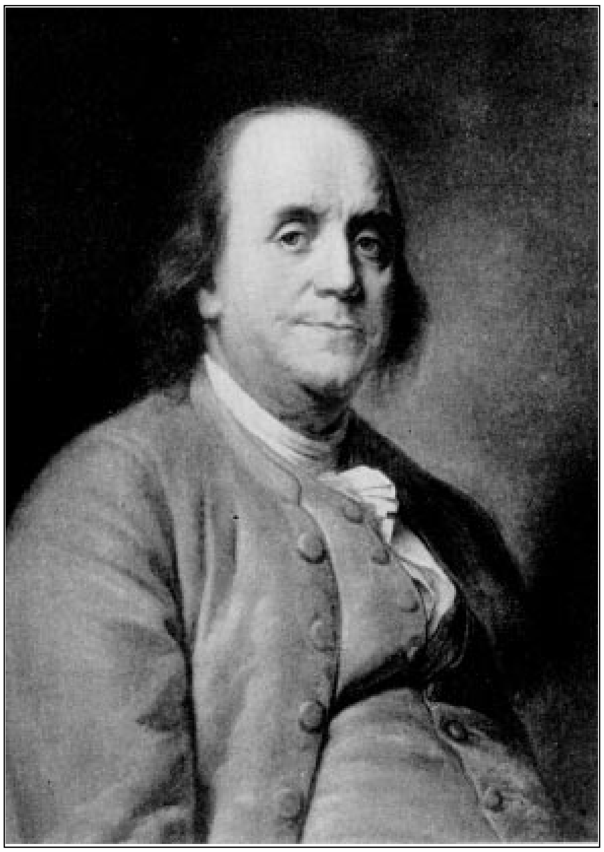
# The IRM Quarterly

FALL 1996, VOL. 6, NO. 3 INSTITUTE FOR ROCK MAGNETISM



*Pilfered from* Benjamin Franklin: The First Civilized American (Profusely Illustrated), *by Phillips Russell, © Bretano's, New York, MCMXXVI*

*Portrait of Benjamin Franklin, by J. S. Duplessis*

# Poor Richard's *Theory of the Earth*

Benjamin Franklin,*esq.*
Mike Jackson
*IRM*

*"…might not, in ancient times, the near passing of some large comet of greater magnetic power than this globe of ours have been a means of changing its poles, and thereby wracking and deranging its surface…?"*

Founding father, statesman, publisher (*Poor Richard's Almanack)* and inventor (bifocal glasses, the Franklin stove, the lightning rod, and the glass harmonica, an instrument for which music was composed by such luminaries as Mozart (*e.g.*, K. 617)), Benjamin Franklin was also a highly regarded scientist, remembered primarily for his pioneering experiments and theories on electricity. Less well known, but equally fascinating, are his views on the formation and history of the Earth, and on terrestrial magnetism. Franklin's remarkable ideas on these phenomena are expressed in two letters written in the 1780's (at about the same time as Hutton's *Theory of the Earth*) and later published in the Transactions of the American Philosophical Society.

Like Hutton, Franklin attempted to explain the evident vertical mobility of the continental crust, evidenced by the occurrence of marine fossils in the highest mountains. Hutton's approach was that of a classical field-oriented geologist, relying heavily on direct observation and speculating no further than the observations warranted: *"We only know that the land is raised by a power which has for principle subterraneous heat; but how that land is preserved in its elevated station, is a subject in which we have not even the means to form conjecture…"* In contrast, Franklin, the "compleat geophysicist" (Pomerantz [1976] notes that "his interests spanned literally all of the disciplines now embraced by *AGU*"), felt at liberty to *"indulge imagination in supposing how such a globe was formed…"* In so doing, he touched on such notions as terrestrial accretion and differentiation, rock deformation, earthquakes, planetary magnetism, and true polar wander, in a marvelously inventive "*Theory of the Earth*" that to a modern earth scientist sounds both quaint and prescient.

### *Conjectures concerning the formation of the Earth, &c.*

*"Does not the apparent wrack of the surface of this globe, thrown up into long ridges of mountains, with strata in various positions, make it probable, that its internal mass is a fluid; but a fluid so dense as to float the heaviest of our substances?" "…part of the high county of Derby being probably as much above the level of the sea, as the coal mines of Whitehaven were below it, seemed a proof that there had been a great bouleversement in the surface of that Island, some part of it having been depressed under the sea, and other parts which had been under it being raised above it. Such changes in the superficial parts of the globe seemed to me unlikely to happen if the earth were solid to the centre. I therefore imagined that the internal part might be a fluid more dense, and of greater specific gravity than any of the solids we are acquainted with; which therefore might swim in or upon that fluid. Thus the surface of the globe would be a shell, capable of being broken and disordered by any violent movements of the fluid on which it rested."*

*"Do we know the limit of condensation air is capable of? Supposing it to grow denser within the surface, in the same proportion nearly as we find it does without, at what depth may it be equal in density with gold?" "…as air has been compressed by art so as to be twice as dense as water,… and as we know not yet the degree of density to which air may be compressed; … possibly the dense fluid occupying the internal parts of the globe might be air*

Poor Richard
*continued on page 5…*

# Visiting Fellows' Reports

Another academic year has begun, and with it comes new challenges, colorful foliage, and the reports of spring and summer visitors. Roy Roshko investigated interparticle magnetic interactions in a variety of synthetic materials, by measuring isothermal remanence acquisition and back-field remanence, and analyzed the resultant Henkel plots in terms of the Preisach phenomonological model. Tim Wawrzyniec took up the challenge of attempting to understand the natural remanence of real rocks (from the Elk Range of Colorado) by studying in detail their bulk magnetic properties.

