I don’t know about you, but I just haven’t been myself for the last couple of years: listless, lethargic, dull-witted and irritable. Downright grouchy. Of course it’s true that events in the millennium so far have been disheartening, even appalling, but the geopolitical zeitgeist isn’t the only thing that’s got me down. As if that weren’t enough, I’ve also got a wicked Solar Max hangover.

As solar cycle #23 peaked in 2000-2001, sunspot numbers swelled, coronal mass ejections triggered geomagnetic storms and auroral activity, and the sun’s magnetic field reversed polarity. Now that the show is over, some sort of a letdown is inevitable.

And it seems that I am not alone. There is a surprisingly extensive* literature on correlations between solar-driven geomagnetic activity and a wide variety of biomedical phenomena. At least it came as a surprise to me, though in retrospect it probably shouldn’t have. After all, since Galvani’s frog experiments we’ve known of the importance of tiny electrical impulses in the nervous system, and it is plausible, at least in a vague way, to imagine subtle effects related to magnetic storms. The plasma streams from coronal mass ejections (CMEs) are made up of fast-moving, highly-ionized particles, some fraction of which are able to penetrate through the Earth’s magnetic field, especially at high latitudes, and to wreak havoc with sensitive electronic instruments. The great magnetic storm of March, 1989, for example, caused the collapse of the Hydro-Quebec power system in Canada, as well as power outages in Scandinavia. To my knowledge, widespread neural failures were not simultaneously reported, but what sort of subtle effects might such events have on our sensitive neural circuitry?

In 1994 R. W. Kay wrote an article in the British Journal of Psychiatry (164, 403-409) entitled “Geomagnetic storms: Association with incidence of depression as measured by hospital admission.” Based on geomagnetic aa and K-index data (see, e.g., NOAA’s web site) for solar cycle 21 (January 1976 - December 1986), and data for the same time period on 3449 hospital admissions, Kay found some statistically-significant trends. For male patients (but not for female ones) there was a 36% increase in admissions for depressed-phase manic-depressive illness in the second week following geomagnetic storms; there was no correlation between magnetic activity and other forms of depression for either gender. Kay postulated a mechanism involving electrochemical changes in the pineal gland, including changes in cell membrane permeability. This gland (called by Descartes “the seat of the soul,” the unique place where body and mind are linked) is responsible for secretion of the hormone melatonin, which, like the related neurotransmitter serotonin, is believed to play a significant role in regulating circadian rhythms. Kay’s hypothesis was that geomagnetic storms might perturb the pineal gland in such a way that melatonin secretion increased, leading to a depression-like state.

* at least based on my cursory survey of easily-accessible online journals and citation indexes.

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Out, I say!
Lady Macbeth, in
Macbeth, act V, scene 1

There is nothing new under the sun but there are lots of old things we don’t know.
Ambrose Bierce (1842 - 1914), The Devil’s Dictionary

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A coronal mass ejection (CME) on Feb. 26-27, 2000 captured by the Extreme UV Imaging Telescope (EIT). A CME blasts an enormous mass (order of $10^{12}$ kg) of charged particles into space, at speeds of millions of kilometers an hour. These images were made using “light” with wavelengths near 195 Å, emitted by highly-ionized iron (Fe XII) atoms at temperatures in the neighborhood of 1 million Kelvin. Courtesy of SOHO/EIT consortium, ESA and NASA.

http://sohowww.nascom.nasa.gov/
Visiting Fellows’ Reports

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Discontinuous deformation as a mechanism of remagnetization of limestones in the Internal Sierras (Southern Pyrenees, Spain)

The aim of this project was to decipher the relationship between the discontinuous deformation (stylolites and cleavage) and the remagnetization that occurs in the Internal Sierras. In many orogens remagnetization has been associated with the circulation of orogenic or basinal fluids, although other processes can remagnetize the rocks, for example: burial diagenesis of clays, dolomitization, dedolomitization, hydrocarbon migration. In recent years the influence of the orogenic fluids in the remagnetization of orogens is discussed.

The development of stylolites and cleavage fronts are related to the deformatonal regime and the mechanical properties of rocks. The mechanisms of cleavage development are: a) rotation of platy or needle minerals, b) syntectonic recrystallization, c) micro-folding, d) pressure solution and e) hydraulic fracturing. The mechanism that dominates depends on the pressure, temperature and strain rate. The timing of the development of cleavage in relation to the development of a fold is now generally accepted to occur in the same tectonic event. From the development of cleavage in different areas, Fourmarier (1951) defined several zones from the surface downwards: 1) a zone devoid of cleavage, limited at the base by the upper cleavage front (estimated at 5-6 km), 2) a zone of fracture cleavage and 3) a zone of slaty cleavage, limited at its base by the lower cleavage front.

In the Pyrenees, the cleavage front was mapped by Choukroune and Seguret (1973). It covers the Axial Zone till the middle part of the turbiditic basin. A paleomagnetic study was carried out to control the different degrees of rotation associated with the thrust system. All the samples in this study were collected within the cleavage zone, and in most of them, a post-folding remagnetization has been found. Other studies (Hogan and Burbank 1996, Pueyo et al. 2002 and Larraosaña et al. 2003) in southern areas and in rocks overlying the turbiditic basin show no remagnetization. For these reasons, the Pyrenees is a perfect site for testing the development of discontinuous deformation as the mechanism of remagnetization.

For this study 78 paleomagnetic sites (10 cores per site), collected in calcareous to calcarenitic rocks from the Upper Cretaceous, are distributed along the thrust front in an east-west area (85 x 15 km). This area is one of the keys for the structural reconstruction of the Pyrenean collision belt due to its situation near the Axial Zone (in the North), and due to its relationship with the sedimentary and tectonic evolutions within the Jaca Basin (piggy-back basin, in the South). The sites are in 2 main thrust sheets: the Larra-Monte Perdido (involving cover material in an imbricate thrust system) and the Gavarnie (involving basement material). The structures of this area are built up by several deformation stages. First, the cover material deforms (early Eocene), and secondly the developed structures are deformed by the basement thrust system (late Eocene and Oligocene).

Stepwise thermal demagnetization gives a widespread inverse component, which is carried by magnetite and does not pass the fold test.

