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Rudolf L. Mössbauer, 1929-2011

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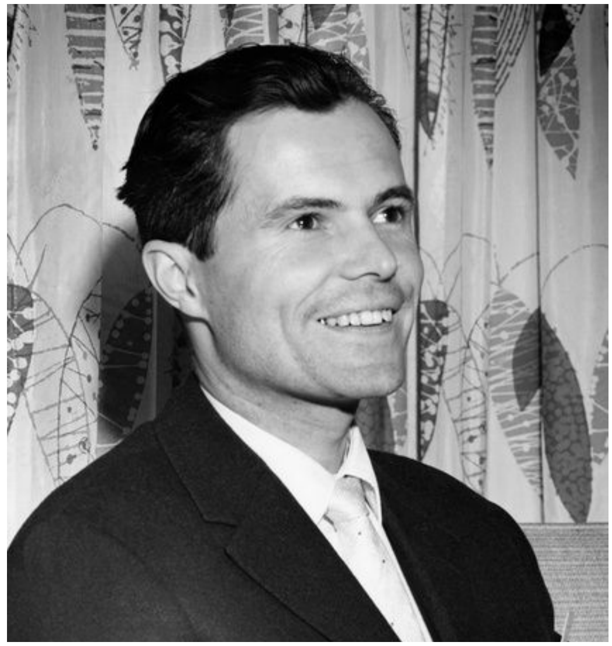
Editor's note: As noted below, Mössbauer spectroscopy has found applications in physics, chemistry, biology, biochemistry, geoscience, archeology, metallurgy and materials science. Because the technique largely targets Fe-bearing materials, it has proved to be an invaluable companion to more standard magnetic measurements in probing the composition and structure of magnetic mineralogy. Mössbauer's legacy remains an active area of research at the IRM, one of very few Earth Science departments in the United States with a Mössbauer spectrometer. We are grateful to Dr. Frankel for providing the following retrospective of Mössbauer's life and work, as well as personal memories from time spent in Mössbauer's lab.



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Rudolf L. Mössbauer, Nobel laureate in Physics in 1961 for the discovery of the effect that bears his name, died in Germany September 19, 2011. Born in Munich in 1929, he studied physics at the Technical University (TU) there. He did his graduate research with Professor Heinz Maier-Leibnitz, who directed his work on nuclear resonance fluorescence. He made his famous discovery at the Physics Institute of the Max Planck Institute for Medical Research, Heidelberg, in 1957 and received his PhD in 1958. In 1960, he accepted a research appointment at Caltech and was promoted to Professor of Physics in 1961, before he was awarded the Nobel Prize. In 1965 he became Professor of Physics at the TU. In 1972 he went to Grenoble, France as director of the Institute Laue-Langevin and the High-Flux Reactor. He returned to the TU in 1977 and retired in 1997. In the latter part of his career he was engaged in neutrino physics as well as Mössbauer spectroscopy.

Mössbauer's graduate research involved emission and absorption of photons by nuclei. In a process called nuclear resonance absorption, a nucleus in its ground state ($E = 0$) can be excited to a state of energy E_1 by absorption of a photon of energy E_1. Due to the uncertainty principle, the excited state has a distribution about E_1 with a full width at half maximum of $\Gamma = h/(2\pi\tau)$, where τ is the mean lifetime of the excited state and h is Planck's constant. If the photon energy is substantially less than E_1-Γ or greater than E_1+Γ, resonance absorption will not occur. Because electromagnetic radiation carries linear momentum, the nucleus must recoil when it absorbs a photon, in order that linear momentum is conserved in the process. Thus some of the photon energy goes into the recoil energy R of the nucleus and is not available for nuclear excitation. Since the recoil energy is generally much greater than Γ, the energy available for excitation will be substantially less than E_1-Γ and resonance absorption will not occur.

Mössbauer's great discovery was that if the absorbing nucleus is embedded in a solid, there is a certain probability that the recoil momentum will be taken up by all the atoms in the solid rather than by the absorbing atom alone. In this situation, linear momentum is conserved, but the recoil energy R goes to zero because the mass of the single nucleus is replaced by the whole mass of the solid, that is, a mass of order 10^{20} times or more the mass of the single nucleus. Thus the full energy of the photon is available for excitation. The same situation holds for a nucleus that de-excites from a state at energy E_1 to the ground state by emitting a gamma ray of energy E_1. This is called recoilless nuclear emission.

In his experiment, Mössbauer observed resonant absorption and excitation of the 129 keV first excited state in ^{191}Ir, using radioactive ^{191}Os as a source. ^{191}Os undergoes beta decay to ^{191}Ir, populating the 129 keV first excited state, which subsequently de-excites by emitting a 129 keV gamma ray. The gamma rays from the source were passed through an absorber with ^{191}Ir in the ground state. The source and absorber were at rest relative to each other. Behind the absorber was a detector to count the 129 keV gamma rays that passed through the absorber. The temperatures of the source and absorber could be

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Visiting Fellow's Reports

Investigation of the magnetic properties of synthetic dusty olivines

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Chondrules are a major component of chondritic meteorites. The mechanism of chondrule formation is an important outstanding question in cosmochemistry. Magnetic signals recorded by iron nanoparticles in chondrules could carry clues to their origin. This project aims to examine the magnetic properties of nanoscale Fe-Ni particles within synthetic meteorite analogues, with the aim of revealing the nature of the magnetic signals recorded and assessing whether they have the potential to retain a preaccretionary remanence.