**Tim F. Wawrzyniec**
University of New Mexico

## Rock Magnetic Properties of Rocks of the Elk Range, Pitkin & Gunnison Counties, Colorado

The rocks of the Elk Range consist largely of the Pennsylvanian-Permian Maroon Formation and numerous late Cretaceous/early to Mid Tertiary granodiorite intrusions. As part of a fault kinematic investigation in the Elk Range, I am applying paleomagnetism to ascertain the difference between structural tilt and vertical axis block rotations associated with Laramide age deformation. In experiments completed at the IRM I have been able to assess systematic differences in magnetic characteristics in rocks of the Maroon Formation that contain apparent primary magnetizations, partial remagnetizations, and complete remagnetizations (both ChRM and TRM). I have also studied the anisotropy of magnetic susceptibility of the late Cretaceous / early Tertiary intrusions. Characterization of these rock magnetic properties provides important and necessary insight into the stability of the observed magnetizations.

Paleomagnetic analysis (completed at the University of New Mexico) of the intrusions has provided results that have been interpreted to suggest that they are overall not suitable for recording ancient magnetic fields. Rock magnetic characterization, which included MicroMag experiments to determine hysteresis parameters and several temperature/susceptibility experiments confirmed this suspicion. Analysis of this rock type using the Lake-Shore Cryotronics Susceptometer confirmed that the magnetic grains within the granodiorite likely consist of coarse grained, multi-domain magnetite.

The Maroon Formation samples are all fine to very fine grained, hematitic sandstone. Paleomagnetic analysis of this material has consisted of step-wise thermal demagnetization up to temperatures of about 680°C. For most of the samples, the magnetization resists decay below temperatures of about 650°. Above such temperatures, the magnetization often decays to less than 10% of the NRM over a narrow range of temperatures, from 10 to 30°C. When this does not occur, there is a significant unblocking event that occurs between 500 and 570°C, suggesting the presence of magnetite in these samples. Experiments using instrumentation made available at the IRM has confirmed these observations/interpretations. Unfortunately, many of the rocks which carry measurable magnetizations in hematite have a susceptibility that is below the detection range of the susceptometers at the IRM. Future work will focus on using the more sensitive, VSM2 to measure temperature-dependent hysteresis parameters. Hopefully these experiments will provide more insight regarding the magnetic character of these rocks.

**Roy Roshko**
University of Manitoba

## Modeling Hysteresis in Particulate and Continuous Recording Media

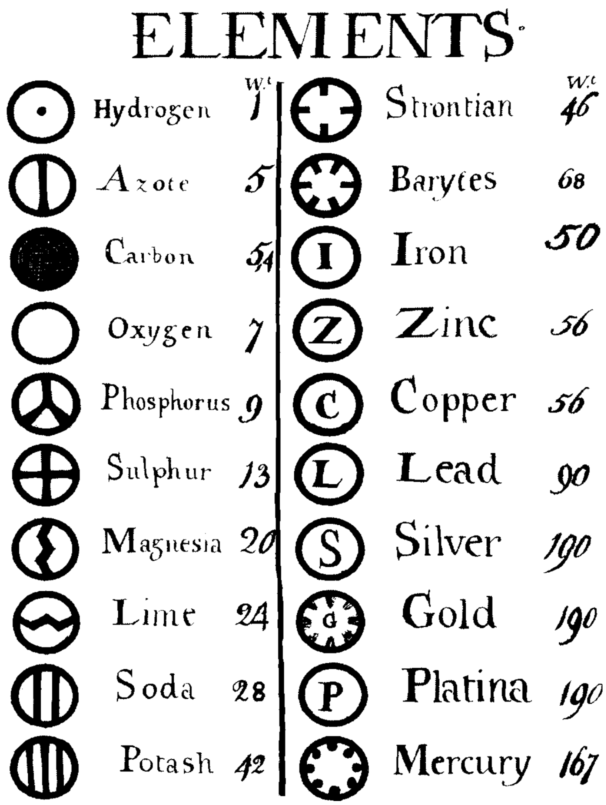
I visited the IRM in order to collect hysteresis and remanence data on a variety of magnetic systems, for comparison with the predictions of a generalized, finite temperature version of the Preisach model which I and my student P. D. Mitchler have developed in collaboration with Dan Dahlberg (U. of Minn.).

The Preisach model is a phenomenological model which describes all hysteretic systems as a collection of bistable "particles", real or hypothetical, each characterized by two outputs ±1, and by two critical applied fields $\alpha$ and $\beta$ ($<\alpha$) at which the particle switches up or down, respectively, and which occur with joint probability $p(\alpha,\beta)$. The response of each individual "particle" to an applied field $h_a$ is a rectangular hysteresis cycle with switching fields $\alpha$ and $\beta$, or equivalently, a coercive field $h_c=(\alpha-\beta)/2$ and an asymmetry field $h_s=(\alpha+\beta)/2$ which locates the center of the cycle.

