliams
An Archean geomagnetic reversal in the Kaap Valley pluton, South Africa, *Science*, *273*, 943-946, 1996.
Antipodal paleomagnetic directions measured for the central and marginal parts of this tonalite intrusion record a geomagnetic reversal that occurred as the pluton cooled. The age of the reversal is constrained by an $^{40}Ar/^{39}Ar$ plateau age from hornblende at 3214±4 Ma, making it the oldest known reversal. This suggests that the Earth has had a reversing, perhaps dipolar, magnetic field for at least 3.2 billion years.

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sensitivity glass probe (100 mg for the plastic probes). Size is also limited by the 5-mm pole gap. The magnetic moment range reaches 5 mAm^2 (5 emu), sufficient for even pure magnetite specimens within the 50-mg mass limit. The moment sensitivity of the AGFM is comparable to that of the MPMS.

Powdered samples and loose sediments can be prepared and measured on the MicroMag, by wrapping them in thin foils or plastic films, or by making "sandwiches" with filter paper and tape and cutting with a paper punch. In practice, however, it is often more convenient to pack such materials in gel caps and use the MicroVSM to measure them. The *IRM*'s MicroMag is configured for room-temperature measurements only.

Cubes and Cylinders

For measurement of natural or various artificial remanences, and for anisotropy measurements, you will probably be working with cylindrical rock cores or sediments packed in plastic cubes, and using the 2-G superconducting rock magnetometer (SRM), the Kappabridge, or perhaps even the Roly-Poly (Jim Marvin's robotic AMS contrivance). A variety of standard specimen shapes/sizes are easily accommodated by these instruments, and the sample constraints are primarily magnetic.

The upper moment limit on the SRM, following its recent upgrade, is about 250 μAm^2 (0.25 emu, or $\approx 2.5 \times 10^{19}$ Bohr magnetons), and natural remanence is easily measurable for specimens (≤ 10 cm^3) of all but the most strongly magnetic natural materials. Anhysteretic remanence and experimental thermoremanence also present few problems, but strong-field isothermal remanence often exceeds the limit, requiring subsampling or measurement on our spinner magnetometer. For this reason, IRM acquisition experiments are generally performed on one of our VSMs rather than the SRM.

The Kappabridge is practically limitless in handling specimens for room-temperature anisotropy measurements (see below for high-T specifications), with a moment-equivalent sensitivity of about 10^{-10} Am^2 ($\approx 5 \times 10^{-8}$ SI volume units for a 10-cm^3 sample) and 6 1/2 decades of dynamic range. The Roly Poly has no known upper limit; its sensitivity is 10^{-6} SI (further unit conversions, especially those involving horsepower or hogsheads, are left to the reader).

Room-temperature hysteresis measurements can be made on rock cylinders and sediment cubes using our original VSM. Size is constrained by the gap between the pickup coils, approximately 20 mm. Strongly magnetic samples are no problem with an upper moment limit of 30 mAm^2. Although the moment sensitivity of 2×10^{-8} Am^2 is an order of magnitude less than the MicroVSM, larger sample volumes make this instrument equally suitable for room-temperature measurement of weak samples. Low-temperature (down to 77 K) measurements can be made with the senior VSM using a gel cap and straw arrangement, on samples that are sufficiently strong.

Anisotropy measurements can be made on the MicroVSM, using 1-cm^3 cubes (rock specimens cut to size or sediments in plastic boxes). This requires cranking out the pole pieces to produce a sufficient sample gap, which decreases both the moment sensitivity and the peak field that can be applied. Computer-controlled rotation of the vibration head enables determination of hysteresis properties and high-field susceptibility as functions of orientation. For samples with very weak anisotropy (say, less than 2%), a host of complicating factors become important; consult an *IRM* staff member before attempting such measurements.

Mössbauer Powders

Mössbauer spectroscopy requires samples with an iron content within an optimal range (with too little Fe there is insufficient absorption to generate a spectrum, and with excessive Fe there is too much absorption). The sample holder is a 1-cm-diameter disk, upon which the sample should form a layer about 50 μm in thickness (approximate volume of 4×10^{-9} m^3), containing roughly 15 mg (within a factor of ≈ 2) of Fe (≈ 20 mg of oxide). For almost all natural materials, this requires extraction and perhaps crushing of the magnetic fraction.

Approaching a kiloKelvin

High-temperature measurements are made on the KappaBridge and on the MicroVSM.

KappaBridge samples rest in a glass test tube inside the furnace. The tube inner diameter is 6 mm, and best accuracy is attained when it is filled to no more than 15-20 mm ($V \approx 5 \times 10^{-7}$ m^3). Rock chips, powders, sediment, etc are suitable; however, sediments with high water and/or organic content should probably be treated to remove some of these substances.