For testing the mentioned hypothesis, a separate study of deformed and undeformed rock volumes has been done. Field and thin-section observations allow distinguishing different domains for single specimens in a few sites, permitting separation of small chips and powder pills of:

1) Undissolved material within and around the cleavage or stylolite planes.
2) Rock unaffected by discontinuous deformation (microlithons).

Besides that, a parallel study in the whole rock (standard specimens) has also been done.

Since magnetite is the pervasive carrier in these rocks, (deduced by unblocking temperatures, IRM and IRM of three components), the differences in granulometry in these domains were studied by means of hysteresis parameters (Day diagram) to prove any possible difference in the magnetic acquisition mechanisms (fig. 1). Hysteresis loops and back field curves were measured at room temperature with a µVSM (for chips) and a VSM (for standard specimens) with a maximum field of 1 T.

All the samples have anomalously high Hcr/Hc ratios with respect to Mrs/Ms ratios. This behavior is associated with bimodal distributions (in grain size, magnetic mineralogy or particle anisotropy) and result in wasp-waisted loops. Many of them are not closed at 1 T due to the temperature-dependent behavior of the paramagnetic fraction of the samples.

In order to find out which minerals are present several types of low temperatures (20-300 K) remanence sequences were run in the MPMS. The results show the presence of the Verwey transition in the cooling curve in most of the samples. The heating curve shows a huge decrease in the measured total moment below 50 K (due to the presence of SP grains, or different magnetic mineralogy). The FCZFC shows the possible presence of goethite because of the larger decrease in the second warming up, and also for some cooling curves after the RTSIRM, where the increase of the total moment is progressive. The presence of pyrrhotite is also shown by the abrupt decay in the cooling curve after SIRM at around 30 K in more than 50% of the samples. Maghemite could be present where the Verwey transition does not appear in the heating curve. The Morin transition is present in a couple of samples. All these minerals are present both in the cleavage and in the microlithon chips.

Other analyses were performed in the Lakeshore instrument but the paramagnetic/ferromagnetic ratio was too high to get any reliable result.

In conclusion, all these results show that the starting hypothesis is not proved or disproved yet (and this is an important finding!): the remagnetization process has not produced any change in the magnetic content between the deformed and non-deformed rock volumes. If the separation technique was not too imprecise to get pure microlithon chips, further processing of the acquired data may show (and this will...
prove the starting hypothesis! a differential magnetic concentration between the deformed and not-deformed samples.

Nevertheless these analyses have already characterized the magnetic mineralogy of the remagnetized samples and give more information about the processes affecting the rocks. They provoked new ideas to carry out other procedures (SEM) and get other results (susceptibility ratio, ARM).

I am very grateful for having the opportunity to be in the IRM, and I want to thank everyone for some discussions, popcorn, “coffee”- time and the dinner.

References:

Fig. 2: Examples of 2 sequences. acu2 is from a cleavage sample and ani5 is from a microlithon sample.

Oxidation of pyrite and marcasite - Processes with environmental significance

This study was focussed on the properties of oxides, hydroxides and hydroxide-sulphates formed from oxidation of sulphides, and it was divided into two parts (1) thermal decomposition, and (2) natural and bacterial oxidation products (in nature most sulphide oxidation is bacterial).

The main effort was on thermal decomposition of two pyrite and marcasite fractions (125-250 μm and 710-1000 μm) treated for 1 h in a Schönsstedt-oven at temperatures ranging from 200 to 650°C. Investigations were made with low-T demagnetisation, and magnetisation measurements, as well as with room-T frequency sweeps, and susceptibility versus frequency and temperature measurements. Results were in agreement with earlier Mössbauer and XRD findings that the oxidation products are “nano-crystalline”, and thus low-T demagnetisation showed just a minor magnetisation left at RT (ie, there is a mixture of SP and SD material). For the 450°C experiments a minor Verwey transition indicated the presence of magnetite - a phase which has not been detected with other methods. At 500°C magnetite was absent as shown by the disappearance of the Verwey-transition, and the magnetic properties were dominated by SP maghemite (SD at 20K). Further increases in temperature caused inversion with the subsequent growing importance of tri-axial SD-hematite. Low-T demagnetisation seems to confirm earlier suspicions that there actually was a decrease in crystallite size between 450 and 500°C, which is very interesting since an increase due to sintering would be the normal thing to expect. However, sintering prevails in the interval 525 and 650°C where it accompanies inversion.

The second part of the investigation was mainly that of making ZFC-FC measurements of hydroxides and hydroxide-sulphates with the MPMS. Phases investigated comprised jarosite (KFe₃(OH)₆(SO₄)₂), schwertmannite (Fe₅O₇(OH)(SO₄)·nH₂O), and goethite (α-FeOOH). For the jarosite the ZFC-FC curve is clearly compatible with a defect antiferromagnetic ordering at c. 60K, although with a parasitic paramagnetism. Previous investigations of this mineral have in general been done with Mössbauer-spectroscopy. Thermal demagnetisation of a 15K SIRM showed the same Tₘ as ZFC-FC. Schwertmannite however, experiences a magnetic ordering at c. 70K whose character is not that certain. The magnetic ordering of schwertmannite have so far been discussed in the literature as “speromagnetic” (a spin glass).

Within applied research, applications of sulphide oxidation lie in the environmental and industrial fields, with AMD (Acid Mine Drainage) and metallurgy (traditional roasting process versus bioremediation of metals) as main subjects of study. For paleomagnetic work these investigations are interesting with respect to natural and laboratory induced CRM-formation upon iron sulphide oxidation.

The staff at the IRM as well as the National Science Foundation and University of Minnesota are gratefully acknowledged for support in terms of knowledge and finacitacion.
Environmental Magnetism in Present Soils, Buenos Aires Province, Argentina

Introduction

This study is focused on the magnetic properties of present soils, in order to understand the influence of different pedogenetic variables on the magnetic signal. Ultimately we will apply this knowledge in the interpretation of magnetic signals of paleosol and their relation with paleoclimatic changes in the past.

Climate, topography (or drainage), parent material, vegetation and time are the main variables which influence soil formation. Topography is the main factor because it controls soil drainage, when climate and parental material are similar. Physicochemical changes and/or neo-formation of ferromagnetic minerals in the soil could be affected by topography. For this reason this project aims to evaluate the degree of variability of the magnetic signal at different geomorphological positions. Present soils from a restricted region (which are developed on the same parent material, pampean loess), coming from relatively high sites and low depressed zones are been studied.