The Preisach model provides a mathematical construction for calculating the history-dependent response of the entire assembly to any sequence of field applications and reversals, provided the switching field distribution $p(\alpha,\beta)$ is specified. The model has direct physical relevance to systems of fine single-domain particles where $h_c$ is due to intrinsic intraparticle anisotropy and $h_s$ is due to a local interparticle interaction field $h_{int}=-h_s$. It also applies to the motion of domain walls through a randomly fluctuating pinning potential created by imperfections and internal stresses, where the switching events at $\alpha$ and $\beta$ are statistically independent Barkhausen jumps occurring within a small volume element of the material.

The model also allows the Preisach distribution itself to evolve in response to the magnetizing process as $p(\alpha+km,\beta+km)$ or $p(h_c,h_s+km)$, where m is the induced magnetization and k is the mean field constant, since switching fields of a "particle" are expected to depend on the state of the neighboring "particles". In our thermal version, each elementary

VF Reports *continued on page 7…*




*Dalton's table of the elements, with his estimated atomic weights, ca 1803, reproduced from Thomas Levenson's* Measure for Measure: A Musical History of Science, *Simon & Schuster, New York, 1994. These values were subsequently corrected by Dalton, Berzelius, and others.*

# 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.*

## XIV INQUA Conference: Environmental Magnetism & Magnetic Stratigraphy

Angelino, A., A. Incoronato, and P. Sarno
Magnetic stratigraphy of Etna products. I. - medieval lavas, *Stud. Geophys. Geod., 40*, 217-224, 1996.

Evans, M. E., Z. Ding, and N. W. Rutter
A high-resolution magnetic susceptibility study of a loess/paleosol couplet at Baoji, China, *Stud. Geophys. Geod., 40*, 225-233, 1996.
Magnetic susceptibility, and its frequency dependence, are strongly correlated for 288 samples spanning 8.3 m in a loess-paleosol couplet. Susceptibility is inversely correlated with bulk sediment grain size, and bimodally distributed, with higher valeus in the paleosol samples. Frequency-dependence in the loess suggests that it is not entirely pristine, but has been affected by incipient pedogenesis.

Eyre, J. K.
The application of high resolution IRM acquisition to the discrimination of remanence carriers in Chinese loess, *Stud. Geophys. Geod., 40*, 234-242, 1996.
Curve fitting for detailed IRM acquisition spectra indicates the presence of four lognormally-distributed coercivity components, with peaks near 10, 35, 110, and 450 mT, respectively. The lower-coercivity IRMs are significantly correlated with susceptibility, and the corresponding carriers are attributed to pedogensis. The higher-coercivity IRMs are independent of susceptibility and may represent primary detrital iron oxides.

Forster, T., et al.
Loess in the Czech Republic: Magnetic properties and paleoclimate, *Stud. Geophys. Geod., 40*, 243-261, 1996.
A composite susceptibility profile for seven loess outcrops in the Czech Republic extends back in time to the Matuyama-Brunhes boundary, based on paleomagnetic measurements. The composite record is correlated with susceptibility profiles from Xifeng (China) and Karamaidan (Tajikistan). Correlation of susceptibility and its frequency-dependence indicates that susceptibility enhancement of the paleosols is due to ultrafine ferrimagnetic particles formed by pedogenic processes.

Han, J. M., et al.
The magnetic susceptibility of modern soils in China and its use for paleoclimate reconstruction, *Stud. Geophys. Geod., 40*, 262-275, 1996.
Magnetic susceptibility measurements for more than 160 modern silty soils show a nonlinear dependence on mean annual values of temperature and precipitation. On the Loess Plateau, susceptibility increases slowly with temperature and precipitation to about 10° C and 700 mm respectively, and much more rapidly thereafter. However, susceptibilities in South China soils are diminished, despite mean annual temperatures exceeding 15° C and precipitation greater than 1200 mm. A climofunction based on polynomial regression yields new reconstructions of paleotemperature and paleoprecipitation for the Loess Plateau.

Oches, E. A., and S. K. Banerjee
Rock-magnetic proxies of climate change from loess-paleosol sediments of the Czech Republic, *Stud. Geophys. Geod., 40*, 287-300, 1996.
Susceptibilities are high in interglacials and interstadials and uniformly low in unweathered loess. Normalized ferrimagnetic susceptibility and ARM are enhanced in paleosols associated with oxygen isotope substages 5c and 5a and in the Holocene soil. The substage 5e paleosol shows evidence of diagenetic loss of fine-grained magnetic minerals. Low-temperature remanence and high-temperature susceptibility measurements indicate that magnetite and maghemite are the dominant magnetic minerals; variation of concentration-independent magnetic properties reflects primarily grain-size variation.

Sroubek, P., et al.
Preliminary study on the mineral magnetic properties of sediments from Kulna cave (Moravian Karst), Czech Republic, *Stud. Geophys. Geod., 40*, 301-312, 1996.
Loess-like silty sediments of Kulna Cave contain a detrital record of climate variation, unaffected by pedogenesis. Susceptibilities are higher in layers deposited in cold climate intervals (in contrast to the typical pattern for surficial loess/paleosols), due to higher ferromagnetic content and to increased proportions of superparamagnetic grains. The increases can be attributed to greater erosion of pedogenic source material during cold intervals with reduced vegetation.

Strzyszcz, Z., T. Magiera, and F. Heller
The influence of industrial emissions on the magnetic susceptibility of soils in Upper Silesia, *Stud. Geophys. Geod., 40*, 276-286, 1996.
Measurements of magnetic properties of metallurgical dusts and fly ash from coal power plants and iron works and nearby soils indicate very high susceptibilities, mostly related to the occurrence of non-stoichiometric multidomain magnetite, ranging from 1 to 20 μm, and in some cases carrying substantial quantities of Pb, Ni, Zn, and Cu. Susceptibility measurements consequently provide a simple method of detecting heavy metal pollutants.