Recently, research in this area has focused on 'dusty olivine' grains within ordinary chondrites. Dusty olivine is characterised by the presence of sub-micron Fe-Ni inclusions within the olivine host. These metal particles form via subsolidus reduction of the olivine during chondrule formation [1]. The Fe-Ni particles have been proposed to acquire a preaccretionary remanence as the chondrule cools through the Curie temperature of Fe [2]. Furthermore they are thought to be protected from subsequent chemical and thermal alteration by the host olivine.

In preparation for my visit to the IRM I produced 3 sets of synthetic dusty olivines, using natural Icelandic olivine (average Ni-content of 0.3 wt%), synthetic Ni-containing olivine (0.1wt% Ni) and synthetic Ni-free olivine as starting materials. The starting materials were ground to powders and packed into a cubic hole within a graphite crucible. The cube dimensions were 4x4x4 mm for the first 14 cubes and 3x3x3 mm for all following cubes. The crucibles containing the samples were placed into a gas-mixing furnace, heated up to 1350˚C under a pure CO gas flow and kept at this temperature for 10 minutes. After this the samples were held in a fixed orientation and quenched into water in a range of known magnetic fields, ranging from 0.2 mT to 1.5 mT.

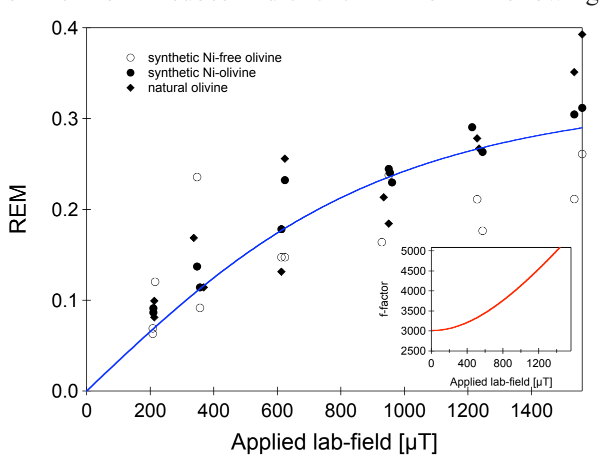

Figure 1. REM ratio (NRM/SIRM ratio) of all samples. (SIRM = IRM at saturation)Open circles: synthetic Ni-free olivine; filled circles: synthetic olivine containing about 0.1wt% Ni; diamonds: natural olivine containing about 0.3wt% Ni. Curve fitting the points to function of magnetisation in varation with applied field is shown in blue. Inset shows calibration, f-factor derived from the fit-curve.

At the IRM I measured NRM demagnetization, ARM acquisition and demagnetization, as well as IRM demagnetization curves for all samples. I also recorded room temperature hysteresis loops and first-order reversal curve (FORC) diagrams for each sample. Low temperature magnetic properties for a selection of 6 samples were obtained via MPMS measurements in order to test for the presence of magnetite. A TRM experiment on 6 selected samples failed unfortunately, as the samples were highly altered during the process.

In general, all samples showed uni-directional, single-component demagnetization behaviour. However, even after applying the highest possible AF-field of 150 mT it was not possible to fully demagnetize the samples. Preliminary results from the demagnetization experiments are depicted in Figure 1. It shows the REM ratio (NRM/SIRM ratio) of all samples versus the respective magnetic field applied during the production of each sample. The graph clearly shows that there is a variation of REM with applied field. The data were fitted to the theoretical expression for TRM as a function of applied field (eq 7.6, [3]). As the lowest magnetic field we could produce in the lab was about 0.2 mT, we clearly find the samples plotting beyond the region of linearity. The calibration factor f, defined so that magnetizing field B (in μT) is equal to f*REM, derived from the fit-curve is shown as inset in Figure 1. It increases at high fields but trends towards a fixed value for low fields in the linear region. For the fit shown here this value is about 3000, which matches well with literature values [4-5]. It appears that there is a distinct difference between the three different types of samples: the ones with higher Ni-content seem to exhibit a generally higher REM ratio. Further work will focus on whether different normalisation schemes (e.g. REM' or ARM normalisation methods) are able to reduce the scatter in the data and provide a more tightly constrained calibration curve.