On the other hand, the studied localities are not exactly in the same climatic area. So, this variable is also evaluated on the basis of soils formed under the same parental material (Buenos Aires Formation). Obtained results will be correlated with those from late Cenozoic loess, coming from relatively high sites.

Hypothetical model of the changes in magnetic minerals during edaphic processes

Many processes are involved in pedochemical mineral weathering. Hydratation and hydrolysis during flooding periods can be followed by subsequent reduction or oxidation. Reductive loss or oxidation may be stressed in acid environments; humic acids formed during pedogenesis may have supplied the required acidity for such dissolution.

The iron released from maghemite dissolution, plus the iron coming from other mineral alteration, forms amorphous complexes with clays or organic material. These complexes could migrate or crystallize as different iron minerals as a consequence of the prevailing environmental conditions. If a reductive environment changes into another of controlled oxidation, in neutral pH conditions, a Fe³⁺/Fe⁴⁺ complex can crystallize as pedogenic magnetite. Such minerals can also be generated by the actions of anaerobic bacteria in reductive environments. Under these circumstances it should be associated to areas of high rainfall and lack of drainage.

The introduction of dissolved oxygen causes rapid oxidation of Fe³⁺ and precipitation of ferric hydroxides if pH>6. Fe⁴⁺ persists for no more than a few minutes in aerated solutions of pH<7. But if these complexes were subjected to highly oxidant environments (e.g. climate with warm and distinctly dry periods), in relatively well drained areas, the forming neo-mineral would be a high coercivity iron oxide (such as hematite).

Thus the presence of SP magnetite could be an indicator of favorable climatic conditions (heavy rainfalls) with a relative drier season and in areas with neutral pH environments, at least during the magnetite genesis. The presence of hematite would indicate a seasonal and more extreme warm-dry condition.

It is very important to take into account pH is an environmental property that could change very fast in soils for many reasons. It is a property in a dynamic equilibrium, and with a close dependence of the rainfall, nature and changes in the water table and nature of parent material.

Samples and results

Verónica

2 sections of non-cultivated soils in different drainage condition were sampled in Zárate area (34°10’S 59°3′W, Buenos Aires Province). According to the analysis S3 is a typical Argiudoll and Ap is a Aquic Argiudoll.

Both soils Sz (with better drainage) and Ap have present basic environmental condition. Typical illuvial horizon characterized both profiles. The magnetic data shows an increase in the amount of ferromagnetic particles, especially in the illuvial horizon. According to low temperature measurements there are SP particles in both profiles. A higher amount seems to be present in Bt horizon of Ap profile. Figure 1 can be related with SP concentration, while figure 2 is controlled by grain size. Samples from Zárate soils (AP-SZ), show higher SP concentration than Verónica soils (R samples). Note in figure 2 the shift toward higher temperatures in R3 samples (non waterlogged soil) which can be related with an increase in SP grain size in Verónica. Figure 1 and 2 from Verónica (R2) shows the lack of SP while soil from Zárate (AP samples) show maximum SP concentration.

Conclusion

In the studied profiles the different drainage condition seems not to be so relevant, at least not in chacoampae plain with small topographic gradients. The main magnetic signal is the same in all profiles for each studied locality. But, some characteristics could appear reinforced by particular drainage conditions. Consequently, to calculate past precipitation on the basis of amount...
of SP particles may not be appropriate.

The present pH measurements could not to be relevant in the analysis. It represents only the present equilibrium of the environment. As it was mentioned before, pH is an environmental property that could change very fast in soils for many reasons. It is a property in a dynamic equilibrium, and with a close dependence with the rainfall, nature and changes in the water table and nature of parent material. It was detected high generation of SP particles in present basic soils. So, it is evident the pH was changing during the soil formation process.

The Eh general condition could be more important, this property was defined on the basis of geological features. Ap soil, worst drained, produced more SP particles, and the present pH is around 9.

As we can see, the magnetic signal is the opposite in both areas. Two important facts must be noted. The generation of SP particles seems to be higher in Zárate. And the loss of detrital magnetite could be higher in the less-drained soils (see example Verónica); it is in agreement with the hypothesis of loss of detrital magnetite by reductive process.

The climatic analysis shows among other properties, Zárate has continental climatic behaviour and more precipitation than Verónica. On the other hand, the hydrological balance remains practically the whole year positive in Zárate, with the only exception of November-December when the potential evaporation slightly exceeds precipitation. Verónica receives less precipitation than Zárate, especially during the summer period, with a clear negative balance.

So, as a simplified interpretation we can think hydrological positive balance (reductive condition 10 months and controlled oxidation in only 2 months) could explain generation of SP particles. And on the other hand, when it is possible to see the magnitude of the loss of detrital magnetite (like in Verónica, because the generation of SP is negligible), the degree of drainage seems to be the variable that manage the process of reduction loss.

An additional variable must be taken into account: time. It could be possible that the time involve in the formation of the studied soils in both area is not the same. We will try to determine the age of these soils using OCR data.

Acknowledgements

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We wish to thank the Institute for Rock Magnetism in Minneapolis (USA) for the use of its facilities. This research is carried out in collaboration with Dr. Pereyra F.X., Lic. Vásquez C.A. and Dr. Compagnucci R from University of Buenos Aires (Argentina).

Fig.1: Low temperature thermal demagnetization for selected samples of saturation of isothermal remanent magnetization, Mrs, imparted at 10 K in a 2.5 T field. The loss of remanence between 10 K and 300 K indicates the presence of SP particles. Note that the effect is greatest in Zárate samples AP15, SZ10 and SZ14. The step near 118 K in the same samples is caused by Verwey transition in magnetite.

Fig.2: % Difference of susceptibility, X, between 20 K and 300 K for several samples. The peak is near 80 K, which is in agreement with ca. 20 nm in diameter, SP grains. Note that the minor % Difference is in sample R210, it shows the lowest remanence loss in Fig.1. Note that the temperature peak shift toward higher values is correlated with higher % difference values, it can be attributed to higher SP grains diameter.
Anisotropy


Rock magnetic investigations show magnetite and also some greigite at two sites. Partial ARM coercivity spectra suggest several grain fractions. AMS foliations are close to bedding, except at one greigite-bearing site where it is inverse. Soft AARM (0-50 mT) foliations are slightly oblique to bedding. Surprisingly, hard AARM (50-100 mT) foliations are perpendicular to bedding. Comparison of two limbs of one fold suggests that AMS foliations are pre-tilting while hard-AARM foliations are post-tilting. Thus two orthogonal fabrics exist in these weakly strained rocks: coarse grains are parallel to bedding, while fine grains are aligned perpendicular to bedding.