Tamrat, E., N. Thouveny, and M. Taieb
Magnetostratigraphy of the lower member of the Hadar Formation (Ethiopia): Evidence for a short normal event in the Mammoth subchron, *Stud. Geophys. Geod., 40*, 313-336, 1996.

Abstracts *continued on page 4…*

…Abstracts
*continued from page 3*

## Magnetic Mineral Properties

Gridin, V. V., G. R. Hearne, and J. M. Honig
**Magnotoresistance extremum at the first-order Verwey transition in magnetite (Fe3O4)**, *Phys. Rev. B, 53 (23)*, 15,518-15,521, 1996.
A large negative magnetoresistance (MR), sharply peaked at the Verwey transition (119.79 ± 0.02 K), has been measured in a synthetic single crystal of magnetite. In an applied field of 7.7 T, the MR exhibited a peak value of -17%, with a half-width of 0.53 K. The associated discontinuous change of the average magnetic moment μ at $T_V$ obtained from the MR data, was of the order of 0.1%, comparable to values obtained in previous magnetization experiments.

Isida, S., et al.
**Pressure effect on the elastic constants of magnetite**, *Physica B, 219-220*, 638-640, 1996.
Longitudinal sound velocity (V) measurements in magnetite at temperatures above 123 K and hydrostatic pressures up to 12 kbar show that V<110> has no pressure dependence, while the elastic constant C11 calculated from V<100>, shows a large softening with increasing pressure below 250 K. The amount of softening of C11 seems to obey the Curie-Weiss law with θ≈120K except near $T_V$.

Okeruda, H., K. Kihara, and T. Matsumoto
**Temperature dependence of structure parameters in natural magnetite: single crystal X-ray studies from 126 to 773 K**, *Acta Crystallogr., B52*, 450-457, 1996.
Cell dimensions, oxygen coordinate, and atomic mean square displacements (msd's) of natural magnetite change reversibly as a funtion of temperature from 126 to 773 K. The oxygen coordinate is nearly constant below 600 K, but increases at higher temperatures, indicating cation disordering over tetrahedral (A) and octahedral (B) sites above 600 K. All msd's increase monotonically with temperature. MSD's of the B atom indicate a change at 630 K from vibration dominantly along [111] to dominantly normal to [111].

Özdemir, Ö., and D. J. Dunlop
**Thermoremanence and Néel temperature of goethite**, *Geophys. Res. Lett., 23 (9)*, 921-924, 1996.
Goethite (α-Fe00H) is antiferromagnetic, with sublattice spins along the crystallographic c-axis, and a Néel temperature previously estimated in the range from 70° to 170° C. Goethite also possesses a weak ferromagnetism below $T_N$. New measurements on oriented crystals of natural goethite indicate a value of 120° C for both $T_N$ (based on low-temperature susceptibility) and $T_C$ (based on thermal demagnetization of TRM). The TRM is highly anisotropic, some 20 times larger parallel to the c-axis than perpendicular to it, indicating that the weak ferromagnetism is not due to spin canting (as in hematite) but to spin imbalance.

Petrovsky, E., et al.
**Transformation of hematite to maghemite as observed by changes in magnetic parameters: Effects of mechanical activation?**, *Geophys. Res. Lett., 23 (12)*, 1477-1480, 1996.
A natural hematite of hydrothermal origin shows changes in magnetic properties related to sample preparation (involving crushing and milling). A strongly magnetic phase with a Curie temperature (630° C) corresponding to maghemite is inferred to have resulted primarily from recrystallization under shear stress due to crushing and milling.

Rennert, P., W. Muck, and A. Chasse
**Calculated spin and angular resolved photoelectron diffraction spectra for magnetite**, *Surface Science, 357-358*, 260-264, 1996.
Spin and angular resolved photoelectron spectra are calculated for magnetite at room temperature. Using the occurring symmetry breaking, the effect of the magnetisation can be clearly separated from the spectra.

Semenov, V. A., and V. S. Shakmatov
**Inelastic scattering of slow neutrons by hematite**, *Fizika Tverdogo Tela (Physics—Solid State), 38 (6)*, 1844-1846, 1996.
According to the four-sublattice magnetic structure model, the dispersion relations for magnetic oscillations of α-$Fe_2O_3$ contain acoustic and optical branches. The dispersion curves for the acoustical and optical modes of α-$Fe_2O_3$ have been measured, and the spectrum of the density of magnon states has been obtained on the basis of the results.

## Paleointensity Methods

McClelland, E., and J. Briden
**An improved methodology for Thellier-type paleointensity determination in igneous rocks, and its usefulness for verifying primary thermoremanence**, *J. Geophys. Res. B, in press*, 1996.
Thellier-Thellier (TT) experiments may fail for various reasons, including alteration during heating, multidomain remanence carriers, and incomplete separation of overprints. Our new method recognizes that alteration during a TT experiment may affect only a limited unblocking temperature spectrum, and uncontaminated NRM may survive in higher unblocking temperature windows. When this is true, valid paleointensities may be recovered by following a particular experimental sequence: partial demagnetization to remove overprints; TT measurements with multiple pTRM checks; and thermal demagnetization of full TRM. The method yields a Cambrian paleointensity estimate for the Ntoya Ring Complex of Malawi.