A typical FORC diagram of one of my samples (cube 10) is depicted in Fig. 2. One distinct feature showing up in all FORC diagrams was a broad vertical spread of the signal at very low coercivities. Closer inspection of the individual FORC curves, however, revealed that the first point of every curve was slightly offset (small inset in Fig. 2). This artefact has been observed previously and seems to be quite a common feature of FORC diagrams recorded using a Princeton VSM. The origin of the artefact is unclear, although it has been observed on a variety of different samples and cannot be removed by increasing the pause time during measurement, hence eliminating the possibility that the offset is caused by time-dependent magnetization processes. Removing the first point of every FORC curve can be achieved using the "remove first point artefact" feature of FORCinel v 1.19 [6]. This procedure reveals the true nature of the FORC signal and significantly improves the appearance of the FORC

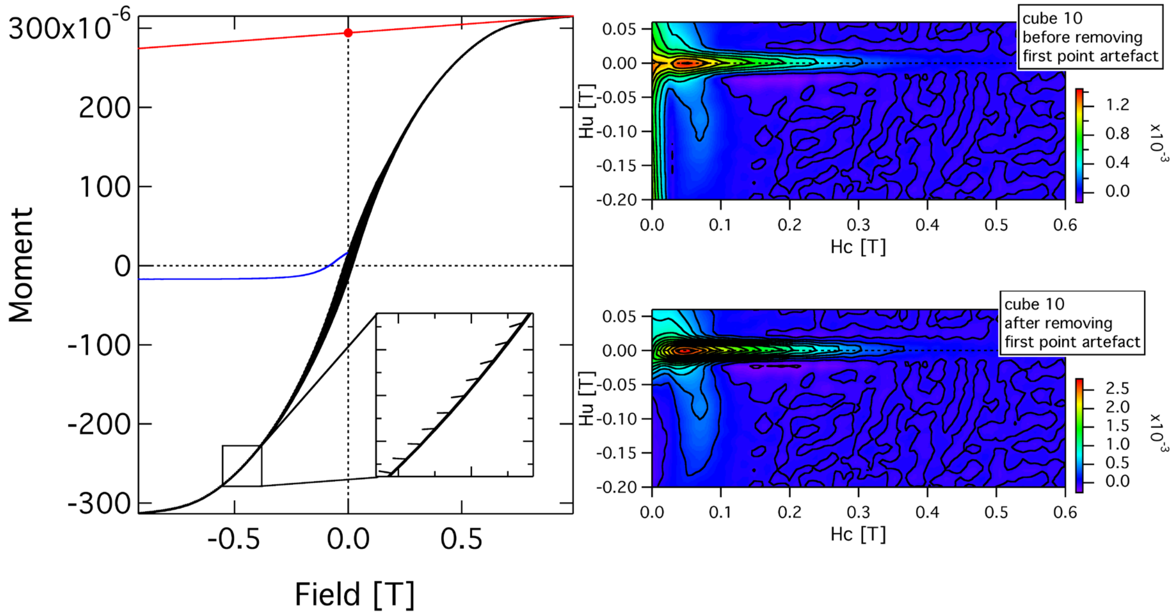

Figure 2. FORC data recorded for sample cube 10. Left: Individual FORCs, inset showing first point artefact. Right: Processed FORCs (SF = 4) before (top) and after (bottom) removing first point artefact.

diagrams (comparison of a FORC before and after the removal is shown in Fig. 2). We suggest that the origin of this artefact be further investigated (possibly through discussions with Princeton Measurements) and that users pay particular attention to the first point in their FORC curves, and remove the artefact if necessary.

The other (real) features showing up in the FORC diagram are a horizontal 'central ridge' with broad coercivity distribution characteristic of non-interacting single-domain particles [7], a broad positive peak at negative H_u values and $10 < H_c < 100$ mT, and a broad negative peak just below the central ridge. The combination of this positive and negative peak can be attributed to a "butterfly" structure characteristic of particles in a single-vortex state [8-10]. This observation indicates that single-vortex states are likely to be important remanence carriers in dusty olivine. Accounting for their presence will be essential in interpreting the remanence of natural samples.

Further work planned includes comparing different methods of non-heating paleointensity determination, such as REM'- and ARM-methods, with a new procedure to calculate paleointensities using FORC measurements [11-12].

References

[1] Boland, J.N. and Duba, A. (1981) *Nature*, 294, 142-144. **[2]** Uehara, M. and Nakamura, N. (2006) *Earth Planet. Sci. Lett.*, 250, 292-305. **[3]** Tauxe, L. (2010) *Essentials of Paleomagnetism*, University of California Press. **[4]** Kletetschka, G., Kohout, T. and Wasilewski, P.J. (2003) *Meteorit. Planet. Sci.*, 38, 399-405. **[5]** Gattacceca, J. and Rochette, P. (2004) *Earth Planet. Sci. Lett.*, 227, 377-393. **[6]** Harrison, R.J. and Feinberg, J.M. (2008) *Geochem. Geophys. Geosys*, 9, Q05016, doi:10.1029/2008GC001987. **[7]** Egli, R., Chen, A.P., Winklhofer, M., Kodama, K.P. and Horng, C.S. (2010) *Geochem. Geophys. Geosys.*, 11, doi: 10.1029/2009gc002916. **[8]** Pike, C.R. and Fernandez, A. (1999) *J. Appl. Phys.*, 85, 6668-6675. **[9]** Dumas, R.K., Li, C.-P., Roshchin, I.V., Schuller, I.K. and Liu, K. (2007a) *Phys. Rev. B*, 75, 134405-1-5. **[10]** Dumas, R.K., Liu, K., Li, C.-P., Roshchin, I.V. and Schuller, I.K. (2007b) *Appl. Phys. Lett.*, 91, 202501-1-3. **[11]** Muxworthy, A.R. and Heslop, D. (2011) *J. Geophys. Res.*, 116, B04102, doi: 10.1029/2010JB007843. **[12]** Muxworthy, A.R., Heslop, D., Paterson, G.A. and Michalk, D. (2011) *J. Geophys. Res.*, 116, B04103, doi: 10.1029/2010JB007844.