The Kappa's sensitivity is critical in high-temperature measurements for a couple of reasons. Samples are smaller than the nominal room-T standard volume by a factor of about 20, so the volume-normalized sensitivity is reduced accordingly. In addition the furnace assembly, though weakly (dia-)magnetic, contributes significantly to the measured values by virtue of its great (relative to the sample) mass. Nevertheless, most natural materials can still be reliably measured without extraction.

MicroVSM high-temperature measurements are most easily made on rock chips or similar solid material, although granular materials and powders can be measured as well. The chief constraint is volume. Samples should fit easily into the 6-mm inner diameter of the furnace, either mounted on the end of a cylindrical ceramic holder, or on a "semicylinder" side-mount holder (the latter holds them more securely, but approximately halves the allowable volume). The ideal size is thus about 2.5 x 5 x 5 mm ($\approx 6 \times 10^{-8}$ m^3, or a mass of roughly 150 mg). Sample mounts and high-temperature cement will be made available during your visit.

Unstrained Domains Stay Mainly in the Plane

For domain imaging by MOKE or MFM, extensive surface polishing is essential to remove topography and surface stresses that affect domain configurations. Preparation is similar to that for microprobe analysis: polishing with diamond slurries down to 0.5 μm, followed by amorphous silica; equipment for this is available at *IRM*. Note that covered thin sections are not usable. You should contact us in advance if you are planning to use either of these instruments.

When in Doubt

The constraints described here are somewhat conservative, *i.e.*, there are often ways to bend or stretch the limits slightly. If you have specimens that you'd like to measure, and are uncertain about feasibility, check with *IRM* staff.

■

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magnetization (J_S) and saturation isothermal remanence (J_{RS}) respectively remove the effects of varying concentration of magnetic minerals, and thereby more reliably reflect the grain size distribution and mineralogy of the magnetic carriers.

I started by preparing 130 samples in *IRM*-standard gel caps and drinking straws. These samples covered the intervals from the lower part of paleosol S1-b, through paleosol S1-c, and into loess L2-3 (roughly equivalent to substages 5c - 5e). The Princeton MicroVSM was used for hysteresis measurements. Simultaneously, 80 samples were analyzed on the Quantum Design MPMS by measuring thermal demagnetization of low-temperature saturation remanence. A few samples of typical soils and loess were subjected to frequency-dependent susceptibility measurements at five frequencies on the Lakeshore susceptometer and high-temperature magnetic susceptibility measurements on the KappaBridge.

The results have demonstrated that paleosols and loess have a very similar magnetic mineral composition, characterized dominantly by magnetite and maghemite, with minor hematite. This allows direct use of χ_f/J_S as an estimate of SP grains. The SP fractions indicated by χ_f/J_S are in excellent agreement with those directly measured with the MPMS. Both show that the relative content of SP grains increase gradually with depth in the paleosol Ah horizon, and decrease very rapidly in the underlying Bw horizon, indicating a pedogenic origin of these ultrafine grains. Furthermore, the SP concentration within paleosol S1-c undergoes large variations, characterized by a small peak at the base and two large peaks above separated by a minimum of less than one third of the paleosol peak and averaged loess values. Together with our previously-obtained magnetic susceptibility signatures at Jiuzhoutai, this indicates that the Asian summer monsoon during the last interglacial maximum (substage 5e) was unstable, adding strong evidence to the debate on Eemian climatic instability. Another interesting result is that both H_{CR} and H_C show similar patterns to that of relative SP content, suggesting that coercivity can also be regarded as an indicator of pedogenesis and climatic change in loess-paleosol sequences. H_{CR}/H_C shows a roughly inverse relationship with the variation of SP grains, indicating MD grains are generally high in loess and low in paleosols, in broad agreement with wind strength variation between glacial (loess) and interglacial (paleosol). However, high values of H_{CR}/H_C in some parts of the paleosol horizons are also evident, suggesting other rock magnetic controls on H_{CR}/H_C, and thus a more cautious use of this ratio as a proxy of MD grains should be kept in mind.