Valet, J.-P., et al.
**Absolute paleointensity and magnetomineralogical changes**, *J. Geophys. Res. B, in press*, 1996.
A new approach for correcting paleointensity determinations for the effects of alteration during heating uses repeated multiple pTRM checks to recognize CRM acquisition and to determine its unblocking temperature spectrum. Application of the technique to natural samples shows that alteration products mostly have $T_{UB}$'s lower than the last heating temperature. Tests with recent and historic lava flows, heated in air or in vacuum, show that the new method yields reliable paleointensity determinations for twice as many vacuum-heated samples as the standard method, and 65% more air-heated samples

## Remanence Acquisition

Borradaile, G. J.
**An 1800-year archeological experiment in remagnetization**, *Geophys. Res. Lett., 23 (13)*, 1585-1588, 1996.
Limestone masonry from monuments dating from AD 300 to 1940 have acquired a viscous remanent magnetization parallel to the ambient magnetic field, carried by PSD-MD magnetite. The temperature $T_D$ required to demagnetize the VRM increases with age, i.e. with acquisition time $t_A$, according to $t_A=mT_D^b$, where m and b are determined by least squares. $T_D$ in most cases far exceeds values predicted from Néel theory, extending up to 350° C.

Løvlie, R., and J. Putkonen
**Dating of thaw depths in permafrost terrain by the paleomagnetic method: Experimental acquisition of a freezing remanent magnetization**, *Geophys. J. Int., 125 (3)*, 850-856, 1996.
Successive controlled freeze-thaw cycles (-18 to +20 C) cause a significant loss of natural remanence in sediments from Spitsbergen, and growth of a component parallel to the ambient field during freezing. Freeze-thaw cycles have a smaller effect on an initial isothermal remanence, and do not significantly affect anisotropy of susceptibility.

Abstracts *continued on page 5…*

…Abstracts *continued from page 4*

## Theory and Modeling

McClelland, E.
Theory of CRM acquired by grain growth, and its implications for TRM discrimination and paleointensity determination in igneous rocks,
*Geophys. J. Int., 126 (1),* 271-280, 1996.

The behavior of grain-growth chemical remanent magnetization (CRM) in single-domain (SD) grains is modeled using Néel's theory for acquisition of thermoremanence (TRM). Model calculations show that the CRM/TRM ratio varies with grain size for both magnetite and hematite, and that the unblocking temperature spectra are different for identical sets of particles carrying CRM and TRM. The results can be used to distinguish TRM from CRM and to determine the validity of using paleointensity techniques based on the assumption of TRM.

…Poor Richard
*continued from page 1*

*compressed. And as the force of expansion in dense air when heated is in proportion to its density; this central air might afford another agent to move the surface, as well as be of use in keeping alive the subterranean fires…"*

*"If one might indulge imagination in supposing how such a globe was formed, I should conceive, that all the elements in separate particles being originally mixed in confusion and occupying a great space, they would … all move toward their common centre: That the air being a fluid whose parts repel each other, though drawn to the common center by their gravity, and rarer as more remote; consequently all matters lighter than the central part of that air and immersed in it, would recede from the centre and rise till they arrived at that region of the air which was of the same specific gravity with themselves, where they would rest; while other matter, mixed with the lighter air would descend, and the two meeting would form the shell of the first earth, leaving the upper atmosphere nearly clear. The original movement of the parts towards their common centre, would naturally form a whirl there; which would continue in the turning of the new formed globe upon its axis, and the greatest diameter of the shell would be in its equator."*

*"… may we not suppose, that when we consume combustibles of all kinds, and produce heat or light, we do not create that heat or light; but only decompose a substance which received it originally as a part of its composition? Heat may thus be considered as originally in a fluid state, but attracted by organized bodies in their growth, becomes a part of the solid. …I can conceive that in the first assemblage of particles of which this earth is composed each brought its portion of the loose heat that had been connected with it, and the whole when pressed together produced the internal fire which still subsists."*

*"Is not the finding of great quantities of shells and bones of animals (natural to hot climates) in the cold ones of our present world some proof that its present poles have been changed? Is not the supposition that the poles have been changed the easiest way of accounting for the deluge, by getting rid of the old difficulty how to dispose of its waters after it was over? Since if the poles were again to be changed, and placed in the present equator, the sea would fall there about 15 miles in height, and rise as much in the present polar regions; and the effect would be proportionable if the new poles were placed anywhere between the present and the equator." "If by any accident … the axis should be changed, the dense internal fluid by altering its form must burst the shell and throw all its substance into the confusion in which we find it."*

*"Might not a wave by any means raised in this supposed internal ocean of extremely dense fluid, raise in some degree as it passes the present shell of the incumbent earth, and break it in some places, as in earthquakes? And may not the progress of such wave, and the disorders it occasions among the solids of the shell, account for the rumbling sound being first heard at a distance, augmenting as it approaches, and gradually dying away as it proceeds?" "…such a wave is producible by the sudden violent explosion… happening from the junction of water and fire under the earth, which not only lifts the incumbent earth that is over the explosion, but impressing with the same force the fluid under it, creates a wave that may run a thousand leagues lifting and thereby shaking successively all the countries under which it passes."*

### *Queries and Conjectures relating to Magnetism*

*"I will not trouble you at present with my fancies concerning the manner of forming the rest of our system. …I will just mention that your observation of the ferruginous nature of the lava which is thrown out from the depths of our volcanoes, gave me great pleasure." "Has the question of how came the earth by its magnetism, ever been considered?"*