Liu Tungsheng and Huang Tu Magnetism

by Ted Evans[1], Friedrich Heller[2], and Simo Spassov[3]

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At the XVIII Congress of the International Union for Quaternary Research (INQUA) held in Bern 21-27 July, a special session was held to recognize the seminal contributions of Professor T.S. Liu to our understanding of past global change and to explore their continuing impact. In a long and fruitful career, Liu Tungsheng demonstrated—among many other things—that the Chinese Loess Plateau (CLP) is the foremost terrestrial archive of millions of years of paleoclimatic and paleoenvironmental variability. Born in 1917, Liu lived through the many turbulent events that rocked China throughout the 20th Century (the Japanese invasion, the Long March, the Cultural Revolution). His formal education was also affected by World War II. Nevertheless he graduated in 1942, and in 1946 commenced what

INQUA Congress Bern, 21st July 2011. Friedrich Heller kicks off Session 59: The magnetostratigraphic and environmental magnetic work of T.S. Liu and its continuing consequences. The screen behind Friedrich shows Liu Tungsheng in his late eighties animatedly addressing a 2006 meeting in Beijing. When last seen, the irksome obstruction in the foreground was attached to Ted Evans. (Photo courtesy of Ramon Egli).

was to become an outstanding career as a geologist. His early work involved fossil fish, but he was soon drawn into loess research, partly as a result of the great excitement surrounding the discovery of Peking Man. In the early 1920's the Austrian paleontologist Otto Zdansky (1894-1988), began excavations at the now-celebrated site of Zhoukoudian. The Canadian anatomist Davidson Black (1884-1934), who was teaching at the Peking Union Medical College, argued that the fossils coming to light represented a new hominid genus for which he suggested the name Sinanthropus (see "Further Hominid Remains of Lower Quaternary Age from the Chou Kou Tien Deposit", *Nature* 120, p.733, 1927). On the basis of this—and further spectacular finds—Black received a grant from the Rockefeller Foundation which he used to establish the Cenozoic Research Laboratory in 1928, the same year that INQUA itself was founded. Naturally, Liu Tungsheng eventually became familiar with all these developments and the scientists behind them, but he seems to have been most influenced by the paleontological work and philosophical writings of the French polymath Pierre Teilhard de Chardin SJ (1881-1955), who acted as a consultant to the Cenozoic Research Laboratory from its inception.

For Quaternary science in general—and for Session 59 at the Bern Congress in particular—the legacy of Zhoukoudian cannot be over-stated. Its impact on the career of Liu Tungsheng was critical, for it was Liu who went on to establish the "ground rules" that underpin paleoclimatic interpretations of the CLP record: (1) loess (huang tu, or yellow earth, in Chinese) is an aeolian deposit, (2) it accumulates during glacial periods when the north-east winter monsoon dominates, (3) soils (now buried and therefore paleosols) form during interglacials when precipitation increases due to enhanced south-west summer monsoons, (4) magnetic remanence locked in the sediments of the CLP captures polarity reversals of the geomagnetic field and thus furnishes a reliable chronology, and (5) magnetic susceptibility profiles of the loess/paleosol sequences provide a robust proxy record of paleoclimatic variability that can be matched to the oceanic oxygen isotope record.

The contributions to Session 59 (www.inqua2011.ch) reflected these various aspects of loess magnetoclimatology. Four invited talks from world leaders paid tribute to the life and work of Professor Liu and demonstrated that the topic is now a mature field of scientific research. But much remains to be done. For example, can the elusive goal of world-wide quantitative paleoclimatology be achieved? This will require advances in site-specific analysis to unravel the spatial variability in source materials (i.e. not all loesses are alike), and in local environmental conditions (i.e. not all pedogenetic pathways are alike). Our understanding of how iron cycling in soils takes place under widely differing conditions will need to be greatly improved. But the task is an important one. It offers the opportunity to map past global change, and thereby to check the results of numerical general circulation models (GCM's), which, in turn, offer one of the best means of predicting the climate change that awaits us. The oral presentations—to a standing-room-only audience—were accompanied by a lively poster session covering several related topics. Not surprisingly, the CLP was strongly represented, but results from Korea, Serbia, Bulgaria, and Alaska were also reported, along with contemporaneous data from marine sediments in the Pacific Ocean were also reported. Temporally, investigations were pushed back to 22 Ma—well outside traditional INQUA enquiries, but highly relevant to figuring out how the CLP evolved.