Hematite (γ-Fe₂O₃, rhombohedral) pole figures measured by means of neutron diffraction were recalculated by reducing the orientation distribution function (ODF) into a set of texture components. The degree of preferred orientation increases considerably from the limbs towards the core of the fold. Corresponding changes of magnetic susceptibility, its anisotropy and its hysteresis parameters indicate larger grains in the fold's nucleus due to varying deformational and texture modifying processes.

Alteration & Remagnetization


A secondary magnetization, acquired during the Permo-Carboniferous Reverse Superchron, is carried by hematite, although it also resides in magnetite at some localities. Locally, the nonconformity between basement rocks and late Paleozoic strata, as well as steep shear zones within the basement rocks, may have been efficient channelways for brines flushed out of basins created during Ancestral Rocky Mountains deformation. On a continental scale, migration of fluids and attending remagnetization is consistent with epigenetic uplift of the Pangean supercontinent and a relative lowering of ground water levels.

Biogeomagnetism


Ferromagnetic transduction models proposed for mobile phone bioeffects are based on the coupling of RF and pulsed electromagnetic emissions to biogenic magnetite present in the human brain, via either ferromagnetic resonance or mechanical activation of cellular ion channels. We have tested these models experimentally for the first time using Magnetospirillum magnetotacticum, which produces intracellular biogenic magnetite similar to that in the human brain. Experimental exposure to mobile phone emissions resulted in a significantly higher proportion of cell death in exposed cultures.


Based on TEM and electron diffraction observations, we report the discovery of nanocrystalline botanical magnetite in iron-rich extracts from disrupted grass cells. The majority of the magnetite nanocrystals display cubic-octahedral shapes, with a minority of hexagonal prism morphologies. Each group has a narrow size distribution; the smallest cube-octahedral botanical nanocrystals (4 ± 1 nm) are an order of magnitude smaller than their bacterial counterparts. These botanical nanocrystals are self-organized in ordered, micrometer-sized agglomerates.


TEM and diffraction studies indicate that phytoferritin occurs in plant cells as crystalline magnetite, ε-Fe₂O₃, and hematite, with single crystallites in the 1 - 50 nm range and agglomerate grain sizes up to 4 um. The three-dimensional agglomerates are built with different biomimetic nanocrystals in three distinct modes of biological self-assembly: 1) ordered magnetite; 2) semi-ordered mixture of magnetite and ε-Fe₂O₃; and 3) random hematite. These self-assemblies correspond to prior TEM reports of crystalline, paracrystalline and amorphous phytoferritin arrangements in sectioned cell samples.

Instruments and Techniques


The deconvolution scheme of Oda and Dobson [1996] has been adapted for treatment of u-channel data and tested using.


Current Abstracts

A list of current research articles dealing with various topics in the physics and chemistry of magnetism is a regular feature of the IRM Quarterly. Articles published in familiar geology and geophysics journals are included; special emphasis is given to current articles from physics, chemistry, and materials-science journals. Most abstracts are culled from INSPEC (© Institution of Electrical Engineers), Geophysical Abstracts in Press (© American Geophysical Union), and The Earth and Planetary Express (© Elsevier Science Publishers, B.V.), after which they are subjected to Procrustean editing and condensation for this newsletter. An extensive reference list of articles (primarily about rock magnetism, the physics and chemistry of magnetism, and some paleomagnetism) is continually updated at the IRM. This list, with more than 5200 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the IRM Quarterly are always welcome.
data from ODP Site 1090. Large amplitude changes of the magnetization vector revealed by the deconvolution treatment are in good agreement with the results obtained on discrete samples extracted from the same u-channels. Application of this procedure to u-channel data from ODP Sites 983 and 984, over a short time interval around 1.255 Ma, permitted enhanced definition of the so-called Bjorn geomagnetic event.

Magnetic Field Records and Paleointensity Methods

Smirnov, A.V., Tarduno, J.A., and Pisakin, B.N., 2003. Paleointensity of the early geodynamo (2.45 Ga) as recorded in Karelia: A single-crystal approach. Geology, v. 31, no. 5, p. 415-418. Rock magnetic and TEM analyses indicate that plagioclase crystals derived from the Burakovka layered intrusion contain PSD- to SD magnetite inclusions. Fifteen reliable Thellier paleointensity results from single plagioclase crystals yield an average paleointensity of 43.2 ± 10.8 μT, which corresponds to a virtual dipole moment of 8.43 ± 2.11 x 10^17 Am^2. Although our result is unlikely to adequately represent the time-averaged field, the mean and range of values are similar to those of the present-day field. These values suggest that the inner core, which may stabilize the geodynamo, had started to grow by Early Proterozoic time.

Yu, Y.J., and Dunlop, D.J., 2002. Multivectorial paleointensity determination from the Cordova Gabbro, southern Ontario. Earth and Planetary Science Letters, v. 203, no. 3, p. 983-98. We interpret the A (1000 Ma) and B (850 Ma) magnetizations to be thermal overprints produced during regional uplift and cooling. Multivectorial A + B paleointensity data were analyzed using pairs of Arai diagrams for the separated A and B vectors. From 18 reliable A results and 15 reliable B results, we find respective VADMs of (3.12±0.36) and (1.82±0.38) * 10^17 A m^2, about 70% and 40% of the average Planerzioic dipole moment. Three sets of paleofield values as a function of paleolatitude, including the Cordova data, support a dipole configuration for the Earth's field in 25-150 Ma time windows around 2700 Ma, 1100 Ma, and 850 Ma.

Magnetic Microscopy and Spectroscopy

Grygar, T., Bezdíčka, P., Dideeék, J., Petrovský, E., Schneeweiss, O., 2003. Fe3O4·Cr2O3 system revised: Ceramics –Silikáty v. 47, no. 1, p. 32-39. Hematite and eskolaite (Cr2O3) are isosstructural oxides with non-linear change of the lattice parameters in their solid solutions. This series was synthesized and characterized by X-ray and neutron powder diffraction, and Mössbauer and electronic spectroscopies. Neither X-ray nor neutron diffraction indicated cation ordering, hypothesized in two reports in 1990’s. Magnetic structure of the solid solution at 0 < x < 0.6, where x = Cr/(Cr + Fe), is similar to that of hematite, but a different, yet unidentified magnetic ordering involving Fe(II) ions is established in solid solution x = 0.8 below its Néel temperature (about 150 K).