*"It has long been a supposition of mine that the iron contained in the substance of this globe, has made it capable of being as it is a great magnet. That the fluid of magnetism exists perhaps in all of space; so that there is a magnetical North and South of the universe as well as of this globe, and that if it were possible for a man to fly from star to star, he might govern his course by the compass. That it was by the power of this general magnetism that this globe became a particular magnet. In soft or hot iron the fluid of magnetism is naturally diffused equally; when within the influence of a magnet, it is drawn to one end of the iron, made denser there, and rarer at the other, while the iron continues soft or hot, it is only a temporary magnet: If it cools or grows hard in that situation, it becomes a permanent one, the magnetic fluid not easily resuming its equilibrium."*

*"Perhaps it may be owing to the permanent magnetism of this globe, which it had not at first, that its axis is at present kept parallel to itself, and not liable to the changes it formerly suffered, which occasioned the rupture of its shell, the submersions and emersions of its lands and the confusion of its seasons." "…as the poles of magnets may be changed by the presence of stronger magnets, might not, in ancient times, the near*

…Poor Richard
*continued on page 6*

*continued from page 5*

*passing of some large comet of greater magnetic power than this globe of ours have been a means of changing its poles, and thereby wracking and deranging its surface, placing in different regions the effect of centrifugal force, so as to raise the waters of the sea in some, while they were depressed in others?"*

*"Such an operation as this, possibly occasioned much of Europe, and among the rest, this mountain of Passy, on which I live, and which is composed of lime stone, rock and sea shells, to be abandoned by the sea, and to change its ancient climate, which seems to have been a hot one."*

*"I do not know whether I have expressed myself so clearly, as not to get out of your sight in these reveries. If they occasion any new enquiries and produce a better hypothesis, they will not be quite useless. You see I have given a loose to imagination; but I approve much more your method of philosophizing, which proceeds upon actual observation, makes a collection of facts, and concludes no further than those facts will warrant. In my present circumstances, that mode of studying the nature of this globe is out of my power, and therefore I have permitted myself to wander a little in the wilds of fancy."*

The idea that the Earth's interior could consist of compressed air is a "fancy" apparently unique to Franklin. Some of the other ideas contained in the letters are, however, less fanciful than they may appear, when viewed in the context of 18th Century natural philosophy. Franklin's notion of magnetism as a fluid was in keeping with post-Newtonian views of "imponderable fluids" such as phlogiston and the ether, which were postulated as mediating agents in the phenomena of optics, gravity, heat, and (in Franklin's influential theories of the 1740's) electricity. According to Harman [1993], Euler and Bernoulli also advanced fluid theories of magnetism (and of fire) in the 1740's, based on the Newtonian ether, and Hutton himself published a unified ether theory in 1792 (*Dissertations on different subjects in natural philosophy*). Franklin's notion of a "universal" magnetism strongly resembles the conception of the ether as a universal primary inertial system, fixed with respect to the "fixed stars," a view that survived until the famous Michelson-Morley experiment of 1887, which ushered in the age of relativity.

There is an interesting (though nonmagnetic) geophysical footnote to Franklin's experiments with lightning and his invention of the grounded protective lightning rod. The idea of equipping buildings with a device that could actually attract lightning strikes met with considerable (and perhaps understandable) resistance, and Franklin's invention was slow to replace more traditional methods of protection, such as ringing church bells to ward off "evil influences" (a practice which resulted in the electrocution of no small number of bell ringers - Cohen gives numerous examples). Nevertheless by the mid 1750's numerous lightning rods had been installed on churches and municipal buildings in Boston and Philadelphia. On November 18, 1755, one of the strongest earthquakes ever felt in New England took place, and lightning rod opponents, led by Rev. Thomas Prince, suggested that it was caused by the build-up of excess electrical fluid collected by Franklin's devices in the Boston area. Harvard professor John Winthrop, a Franklinist, rebutted that (in essence) the earth was too good a conductor and any electrical excess would be rapidly and harmlessly dispersed; nevertheless the controversy lingered and possible relationships between lightning and earthquakes were given serious scientific consideration for some time afterward.

*"…the fluid of magnetism exists perhaps in all of space; so that there is a magnetical North and South of the universe as well as of this globe, and that if it were possible for a man to fly from star to star, he might govern his course by the compass…"*

Heilbron numbers Franklin among "the most important natural philosophers of the Age of Reason," chiefly for his work on electricity. Cohen includes among Franklin's major scientific contributions the law of conservation of charge, the distinction between conductors and insulators, and the first theoretical explanation of the Leyden jar (capacitor). But from the perspective of a post-Enlightenment rock magnetist, Franklin is at his best in giving "a loose to imagination" and "wandering in the wilds of fancy," in attempting to explain a wide variety of geologic phenomena through a unified model of the globe and its history, in much the same way as our modern paradigm of plate tectonics. That he was in fact wrong about nearly all of it is immaterial - it is not his theory but his creativity of thought that stands the test of time.

## Bibliography

Cohen, I. B., *Benjamin Franklin's Science*, Harvard University Press, Cambridge MA, 1990.

Franklin, B., Conjectures concerning the formation of the Earth, &c., *Am. Philos. Soc. Trans., 3*, 1-5, 1793 (reprinted in Pomerantz, 1976 and in Hazen, 1979.