It is altogether fitting that Session 59 honored Liu Tungsheng, who was a past president of INQUA, at the first congress to be held after his death in 2008, and on the occasion of the inaugural presentation of the Union's Liu Tungsheng medal.

Current Articles

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

Magnetic Fabrics and Anisotropy

Anchuela, O., A. Imaz, A. Juan, and J. Llorens (2011), Acquisition and blocking of magnetic fabrics in synsedimentary structures, Eocene Pyrenees, Spain, *Geophys. J. Int.*, 186, 1015-1028.

Cañón-Tapia, E. (2011), AMS in Granites and Lava Flows: Two End Members of a Continuum?, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana,

and D. Ivers, pp. 263-280, Springer, New York.
Hrouda, F. (2011), Anisotropy of Magnetic Susceptibility in Variable Low-Fields: A Review, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 281-292, Springer, New York.
Larrasoana, J., M. Gomez-Paccard, S. Giralt, and A. Roberts (2011), Rapid locking of tectonic magnetic fabrics in weakly deformed mudrocks, *Tectonophys.*, 507, 16-25.
Mamtani, M., S. Piazolo, R. Greiling, A. Kontny, and F. Hrouda (2011), Process of magnetite fabric development during granite deformation, *Earth Planet. Sci. Lett*., 308, 77-89.
Raposo, M. I. B. (2011), Magnetic Fabric of the Brazilian Dike Swarms: A Review, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 247-262, Springer, New York.

Archeomagnetism

Goguitchaichvili, A., C. Greco, and J. Morales (2011), Geomagnetic field intensity behavior in South America between 400 AD and 1800 AD: First archeointensity results from Argentina, *Phys. Earth Planet. Int*., 186, 191-197.
Hartmann, G., A. Genevey, Y. Gallet, R. Trindade, M. Le Goff, R. Najjar, C. Etchevarne, and M. Afonso (2011), New historical archeointensity data from Brazil: Evidence for a large regional non-dipole field contribution over the past few centuries, *Earth Planet. Sci. Lett*., 306, 66-76.
Tema, E. (2011), Archaeomagnetic Research in Italy: Recent Achievements and Future Perspectives, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 213-234, Springer, New York.

Environmental Magnetism

Bailey, I., Q. S. Liu, G. Swann, Z. Jiang, Y. B. Sun, X. Zhao, and A. Roberts (2011), Iron fertilisation and biogeochemical cycles in the sub-Arctic northwest Pacific during the late Pliocene intensification of northern hemisphere glaciation, *Earth Planet. Sci. Lett.*, 307, 253-265.
Chague-Goff, C., J. Schneider, J. Goff, D. Dominey-Howes, L. Strotz (2011), Expanding the proxy toolkit to help identify past events - Lessons from the 2004 Indian Ocean Tsunami and the 2009 South Pacific Tsunami, *Earth Sci. Rev*., 107, 107-122.
Horng, C., and C.-A. Huh (2011), Magnetic properties as tracers for source-to-sink dispersal of sediments: A case study in the Taiwan Strait, *Earth Planet. Sci. Lett*., 309, 141-152.
Jordanova, D., Grygar, T., Jordanova, N., and Petrov, P. (2011), Palaeoclimatic Significance of Hematite/Goethite Ratio in Bulgarian Loess-Palaeosol Sediments Deduced by DRS and Rock Magnetic Measurements, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 399-412, Springer, New York.
Kletetschka, G. (2011), Magnetic Measurements on Maple and Sequoia Trees, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 427-441, Springer, New York.

Extraterrestrial Magnetism

Treiman, A., and E. Essene (2011), Chemical composition of magnetite in Martian meteorite ALH 84001: Revised appraisal from thermochemistry of phases in Fe-Mg-C-O, *Geochim. Cosmochim. Acta*, 75, 5324-5335.
Uehara, M., J. Gattacceca, H. Leroux, D. Jacob, and C. J. Van Der Beek (2011), Magnetic microstructures of metal grains in equilibrated ordinary chondrites and implications for paleomagnetism of meteorites, *Earth Planet. Sci. Lett*., 306, 241-252.