Conference Report: 5th Biennial Castle Meeting

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Over eighty paleomagnetists from twenty-four countries gathered in August to discuss New Trends in Paleomagnetism at the fifth Biennial Castle meeting, sponsored by the Academy of Science of the Czech Republic and the Slovak Academy of Sciences. This year's meeting was held at Topolcianky, an 18th-century chateau used in the 20th century as the summer home of the president of the Czechoslovak Republic. Papers and posters presented at the meeting covered a wide range of topics including paleopole positions, anisotropy of magnetic susceptibility, archaeomagnetism, magnetostratigraphy and environmental magnetism. The informal atmosphere of the conference provided an excellent opportunity for scientists from Western Europe, North and South America and Japan to share ideas and develop friendships with their colleagues from Eastern Europe. Scientific and social interactions were facilitated by the fine hospitality provide by the conference hosts from the Geophysical Institutes in Bratislava and Prague. Activities included an evening of Slovak folk music, a concert of classical music played by a noted Slovak violinist, a half-day field trip to an historic mining town, and festive opening and closing dinners. Accompanying persons were kept busy with visits to several interesting sites in western and central Slovakia. After the meeting, most attendees took part in a two-day excursion to the High Tatra mountains of eastern Slovakia. ■

Ørsted, Hans Christian

Aug. 14, 1777-Mar. 9, 1851

To Ørsted belongs one of the most important discoveries in the history of science: electromagnetism was first clearly demonstrated in a lecture he gave in the spring of 1820, with the deflection of a compass needle resulting from flow of current in a wire. Ørsted's studies ranged widely, including acoustic oscillation (he is shown here holding a square plate with a so-called Chladni pattern) and metallurgy (he is credited with the first extraction of aluminum from clay in 1825). The International Electrotechnical Commission in 1930 designated the (cgs) unit of magnetic field the Ørsted [1 Oersted = $10^7 / (4\pi)$ A/m].

Equipment Upgrades

Two pieces of instrumentation at the *IRM* are currently being treated to upgrades, and a third is slated for major improvements this summer.

Our venerable 2-G superconducting rock magnetometer (SRM), after ten years of continuous service, is receiving a new set of electronics that will extend its dynamic range. More rapid flux counting should enable measurement of magnetic moments up to 10^{-3} Am^2 (1 emu), at least an order of magnitude greater than previously possible. Isothermal or other remanences that for many samples had to measured on a spinner magnetometer will now be measurable on the SRM. An additional benefit of the upgrade is that the new electronics generate less heat, and are expected to have a longer life expectancy as a result. Still to come for the SRM is a new cryopump.

A new ^{57}Co source for the Mössbauer spectrometer has arrived, and a new detector is en route. The old source has been in use for about four years, or roughly six half-lives, and its initial 50 milliCurie gamma-ray output has consequently diminished to less than 1 mCi. The time required to measure a Mössbauer spectrum has of course increased accordingly, and the new source will thus allow measurements to be made 50 times faster: in a matter of hours rather than days. The sensitive new argon/methane gas proportional gamma counter is expected to further reduce measurement time, perhaps by another factor of three.

Next in line for an upgrade (planned for early summer) is the Quantum Design MPMS. Improvements to the temperature control system will enable significantly faster temperature sweeps with reduced over- and undershoots, especially when warming or cooling through the 4.2 K boiling point of ^{4}He. A "reciprocating-sample" measurement system, using phase-locked SQUID sensing with oscillating samples, will improve sensitivity by about an order of magnitude to 10^{-11} Am^2 (10^{-8} emu).

IRM News

Congratulations to Sanghamitra Sahu who culminated her distinguished term as an IRM graduate student by defending her PhD dissertation January 27. Her thesis, entitled "An Experimental Study of the Effects of Stress on the Magnetic Properties of Magnetite," involved detailed magnetic studies of synthetic polycrystalline glass-ceramic PSD magnetites, before and after application of uniaxial stresses between 30 and 120 MPa, with the goal of improving our understanding of remanence mechanisms.

High- and low-temperature hysteresis measurements, low-temperature cycling of various types of remanence, and MFM (magnetic force microscope) domain imaging shed light on the mechanisms of remanence and coercivity in these samples. The temperature-dependent hysteresis measurements showed $H_C \propto \lambda$ and $H_C \propto J_S^{2.2}$, indicating magnetostrictive control of coercivity from 20 K to 873 K. Increasing applied loads resulted in elevated H_C and diminished χ_0, due to increased dislocation density. Low-temperature demagnetization (LTD) of ARM and SIRM preferentially removed a fraction with low AF stability, and the "memory" fraction that survives LTD increased with increasing applied loads. These results indicate that magnetic memory, ARM and SIRM are at least partially controlled by internal stress.

Following a brief respite, Mitra is now moving on to begin a new career at Seagate Technology, and we wish her all the best.

Collectors Series #4. Clip and save! Collect them all!

Painting by D. Hvidt, Copenhagen, 1822; reproduced from Oersted and the Discovery of Electromagnetism, *by B. Dibner, ©1961 Burndy Library, Norwalk, CT.*

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; and Mike Jackson, Senior Scientist/Facilities Manager.

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