Franklin, B., Queries and conjectures relating to Magnetism, and the Theory of the Earth, *Am. Philos. Soc. Trans., 3*, 10-13, 1793 (reprinted in Hazen, 1979).

Harman, P. M., *After Newton: Essays on Natural Philosophy*, Ashgate Publ., Brookfield VT, 1993.

Hazen, R. M., *North American Geology: Early Writimgs, Benchmark Papers in Geology, v. 51*, Dowden, Hutchinson & Ross, Stroudsburg, PA, 1979.

Heilbron, J. L., Franklin's physics, *Physics Today*, July, 1976 (reprinted in *History of Physics*, S. R. Weart and M. Phillips, *eds.*, Amer. Inst. of Physics, New York, 1985).

Hutton, J., Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Globe, *Trans. Royal. Soc. Edinburgh, v. I, part II*, 209-304, 1788 (reprinted in *Contributions to the History of Geology*, G. W. White, *ed., v. 5*, Hafner Publ., Darrien CT, 1970).

Pomerantz, M. A., Benjamin Franklin - The Compleat Geophysicist, *EOS Trans. Am Geophys. Union, 57*, 492-505, 1976.

…Visiting Fellow Reports

*continued from page 2*

rectangular cycle is assigned an equivalent energy level scheme consisting of two stable energy minima $\pm h_s$ separated by a potential maximum $h_c$. At a finite temperature T and for a given experimental observation time t, "particles" are allowed to relax by thermal activation over the smaller of the two energy barriers $W=h_c-|h_s|$, up to a maximum barrier height $W^*=k_B T\ln(t/\tau_0)$, where $\tau_0$ is a microscopic time. Numerical calculations based on the model show how the hysteresis cycle and the principal remanences are affected by thermally induced relaxation and, in turn, how this influences the interpretation of Henkel plots, which provide information on the distribution of interaction fields.

I used the Quantum Design MPMS and the new Princeton VSM to measure the virgin magnetizing curve $m_v(h_a)$ and the magnetizing remanence $i_m(h_a)$ as a function of applied field $h_a$ to positive saturation $i_\infty$, and the descending branch $m_d(-h_a)$ of the major hysteresis loop and the demagnetizing remanence $i_d(-h_a)$ to negative saturation $-i_\infty$. The measurements were performed over a wide range of temperatures, and for both ac and thermally demagnetized (if possible) initial states. Parametric Henkel plots of $i_d/i_\infty$ versus $i_m/i_\infty$ were constructed using the applied field as the matching variable. Deviations from the Wohlfarth line $i_d/i_\infty=1-2(i_m/i_\infty)$ are an indication of interaction effects.

I studied a variety of magnetic materials including recording media, like thin film longitudinal CoCr and $CrO_2$ audio tape, and random binary and ternary mixtures of 3d transitional elements like $Fe_{65}Ni_{35-x}Cr_x$ (x=0.12), where the exchange bond disorder is sufficient to frustrate the ordering process, yielding a relatively soft ferromagnetically ordered state with a low Curie temperature $T_c$=100 K, which collapses into a glassy, orientationally random spin configuration at low temperatures $T\leq 20$ K.

Although our analysis is not yet complete, a number of very interesting features have already emerged:

(a) Not surprisingly, the recording media exhibit virtually no thermal relaxation effects, even close to the Curie temperature, and their behavior is dominated by the explicit temperature dependence associated with the spontaneous magnetization, the anisotropy constant, and the mean interaction field. However, our comparison of ac and thermally demagnetized $CrO_2$ audio tape at various temperatures indicates that, in accord with our predictions, the thermally demagnetized state is much more sensitive to mean field interaction effects than the ac state, and that these interactions are ferromagnetic (k>0) in $CrO_2$. This feature is totally obscured by a large randomness-induced demagnetizing-like curvature in the Henkel plot under the usual ac conditions.

(b) In the reentrant ferromagnets, the Henkel plot shows a temperature dependent change in curvature from demagnetizing-like (k<0) in the low-temperature spin glass phase to magnetizing-like (k>0) as the system enters the high-temperature ferromagnetic phase. We believe that this is possibly the first observation of such a change in curvature which may be correlated with a change in the ordered state, although the details of this relationship are yet to be worked out.

(c) The Henkel plots of spin glasses all show anomalous demagnetizing-like curvature at low reduced temperatures and, in fact, violate the nominal lower boundary $i_d=-i_m$. Furthermore, at higher reduced temperatures, the field dependence of the IRM exhibits a peak which becomes more pronounced and shifts towards lower fields with increasing temperature. We can replicate both of these unusual features using the Preisach model, if the coercive fields of the particles are allowed to decrease on average in proportion to the magnetization m induced in the system, as $\bar{h}_c=\bar{h}_{co}-\gamma m$. This allows the system to thermally relax progressively closer to the equilibrium limit (zero remanence) as the magnetization increases. The effect has also been observed in fine particle suspensions and may be a general feature of all barrier activated systems, including granular geological materials.

# The Metaphysical Corner

*"…an attempt is made to explain the nature of negative numbers by allusion to book-debts and other arts. Now, when a person cannot explain the principles of a science without a reference to metaphor, the probability is that he has never thought clearly upon the subject… A number…submits to being taken away from another number greater than itself, but to attempt to take it away from a number less than itself is ridiculous. Yet this is attempted by algebraists, who talk of a number less than nothing, of multiplying a negative number into a negative number and thus producing a positive number… This is all jargon, at which common sense recoils."*

—William Frend, *The Principles of Algebra*, 1796

Quoted in "Metamathematics and the modern conception of mathematics" by M. Kenner, *Mathematics Teacher*, *51*, 350-357, 1958; reprinted in *From Five Fingers to Infinity: A Journey Through the History of Mathematics*, edited by F. J. Swetz, Open Court, Chicago, 1994.