Geomagnetism

Deenen, M., C. Langereis, D. J. J. Van Hinsbergen, and A. Biggin (2011), Geomagnetic secular variation and the statistics of palaeomagnetic directions, *Geophys. J. Int*., 186(2), 509-520.
Jarboe, N. A., R. S. Coe, and J. Glen (2011), Evidence from lava flows for complex polarity transitions: the new composite Steens Mountain reversal record, *Geophys. J. Int*., 186, 580-602.
Pavlov, V. E., F. Fluteau, R. Veselovskiy, A. Fetisova, A. Latyshev (2011), Secular Geomagnetic Variations and Volcanic Pulses in the Permian-Triassic Traps of the Norilsk and Maimecha-Kotui Provinces, *Inv. Phys. Solid Earth*, 47, 402-417.
Valet, J.-P., and Herrero-Bervera, E. (2011), Time-Averaged and Mean Axial Dipole Field, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 131-138, Springer, New York.
Valet, J.-P., and Herrero-Bervera, E. (2011), A Few Characteristic Features of the Geomagnetic Field During Reversals, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 139-152, Springer, NY.

Magnetic Field Records

Bohnel, H., Herrero-Bervera, E., and Dekkers, M. J. (2011), Paleointensities of the Hawaii 1955 and 1960 Lava Flows: Further Validation of the Multi-specimen Method, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 195-212, Springer, New York.
Herrero-Bervera, E., and Acton, G. (2011), Absolute Paleointensities from an Intact Section of Oceanic Crust Cored at ODP/IODP Site 1256 in the Equatorial Pacific, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 181-194, Springer, New York.
Mochizuki, N., H. Oda, O. Ishizuka, T. Yamazaki, and H. Tsunakawa (2011), Paleointensity variation across the Matuyama-Brunhes polarity transition: Observations from lavas at Punaruu Valley, Tahiti, *J. Geophys. Res*., 116, B06103.
Spassov, S., Hus, J., Heller, F., Evans, M. E., Yue, L., and von Dobeneck, T. (2011), The Termination of the Olduvai Subchron at Lingtai, Chinese Loess Plateau: Geomagnetic Field Behavior or Complex Remanence Acquisition?, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 235-246, Springer, New York.
Stanton, T., P. Riisager, M. Knudsen, and T. Thordarson (2011), New palaeointensity data from Holocene Icelandic lavas, *Phys Earth Planet. Int*., 186, 1-10.

Rock and Mineral Magnetism

Alva-Valdivia, L. M., and H. Lopez-Loera (2011), A review of iron oxide transformations, rock magnetism and interpretation of magnetic anomalies: El Morro Mine (Brazil), a case study, *Geofisica Int*., 50, 341-362.
Brown, L. L., McEnroe, S. A., Peck, W. H., and Nilsson, L. P. (2011), Anorthosites as Sources of Magnetic Anomalies, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 321-342, Springer, NY.
Church, N., J. Feinberg, and R. Harrison (2011), Low-temperature domain wall pinning in titanomagnetite: Quantitative modeling of multidomain first-order reversal curve diagrams and AC susceptibility, *Geochem. Geophys. Geosys*., 12.
Fabian, K., N. Miyajima, P. Robinson, S. Mcenroe, T. Ballaran, and B. Burton (2011), Chemical and magnetic properties of rapidly cooled metastable ferri-ilmenite solid solutions: implications for magnetic self-reversal and exchange bias-I. Fe-Ti order transition in quenched synthetic ilmenite 61, *Geophys. J. Int*., 186, 997-1014.

Fabian, K., Robinson, P., McEnroe, S. A., Heidelbach, F., and Hirt, A. M. (2011), Experimental Study of the Magnetic Signature of Basal-Plane Anisotropy in Hematite, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 311-320, Springer, New York.

Herrero-Bervera, E., Acton, G., Krasa, D., Rodriguez, S., and Dekkers, M. J. (2011), Rock Magnetic Characterization Through an Intact Sequence of Oceanic Crust, IODP Hole 1256D, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 153-168, Springer, New York.

Kars, M., C. Aubourg, and J. Pozzi (2011), Low temperature magnetic behaviour near 35 K in unmetamorphosed claystones, *Geophys. J. Int*., 186, 1029-1035.

Kind, J., A. Gehring, M. Winklhofer, and A. Hirt (2011), Combined use of magnetometry and spectroscopy for identifying magnetofossils in sediments, *Geochem. Geophys. Geosys.*, 12.

Krasa, D., Herrero-Bervera, E., Acton, G., and Rodriguez, S. (2011), Magnetic Mineralogy of a Complete Oceanic Crustal Section (IODP Hole 1256D), in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 169-180, Springer, New York.

Oliva-Urcia, B., A. Kontny, C. Vahle, and A. Schleicher (2011), Modification of the magnetic mineralogy in basalts due to fluid-rock interactions in a high-temperature geothermal system (Krafla, Iceland), *Geophys. J. Int*., 186, 155-174.

Potter, D. K., T. M. Al-Ghamdi, and O. Ivakhnenko (2011), Sensitive Carbonate Reservoir Rock Characterization From Magnetic Hysteresis Curves and Correlation with Petrophysical Properties, *Petrophys*., 52, 50-66.

Till, J., M. Jackson, J. Rosenbaum, and P. Solheid (2011), Magnetic properties in an ash flow tuff with continuous grain size variation: A natural reference for magnetic particle granulometry, *Geochem. Geophys. Geosys*., 12, Q07Z26.