Hatanaka, S., Matsushita, N., Abe, M., Nishimura, K., Hasegawa, M., and Handa, H., 2003. Direct immobilization of fluorescent dyes onto ferrite nanoparticles during their synthesis from aqueous solution. Journal of Applied Physics, v. 93, no. 10, p. 7569-70. FITC-avidin, a fluorescent substance, was successfully immobilized onto the surfaces of nanoparticles of ferrite of a mixture between FeO2 and γ-Fe2O3, during the synthesis of the nanoparticles from an aqueous solution containing Fe2+, Fe3+, and FITC-avidin. The particles were spherical in shape and 10 nm in size. Utilizing the fluorescent magnetic particles, we successfully observed magnetic patterns (track pitch 187.5 μm) written on a floppy disk.

Lehlool, A. F., Mahmood, S. H., and Williams, J. M., 2002. On the particle size dependence of the magnetic anisotropy energy constant. Physica B, v. 321, no. 1, p. 159-62. Mössbauer spectroscopy is used to study a system of Fe3O4 fine particles (12.6 nm) at temperatures from room temperature down to 5 K. The average hyperfine magnetic field is found to decrease with increasing temperature. The effective magnetic anisotropy energy constant, K, is estimated to be lower than that obtained by others for systems with smaller sizes, which is consistent with the dependence of the magnetic anisotropy energy constant on the particle size.

Rasa, M., and Philippe, A. P., 2002. Scanning probe microscopy on magnetic colloidal particles. Journal of Magnetism and Magnetic Materials, v. 252, no. 1, p. 101-3. We report some first results on magnetite and iron nanoparticles studied with atomic force microscopy (AFM). The use of magnetic force microscopy (MFM) on such small particles is explored both experimentally and theoretically. We present models which allow to estimate with MFM the magnetic moment of a single superparamagnetic nanoparticle, which cannot be done with other techniques.

Magnetization Processes

Dunlop, D.J., Partial thermoremanent magnetization: Louis Néel's legacy in rock magnetism — invited. Journal of Applied Physics, v. 93, n. 10, p. 8236-40. Much effort has been devoted to testing the laws of additivity, reciprocity, and independence of partial TRMs, which partition the blocking temperature range and appear in nature as successive overprints of the original TRM. For SD grains, the laws are explained by Néel’s theories and are verified experimentally. For MD grains, additivity holds but partial TRMs do not demagnetize over exactly the original blocking temperature interval (nonreciprocly) and are not entirely independent of one another when acquired in different directions. The current frontier in rock magnetism is to overcome this nonideal partial TRM behavior in order to extract precise and trustworthy records of ancient Earth’s magnetic field directions and intensities.

Özdener, Ö., and Dunlop, D.J., 2002. Thermoremanence and stable memory of single-domain hematites. Geophysical Research Letters, v. 29, no. 18, p. 24-1-4. TRM in seven samples (grain sizes between 0.12 and 0.42 μm) was unaffected by 100 mT AF demagnetization and by 600°C thermal demagnetization. The TRM memory recovered after zero-field cycling through the Morin transition (T_m≈240 K) was parallel to the original TRM and equally resistant to thermal demagnetization. TRM and TRM memory of SD hematites are mainly due to the hard spin-canted magnetism above the Morin transition, and not to the small and softer defect magnetism that survives below T_m. However, the defect magnetism may play a role in renucleating the spin-canted magnetism in a preferred direction during warming through T_m. Although smaller than TRM intensities of MD hematites, SD TRMs are potent sources of remanent magnetic anomalies, particularly for larger grains (10-15 μm), and are likely to be more stable over geological time than MD hematite TRMs.

Rodriguez, A. F. R., Oliveira, A. C., Morais, P. C., Rabelo, D., and Lima, E. C. D., 2003. Study of magnetic susceptibility of magnetite nanoparticles. Journal of Applied Physics, v. 93, no. 10, p. 6963-5. Dynamic susceptibility (DS) and TEM were used to investigate dispersed magnetite nanoparticles. The field dependence of χ′′ was modeled using an asymmetric double well potential for relaxation. The size dependence of the magnetic susceptibility was included in the data analysis. Nanoparticle-size parameters obtained from the analysis of the DS data (19.1 and 18.2 nm) are in excellent agreement with the values obtained from the fitting of the TEM data (19.2 and 20.1 nm).

Seyoum, H. M., Bennett, L. H., and Dell Torre, E., 2003. Temporal and temperature variations of de magnetic aftereffect measurements of Fe3O4 powders. Journal of Applied Physics, v. 95, no. 5, p. 2820-2. DC magnetization measurements on fine Fe3O4 powder in the temperature range of 5 K<T<300 K show two distinct relaxation processes. The two processes display pronounced peaks 10, 35, 60, and 85 K below the Verwey transition (Tv) and different behavior above Tv. At the same time, high field irreversibility in M(T) curves in ZFC and FC states and a considerable increase in coercivity have also been observed below Tv. This is related to the freezing of disordered spins in reorganization of the domain structure.

Verrier, V., and Rochette, P., 2002. Estimating peak currents at ground lightning impacts using remanent magnetization. Geophysical Research Letters, v. 29, no. 18, p. 14-1-4. We introduce an original rock magnetic method based on AF demagnetization to define both the geometry and the intensity of peak lightning-strike magnetic fields. On a schoolyard tree struck by lightning, we were able to locate the impact to within a few centimeters, to prove that it was a vertical
negative current and to estimate a peak current intensity of 99.7 kA. This value is 14 kA higher than the one provided by Meteoroe lightning detection network and offers an independent calibration.

Mineral & Rock Magnetism

Al-Malah, A., El-Hasan, T., Lataifah, M., and O’Shea, M., 2002. Geochemical and mineralogical related magnetic characteristics of the tertiary-quaternary (Umm Al-Qutein) basaltic flows from the basaltic field of Harra El-Jabban, northeast Jordan: Physica B, v. 321, no. 1, p. 396-403. Modal analysis shows (titanomagnetite up to 11 wt%, with TiO2 content 25 - 27 wt%). By doing zero-field cooling (ZFC), we can classify the magnetic anisotropy of the three samples studied. A mixture of two magnetic phases (ferromagnet and ferrimagnet) was present, due to the high total Fe3O4. The ferrimagnetic phase was confirmed by the tendency of the magnetization toward zero value (compensation temperature) as we warm up the samples in ZFC and field-cooling methods.