## Curie, Pierre

*May 15, 1859-Apr. 19, 1906*

Before his Nobel Prize-winning collaboration with his wife Marie (*née* Sklodowska), studying the nature of radioactivity, Pierre discovered the phenomenon of piezoelectricity while investigating crystallography with his brother Jacques. In his celebrated doctoral studies on magnetism, he investigated the effects of temperature on magnetism, and identified the transition between ferromagnetism and paramagnetism, that today bears his name. His experimental results provided a basis for the important theoretical contributions of his student Paul Langevin.

# Visiting Fellowship Applications Due Soon For Spring - Summer 1997

*For application forms, write to IRM or get them from our Web site.*

The *IRM*, with its unique array of well-maintained and carefully calibrated instrumentation and its courteous and helpful staff, is yours for the asking! An *IRM* Visiting Fellowship gives you full access to our laboratory instruments for up to ten days, along with a travel allowance of up to $500 (sorry, *per diem* expenses - lodging and meals - are not included), and as much lab coffee as you can tolerate.

All you have to do to apply is to write a brief (2-3 page) proposal describing the experiments or measurements you want to carry out, and their significance. Applications are welcome from researchers in any country and in any field of study relevant to the magnetism of natural materials. Applicants are particularly encouraged to take advantage of the chosen focus for cooperative research each year. During 1996-7, the focus is on very-high-resolution recording of paleoclimate and paleomagnetic field variations.

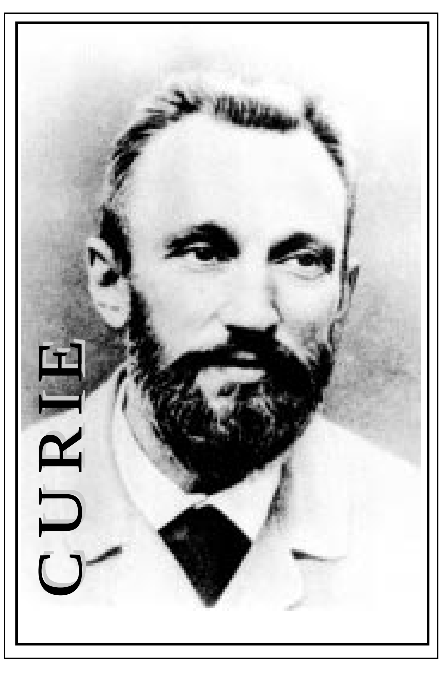
In general, advanced studies with specific, narrowly-defined objectives, and which make effective use of the *IRM's* unique instrumentation, are given preference over initial reconnaissance studies, or investigations based on "routine" measurements (*i.e.*, using widely-available equipment). We expect to award seven Visiting Fellowships for the spring-summer interval.

Slap on an official cover page and instrument scheduling worksheet, and get it to IRM by December 13, 1996, (yikes! Friday the 13th!) (i.e., right before the Fall AGU meeting) (I fear I must confess here to a (slight) tendency to over-use parenthetical remarks) and we'll look forward to seeing you when the snow melts (March - August) (at least we hope it'll melt by then).

# What's New at the *IRM*

**David Williamson**, of the Laboratoire de Géologie du Quaternaire (Aix-en-Provence, France) is beginning a one-year stay at the IRM, sponsored by the Centre Nationale de la Récherche Scientifique. David, with colleagues Nicolas Thouveny, Maurice Taieb and others, has worked extensively on paleomagnetism and rock magnetism of African and European lake sediments, and Quaternary environmental and magnetic field variations. He will expand on that research during a joint sabbatical in the IRM and the University of Minnesota's Limnological Research Center (LRC). David arrived in late August, and stayed in town just long enough to get his family settled before leaving for an extensive lake coring expedition in Tanzania. We anticipate a very productive and rewarding collaboration during the months ahead.

*Collectors Series #3. Clip and save! Collect them all!*




*From Marie Curie, by Susan Quinn, ©1995 Simon & Schuster, New York.*

PERSPECTIVES

*"Error can never be consistent, nor can truth fail of having support from the accurate examination of every circumstance"*
James Hutton, *Theory of the Earth*, 1788

*"As far as the propositions of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality"*
Albert Einstein, addressing the Prussian Academy of Sciences, 1921

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**, Assistant Professor/Associate Director; **Jim Marvin**, Senior Scientist; and **Mike Jackson**, Senior Scientist/Facilities Manager.

Funding for the *IRM* is provided by the **W. M. Keck Foundation**, the **National Science Foundation**, and the UNIVERSITY OF MINNESOTA.

The *IRM Quarterly* is published four times a year by the staff of the *IRM*. If you or someone you know would like to be on our mailing list, if you have something you would like to contribute (*e.g.*, titles plus abstracts of papers in press), or if you have any suggestions to improve the newsletter, please notify the editor:

**Mike Jackson**
Institute for Rock Magnetism
University of Minnesota
291 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455–0128
phone: (612) 624-5274
fax: (612) 625-7502
e-mail: irm@geolab.geo.umn.edu
web: http://www.geo.umn.edu/orgs/irm/irm.html

IRM
Institute for Rock Magnetism