Mineral Physics and Chemistry

Bauer, M., P. Davydovskaya, M. Janko, M. Kaliwoda, N. Petersen, S. Gilder, and R. Stark (2011), Raman spectroscopy of laser-induced oxidation of titanomagnetites, *J. Ramen Spectrosc*., 42, 1413-1418.

Peng, Z. W., J. Hwang, M. Andriese, W. Bell, X. Huang, and X. Wang (2011), Numerical Simulation of Heat Transfer during Microwave Heating of Magnetite, *ISIJ Int*., 51, 884-888.

Tectonics/Paleomagnetism

Cande, S., and D. Stegman (2011), Indian and African plate motions driven by the push force of the Reunion plume head, *Nature*, 475, 47-52.

Domeier, M., R. Van Der Voo, E. Tohver, R. Tomezzoli, H. Vizan, T. Torsvik, and J. Kirshner (2011), New Late Permian paleomagnetic data from Argentina: Refinement of the apparent polar wander path of Gondwana, *Geochem. Geophys. Geosys*., 12, Q07002, doi:10.1029/2011GC003616.

Dominguez, A., R. Van Der Voo, T. Torsvik, B. Hendriks, A. Abrajevitch, M. Domeier, B. Larsen, and S. Rousse (2011), The ~270 Ma palaeolatitude of Baltica and its significance for Pangea models, *Geophys. J. Int.*, 186, 529-550.

Hillhouse, J., and S. Gromme (2011), Updated paleomagnetic pole from Cretaceous plutonic rocks of the Sierra Nevada, California: Tectonic displacement of the Sierra Nevada block, *Lithosphere*, 3, 275-288.

Piper, J., J. Zhang, B. Huang, and A. Roberts (2011), Palaeomagnetism of Precambrian dyke swarms in the North China Shield: The ~1.8 Ga LIP event and crustal consolidation in late Palaeoproterozoic times, *J. Asian Earth Sci*., 41, 504-524.

Rodriguez-Pinto, A., M. Ramon, B. Oliva-Urcia, E. Pueyo, and A. Pocovi (2011), Errors in paleomagnetism: Structural control on overlapped vectors - mathematical models, *Phys. Earth Planet. Int*., 186, 11-22.

Soto, R., A. M. Casas-Sainz, and J. Villalain (2011), Widespread Cretaceous inversion event in northern Spain: evidence from subsurface and palaeomagnetic data, *J. Geol. Soc*., 168, 899-912.

Titus, S., S. Crump, Z. Mcguire, E. Horsman, and B. Housen (2011), Using vertical axis rotations to characterize off-fault deformation across the San Andreas fault system, central California, *Geology*, 39, 711-714.

Instrumentation and Techniques

Beron, F., G. Soares, and K. Pirota (2011), First-order reversal curves acquired by a high precision ac induction magnetometer, *Rev. Sci. Instrum*., 82(063904).

Chadima, M., J. Pokorný, M. Dušek (2011), Rema6W-MS Windows Software for Controlling JR-6 Series Spinner Magnetometers, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, Springer, NY.

Other

Bosák, P., and Pruner, P. (2011), Magnetic Record in Cave Sediments: A Review, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 343-360, Springer, New York.

Moulin, M., F. Fluteau, V. Courtillot, J. Marsh, G. Delpech, X. Quidelleur, M. Gerard, and A. E. Jay (2011), An attempt to constrain the age, duration, and eruptive history of the Karoo flood basalt: Naude's Nek section (South Africa), *J. Geophys. Res*., 116.

Orgeira, M. J., Egli, R., and Compagnucci, R. H. (2011), A Quantitative Model of Magnetic Enhancement in Loessic Soils, in *The Earth's Magnetic Interior*, ed. E. Petrovsky, E. Herrero-Bervera, T. Harinarayana, and D. Ivers, pp. 153-168, Springer, New York.

Sato, S., Z. Yang, Y. Tong, M. Fujihara, H. Zaman, M. Yokoyama, K. Kitada, Y. Otofuji (2011), Inclination variation in the Late Jurassic to Eocene red beds from southeast Asia: lithological to locality scale approach, *Geophys. J. Int.*, 186, 471-491.

Velasco-Villareal, M., J. Urrutia-Fucugauchi, M. Rebolledo-Vieyra, and L. Perez-Cruz (2011), Paleomagnetism of impact breccias from the Chicxulub crater - Implications for ejecta emplacement and hydrothermal processes, *Phys. Earth Planet. Int*., 186, 154-171.

Rudolf L. Mössbauer, 1929-2011, ***cont'd. from pg. 1***

independently varied. The idea was that thermal energy could make up the loss of recoil energy and restore resonant absorption in the absorber. Thus Mössbauer expected that heating and cooling the absorber should increase and decrease absorption, respectively.