Matzka, J., Krása, D., Kunzmann, T., Schult, A. and Petersen, N., 2003, Magnetic state of 10–40 Ma old ocean basalts and its implications for natural remanent magnetization: Earth and Planetary Science Letters, v. 206, no. 3-4, p. 541-553. Hysteresis parameters, Curie temperatures, M(T) and reflected light microscopy show titanomagnetite and titanomaghemite with increasing oxidation state with age. A minimum in M(T) in the age interval 10 to 40 Ma coincides with low NRM intensity. In the same age interval M(T) curves display a maximum above room temperature (Néel P-type) and, sometimes, a self-reversal of maximum above room temperature (Néel type). These properties can be explained by titanomaghemite low-temperature oxidation. A corresponding measurement of the NRM at elevated temperature shows a maximum above room temperature, providing evidence that the NRM is equally carried by titanomaghemites, and that the low NRM intensities for ~20 Ma old ocean basalts are caused by the low saturation magnetization of these titanomaghemites.

McEnroe, S. A., Harrison, R. J., Robinson, P., and Langenhorst, F., 2002, Nanoscale haematite-ilmenite lamellae in massive ilmenite rock: an example of 'lamellar magnetism' with implications for planetary magnetic anomalies: Geophysical Journal International, v. 151, no. 3, p. 890-912. Haemo-ilmenite layers from Rogaland, Norway contain fine exsolution intergrowths and larger titanohaematite lamellae in the host ilmenite grains. Samples have high coercivities, and average NRM values of 25 A m⁻¹, which typically show 2 per cent saturation in the NRM state. The magnetization in these samples is too high to be solely accounted for by a spin-canted AF moment in the haematite. Based on Monte Carlo simulations of haematite-ilmenite interfaces at the atomic scale and on measured rock-magnetic properties, we predict that the magnetization is carried by a ferrimagnetic substructure produced at the contacts of the very fine-scale titanohaematite and ilmenite exsolution lamellae.

Modeling and Theory

Tan, X., and Kodama, K. P., 2003, An analytical solution for correcting palaeomagnetic inclination error: Geophysical Journal International, v. 152, no. 1, p. 228-36. Based on Stephenson’s continuous orientation function (OD) function for anisotropic magnetic particles, we derive magnetic bulk-sample anisotropy parameters and inclination-correction equations. In addition to our new equations for correcting red bed inclination error, the results confirm previous inclination corrections for magnetite-bearing samples, based on a simple, discrete-particle OD model.

Tauxe, L., Bertram, H. N., and Seberino, C., Physical interpretation of hysteresis loops: Micromagnetic modeling of fine particle magnetite: Geochemistry Geophysics Geosystems, v. 3, no. 10, doi:10.1029/2001GC000241. In the last decade, numerical micromagnetic modeling has revealed the existence of nonuniform remanent states - the “flower” and “vortex” configurations - which suggest plausible explanations for many hysteresis measurements yet fall short of explaining high M_s, high H_c, such as those commonly observed in fine grained submarine basalts. We extend numerical simulations to a greater variety of shapes and sizes, including random assemblages of particles and shapes more complex than simple rods and cubes. Our simulations provide plausible explanations for a wide range of hysteresis behavior.

Synthesis and Properties of Magnetic Materials

Hao, Z., Li, J., Liu, J. P., Wang, Z. L., and Sun, S. H., 2002, Exchange-coupled nanocomposite magnets by nanoparticle self-assembly: Nature, v. 420, no. 6914, p. 395-8. FePt and Fe3O4 particles are incorporated as nanometre-scale building blocks into binary assemblies. Subsequent annealing converts the assembly into FePt-FcPt nanocomposites, where FePt is a magnetically hard phase and FePt a soft phase. An optimum exchange coupling can be obtained by independently tuning the size and composition of the individual building blocks. We have produced exchange-coupled isotropic FePt-FcPt nanocomposites with an energy product of 20.1 MG Oe, which exceeds the theoretical limit of 13 MG Oe for non-exchange-coupled isotropic FePt by over 50 per cent.

Nishimura, K., Uchida, H., Inoue, M., Sendoh, M., Ishiyama, K., and Arai, K. I., 2003, Magnetic micromachines prepared by ferrite plating technique: Journal of Applied Physics, v. 93, no. 10, p. 6712-14. By the stereolithography technique and the ferrite plating, we fabricated three types of magnetic micromachines which coated Fe3O4, CoFe2O4, and ZnFe2O4 respectively. The stereolithography technique enables one to form the spiral-shape resinous templates and the ferrite plating enables one to coat the ferrites uniformly onto these templates from an aqueous solution. The total machine weight is light because a resin of the template body is almost the same density as water. We verified that the machines swim freely and wirelessly in water by applying a rotational magnetic field. As these machines coated with ferrites have the biocompatibility, there is the possibility of medical microrobots which swim in the human body for medical operations.

Peralles-Perez, O., Sasaki, H., Kasuya, A., Jeyadevan, B., Tohji, K., Hihara, T., and Sumiyama, K., 2002, Production of monodispersed particles by using effective size selection: Journal of Applied Physics, v. 91, no. 10, p. 6958-60. Stable suspensions of nearly monodispersed nanoparticles of magnetite (d=102 nm) were obtained from polydispersed powders (d=40 nm) synthesized from aqueous solutions at 25°C. Two size selection methods are based on interfacial interaction between nanosize magnetic particles, anionic surfactants, and nonpolar solvents. By selecting a suitable surfactant type and/or conditions to modify the particle-particle separation distance, only smaller particles can be stabilized against aggregation and settling making a size sensitive separation possible. Magnetic measurements of the fractions confirmed the effectiveness of the developed size selection methods.