Here is Mössbauer's description of the experiment, taken from his Nobel Prize lecture: "If the relative shift of the emission and the absorption lines resulting from the recoil-energy losses is only of the order of magnitude of the line widths, a temperature increase leads, under favorable conditions, to a measurable nuclear absorption effect... The simultaneous cooling of the source and the absorber with liquid air led to inexplicable results, for which I first blamed effects associated in some way with the cooling of the absorber. In order to eliminate these unwanted side effects, I finally left the absorber at room temperature and cooled only the source...In a second series of experiments I attempted to explain the side effects which had appeared in the simultaneous cooling of the source and the absorber during the earlier experiments. The result of this attempt was striking: instead of the expected decrease, a strong increase in the absorption clearly manifested itself when the absorber was cooled. This result was in complete contradiction to the theoretical expectation. …In considering the possible sources of the anomalous resonance effect, I now began to subject the hypothesis of the existing theory to a critical examination. The views originally held as to the shape and energy of the emission and absorption lines were based on the assumption that the emitting and absorbing nuclei can be treated as free particles. It was therefore natural to modify this assumption, taking into account the fact that source and absorber were each used in crystalline form. Therefore, I first attempted to explain the observed anomalous resonance absorption by assuming that the recoil momentum was not transferred to the single nucleus. It should rather be transferred to an assembly of nuclei or atoms which include nearest or next nearest neighbors surrounding the nucleus under consideration. After the failure of this and other attempted explanations, based on a purely classical point of view, I turned my attention to a quantum-mechanical treatment of the problem." This meant a model comprising harmonic oscillators with quantized, equally-spaced energy states, with the separation between states comparable to the recoil energy. This model had been previously been used to analyze elastic and inelastic scattering of x-rays in solids, and supported his idea that resonant absorption increased as the temperature decreased because of the increased fraction of recoilless emission and absorption events.

In Mössbauer spectroscopy, which followed the discovery of recoilless nuclear resonance, the source and absorber are put into relative motion, modulating the energy of the gamma-rays recoillessly emitted by the source. This technique has found applications in physics, chemistry, biology, biochemistry, geochemistry, mineralogy, archeology, metallurgy and materials science. It has also been used for the study of extraterrestrial materials on the surface of Mars, and for the study of meteorites here on earth. According to Professor Bruce Moskowitz, two memorable applications of Mössbauer spectroscopy to geophysics are: i) the study of the magnetism and crystal chemistry of the titanomagnetites by Subir Banerjee in the 1960's, shortly after the technique became available; and (ii) the recent discovery of (titano)magnetite in Martian rock, soil, and dust by a spectrometer on the Spirit rover.

Many German physicists have won the Nobel prize for Physics, but Mössbauer was especially significant for being the first to win for work done in Germany following the devastation of WWII. As such he represented the rebirth of German science after the war. Mössbauer tried to use his celebrity to reform the structure of science in German universities toward the American model he had experienced at Caltech. This meant moving from a strongly hierarchical system, with one or two dominant professors in a department, to an egalitarian system with more or less equal full professors heading parallel research programs. My impression is that this program, sometimes called the Second Mössbauer Effect, has progressed, but not uniformly, in German universities.

In 1967-68, I held a postdoctoral position in Mössbauer's research group at the Garching campus of the TU. The group was quite large, comprising undergraduates to visiting scientists. Mössbauer was a handsome man with a serious but friendly manner. Certainly he was more formal than is common in the US, but that was generally true of German professors. Most impressive to me was the clarity and precision with which he talked about physics, both informally and during lectures or public talks. The lectures were meticulously prepared and were invariably brilliant and illuminating. His students treated him with great respect, holding his coat, opening the door for him, fetching a chair when he came to the lab, etc. So I was amazed to see the same students pouring beer on him at parties during Fasching, the Bavarian equivalent of Carnival. He bore this indignity gracefully. The next day it was business as usual at the laboratory. Here was a man who had made a remarkable discovery and had received great recognition, even adulation, as a graduate student. Yet, in the ensuing years of celebrity, he had managed to retain a healthy sense of humor.

For scientists, the importance of one's work is ultimately decided, not by prizes or awards, but by the influence the work has on the science done by others. It is no exaggeration to say that many thousands of papers have been published in which Mössbauer spectroscopy has played a significant role. By this criterion, Rudolf Mössbauer's scientific career was very successful indeed.

For more information on the Mössbauer effect and geological applications of Mössbauer spectroscopy:

Hunt, C., (1992), Mössbauer: Marvelous measurements of magnetic minerals, *IRM Quarterly*, 2:3.

Solheid, P.A. (1998), Mössbauer revisited, *IRM Quaterly*, 8:3.

Berquó, T.S., P. Solheid (2004), Mössbauer revisited again: Measurements in applied fields, *IRM Quarterly*, 14:2.

Dyar, M.D., D.G. Agresti, M.W. Schaefer, C.A. Grant, and E.C. Sklute (2006), Mössbauer spectroscopy of Earth and planetary materials, *Annu. Rev. Earth Planet. Sci.*, 34, 83-125.

Murad, E., (2008) Mössbauer mini-course notes, available on IRM website: http://www.irm.umn.edu/IRM/lecture_notes.html

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