Roy, R., Peelamedu, R., Grimes, C., Cheng, J., and Agравal, D., 2002, Major phase transformations and magnetic property changes caused by electromagnetic fields at microwave frequencies: Journal of Materials Research, v. 17, no. 12, p. 3008-11. Crystalline phases can be made noncrystalline and hard magnets can be converted to soft magnets in the solid state in several seconds at temperatures far below the melting points. New crystal structures and magnetic structures of ferromagnetic oxides (ferrites such as BaFe12O19, CoFe2O4, Fe3O4, and ZnFe2O4, etc.) are formed by reacting either the stoichiometric mixture of oxides or the preformed phase-pure crystalline material in a pure H field (or E field) at microwave (2.45 GHz) frequencies. These major changes in the magnetic properties as well as major structural phase changes are caused by the magnetic field.
Magnetic Butterfly Diagram, showing evolution of the solar magnetic field though approximately 2½ cycles. As in the conventional Maunder Butterfly Diagram, sunspot activity can be seen to originate near ±30° latitude and migrate equatorward during each cycle. This plot also shows the accompanying dipole field reversals, with alternating positive (inward) and negative (outward) flux in the polar regions. Source: The Solar Dynamo, http://science.nasa.gov/ssl/pad/solar/dynamo.htm

role in some types of clinical depression. Numerous related studies follow a similar empirical approach, identifying (or challenging previously-claimed) statistical correlations between geomagnetic indices and the occurrence of various medical conditions. Some of these seem generally plausible (e.g., migraines, epileptic seizures, and cardiac failures), and others are more unexpected. For example Randall & Moos published a 1993 article in the International Journal of Biometeorology (37, 72-77) entitled “The 11-year cycle in human births.” They compiled national and regional birth data for the period 1930-1984 for the U.S., England and Wales, New Zealand, Japan, Switzerland, New South Wales Australia, and Baden-Württemburg Germany. They then compared these statistics with the aa geomagnetic activity index and related parameters including the Wolf sunspot index and temperature. Astonishingly, the strongest bivariate correlation was between births and sunspots (Spearman rank correlation coefficient 0.86, p<0.01). The correlation of temperature with sunspots was nearly as strong (0.77, p<0.01), and that between geomagnetic activity and sunspots, though significant, was surprisingly weak in comparison (0.55, p<0.05). As far as a possible mechanism for solar modulation of human birth rates, the authors remained wisely noncommittal: “A multiplicity of geophysical and cultural factors is involved in generating the worldwide... temporal patterns of conception.”

A fairly large number of similar number-crunching papers have been produced by a group here at the University of Minnesota: the Chronobiology Center, associated with the Minnesota Supercomputing Center, and directed by Franz Halberg (originator of the widely-used term “circadian” as well as a host of other less-well-known periodicity terms, such as “circaseptan” (~weekly) and “circatrigintan” (~monthly)). Biorhythm periodicities are of interest from a purely scientific viewpoint, and may have some prognostic value in medicine. A number of chronobiological papers examine periodicity and phase relationships in an effort to unmix endogenous biochemical processes, ubiquitous societal effects, and external (e.g., solar/geomagnetic) influences. In one example, a database of some 130,000 deaths from myocardial infarction in Minnesota from 1968 to 1996 showed a highly significant (p<0.001) 10.5-year periodicity, in phase with or slightly lagging the solar activity cycle [Cornélisson et al, 2002].

The circaseptan has proven more difficult to deconvolve. A circaseptan periodicity in the geomagnetic field appears to be a controversial proposition in itself: Cornélisson et al [2001, 2002] conclude, based on magnetometer data from Antarctica, that such a period does indeed exist, at least intermittently, and moreover that it appears to exert some control on heart-rate variability and myocardial infarction. They refer to a “sector structure of the interplanetary magnetic field [Wilcox & Ness, 1965]” as the source of the weekly periodicity in Kp and aa. Naturally it is difficult to eliminate other possibly dominant effects. For example, Alania et al [2001] identified a strong circaseptan variation in automobile accidents in Poland between 1990 and 1999, but concluded that “maximum car accident events take place in Poland on Friday and practically does not depend on the level of solar and geomagnetic activities.”

Moreover correlation, however statistically significant, does not necessarily prove causation. For example, look at the time series plotted in the figure on page 10. Both data sets exhibit short-term (circatrigintan) variations that appear to be random, superimposed on a slow systematic trend, rising to a maximum in 2000 and then declining. Not surprisingly, one of these variables (#2) is the Wolf sunspot index, which peaked at 169 in July, 2000. Have you guessed what the other variable is? (hint: To buy or not to buy - that is the question.) It is the Dow Jones Industrial Average stock-market index. For the 88-month interval beginning in January, 1996, these indices exhibit a highly significant statistical correlation (R²=0.69, p<0.01), although for the previous several decades, no such correlation exists. Is it conceivable that some causative connection took hold in 1996, about the time that US Federal Reserve chairman Alan Greenspan famously attributed rising stock prices to “irrational exuberance”? Undoubtedly “a multiplicity of cultural factors” must be involved in controlling stock prices, but any sort of geomagnetic influence would...
...magnetic storms
continued from p. 9

appear to be conclusively ruled out by the fact that the stock boom and bust slightly preceded the correlative solar activity.

Empirical correlations alone are intriguingly suggestive, but insufficient to demonstrate a causal relationship, so let us turn to theory and experimental studies (which are understandably rarer than empirical ones). Electromagnetic induction is probably the most obvious mechanism to consider. Durand-Manterola et al [2001] calculated the magnitude of electrical eddy currents that would be induced in cells of different sizes by sinusoidally-varying magnetic fields of different frequencies and amplitudes. They find that currents of 1 to 30 pA, comparable to those generated by cells themselves during normal activity, can result from micropulsations and whirls, as well as from lightning discharges. These phenomena have frequencies in the $10^3 - 10^4$ Hz range, and amplitudes up to a few nT.

Measurable biomedical effects of weak-field induction are apparently confirmed by direct monitoring of EEG responses to controlled field variations: studies have reported significant effects for weak alternating fields (3 Hz, 0.1 mT in human volunteer subjects [Heusser et al., 1997]; 60 Hz, 0.25 mT in rabbits [Marino et al., 2003]), but no measurable effects produced by step changes in dc field intensity or orientation [Sastre et al., 2002]. Indeed a mechanism seems more elusive for linking very low-frequency field variations to any sort of biological effects, since inductive currents thereby generated are negligible. Yet there is some evidence for such effects.

One early experimental study [Keshavan et al., 1981] bears the horrifying/fascinating title “Convulsive threshold in humans and rats and magnetic field changes: Observations during total solar eclipse.” Psychiatric patients undergoing electroconvulsive therapy were administered shocks of progressively increasing strength until the convulsive threshold was reached, both on a control day of “normal” magnetic field variation, and on the day of a solar eclipse, when solar ionizing radiation was significantly cut off by the interposition of the moon. Magnetometer readings showed a 19 nT transient variation due to the eclipse, and convulsive thresholds in both the human patients and in laboratory rats were reduced by statistically-significant amounts compared to the control-day thresholds. The control day was chosen to be 28 days later (1 lunar synodic period and very close to one solar rotation period), to minimize differences related to those periods, and the authors therefore concluded that the small 19 nT field variation was responsible for depressing the thresholds, through a mechanism that remained unexplained.

A less shocking, but nevertheless rather surprising finding is that vision is affected by weak dc magnetic fields: for example, the threshold light intensity for visual perception is reported to be slightly but significantly raised in the direction parallel to the field [Thoss et al., 2002]. Which brings us to the related question of magnetoreception in humans: are we able to detect ambient magnetic field characteristics? Various animals (e.g., birds and sea turtles) are known to navigate with the aid of magnetoreception, involving biomineralized magnetite particles. Similar particles have been found in human brain tissue by recently-inaugurated AGU Fellow Joe Kirschvink and colleagues [1992]. Are these nonfunctional evolutionary vestiges, like the coccyx, or are they part of a viable sensory apparatus that enables us, without our conscious awareness, to perceive ambient field orientation?

Three conceivable mechanisms for dc magnetic field bioeffects in humans - including magnetoreception - were discussed (and dismissed) by Sastre et al [2002]. First, and most obvious, is the torque exerted on the permanent magnetic moment of single-domain magnetites, which may act as tiny switches for opening/closing transmembrane ion channels [e.g., Kirschvink et al., 2001] or produce other changes in neural cell activity. Sastre et al [2002] conclude that their EEG measurements during controlled field reversals should show evidence of such activity if it occurs, but do not. Similarly they argue against induction related to motion in a static field, and field-control of chemical reaction rates that involve electron spin states, based on lack of observed EEG response. Yet they acknowledge several caveats and remaining puzzles, including one of their own experimental results, which did show significant ($p<0.01$) changes resulting from a sudden steepening of the ambient field inclination to a near-vertical orientation. The question remains open.

We have been mesmerized by magnetism since, well, Mesmer (1734-1815). Mesmer’s 1766 dissertation at the University of Vienna dealt with gravitational effects of the planets on human health, mediated by one of the ethereal “imponderable fluids” then in scientific vogue. Gravity gradually lost its attraction for him, though, and he dropped it in favor of animal magnetism, its attraction for him, though, and he eventually ran into trouble with the Vienna authorities, and he moved to Paris in 1778. There, too, charges of fraud caught up with him, and in 1784, Louis XVI commissioned an inquiry into the matter. The panel was chaired by Ben Franklin, and met at his residence in Passy; members included Lavoisier and one Dr Joseph Guillotin. Mesmer refused to cooperate, but one of his protégés, Charles Daslon, volunteered to face the commission. Their
Galvani, Luigi
b. Sept. 9, 1737, Bologna, Papal States (Italy)
d. Dec. 4, 1798, Bologna, Cisalpine Republic

Galvani completed his medical doctorate at the University of Bologna in 1762, with a dissertation entitled De Ossibus, on bone structure and development. Gradually his interests shifted from anatomy to physiology, and in the late 1770’s he conducted his famous frog experiments, investigating the electrical stimulation of muscle contractions. His 1791 publication of De Virtus Electricitatis in Motu Musculari attracted the attention of contemporaries including Volta, who coined the term galvanism. Volta disagreed with Galvani’s conclusion that electricity resided in the animal as a vital force, believing instead that it was generated by the contact of dissimilar metals, and pursuit of the idea led to his development of the voltaic pile.

"the only magnets clinically proven" to relieve suffering from fibromyalgia, lupus, sciatica, herniated discs, asthma, bronchitis, cataracts, chronic fatigue syndrome, colitis, diverticulitis, heart disease, multiple sclerosis, and more than 50 other health conditions. Equally serious is the rising tide of pseudoscience, against which various resources have been organized, including the Skeptic Society (whose director, Michael Shermer, writes a regular column in Scientific American), and Quackwatch, which specializes in fraudulent medical claims.

Naturally not all combinations of magnetism and medicine are fraudulent. Nuclear magnetic resonance has become a standard tool in high-resolution medical imaging. Pulsed magnetic fields are now being used in transcranial magnetic stimulation (TMS) for mapping motor functions in the brain, by inducing current pulses in specific localized regions and observing the galvanic-like muscle responses thereby elicited. TMS is also being studied by NIH as an alternative to electroconvulsive therapy in treating depression; by localizing induced current in the prefrontal cortex, and steering clear of the motor-control and memory areas, researchers hope to produce the same positive results obtained with ECT, while avoiding seizures, memory loss and other side effects.

Some time in about 2012, the sun will resume normal polarity. I don’t know about you, but until then I’m keeping a magnet under my hat, an eye on the space weather, and my tongue in my cheek...

Acknowledgment: Thanks to Betsy Leach for suggesting this article and for an introduction to the biomedical literature on geomagnetic effects.

Information sources:


Mesmer, the Franklin Commission, and Their Legacy, http://isit-socrates.berkeley.edu/~kihlstrm/mesmer84.htm


Magnetic Stimulation Studied as Alternative to ECT for Depression, http://www.nimh.nih.gov/events/pmagrec.htm


Franklin, B. and A. Lavoisier. "Report of the Commissioners Charged by the King to Examine Animal Magnetism" (reprinted in an English translation in Skeptic, 4 (3)).


Heusser, K., D. Tellchaff and F. Thoss, Influence of an alternating 3 Hz magnetic field with an induction of 0.1 millitesla on chosen parameters of the human occipital EEG, Neuroscience Letters, 239 (2-3), 57-60, 1997.


Marino, A., E. Nilsen and C. Frilot, Consistent magnetic-field induced dynamical changes in rabbit brain activity detected by recurrence quantification analysis, Brain Research, 964 (2), 317-326, 2003.

Roederer, J. G., Are magnetic storms hazardous to your health?, EOS, 76(44), 441-8, 1995.


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