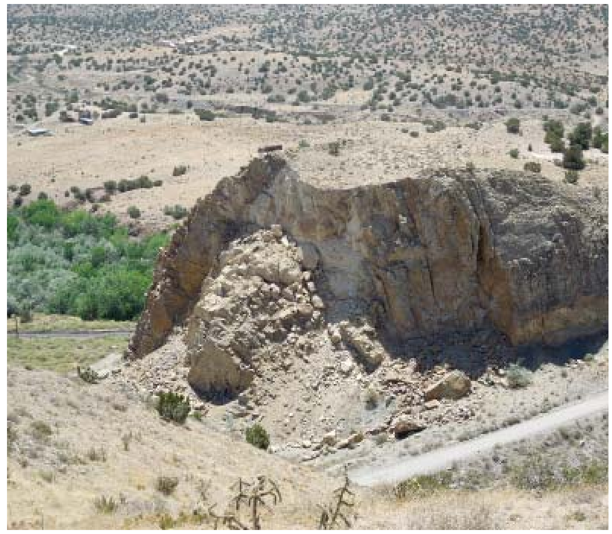
The IRM Quarterly
Spring 2012, Vol. 22 No. 1
ISSN: 2152-1972

Inside...

"Blowin' in the Wind" and "Beneath Still Waters": A Report on the 9th Santa Fe Conference on Rock Magnetism

Julie Bowles, Mike Jackson,
Bruce Moskowitz, IRM



The Devil's Throne, an Oligocene hornblende-latite porphyry that was emplaced into the Cretaceous Mancos Shale.

The 9th Santa Fe Conference on Rock Magnetism was held June 21-24 on the always beautiful campus of St. John's College in Santa Fe, New Mexico. The Santa Fe meetings are designed to allow collaborative exploration of the state of the art in our field, in an informal, interactive discussion-oriented mode. This year's conference was filled to its capacity of 50 people, and we were disappointed at being unable to accommodate those on a long waiting list. However, it was exciting to have so much interest in the meeting, which we attribute to the excellent program of speakers and topics put together by the session chairs who volunteered their time.

Eighteen people arrived in Santa Fe a day early to participate in a field trip to the nearby Cerrillos Hills. The field trip was expertly put together and led by Mike Petronis and Jennifer Lindline of New Mexico Highlands University. We all had a great time looking at the Oligocene Cerrillos Hills Igneous Complex, a series of dikes, sills, stocks and laccoliths that are intruded into the Cretaceous Mancos Shale. Details on the paleomagnetic work that has been done in the area over the past few decades were provided by Laurie Brown (University of Massachusetts) and Mike Petronis. We also learned about the very rich and long mining history in the area from John Rodgers.

After returning to St. John's College and a quick dinner in the cafeteria, the official meeting convened with an evening session devoted to atmospheric dust. Our first keynote speaker was Irina N. Sokolik from Georgia Institute of Technology. Irina is an expert in remote sensing and radiative transfer. In the tradition of these Santa Fe Meetings, Irina gave us a great "outsider's" perspective on how we quantify the amount of dust in the atmosphere, its sources, and its effects on climate. Because dust both reflects and absorbs radiation, it is poorly understood in terms of climate forcing. This means that accurate modeling of dust's optical properties is crucial, as is understanding how those properties change as dust composition changes. A lively question and answer session followed, focusing on the magnetic fraction of atmospheric dust, in particular ferric oxides like hematite which play an important role in the radiative properties of most dust. The lecture was followed by a wine reception on the balcony overlooking the mountains, and people had a chance to further discuss the lecture and to catch up with old friends. Irina's presentation can be found on the meeting website: www.irm.umn.edu/SantaFe9/ .

Thursday morning began with a working session on environmental magnetism (Chairs: France Lagroix, Institut de Physique du Globe de Paris; Richard Reynolds, US Geological Survey) that tied into the keynote lecture from the night before. The session focused on Fe oxides in the modern environment with a focus on atmospheric dust. Bernie Housen (Western Washington University) described the magnetic properties of particulate matter collected by tree leaves in Bellingham, Washington. Leaves can be useful pollution biomonitors because they are both abundant and inexpensive (they DO grow on trees), but there are questions about their sampling efficiency/selectivity. Discussion focused on the need for air quality monitoring studies like this that sample air at street level (as opposed to on top of buildings), while finding ways to properly calibrate the data. Take-home message from the talk: Don't ride your bike uphill behind a diesel bus.

Barbara Maher (Lancaster University) gave an overview of environmental magnetism as it relates to Fe oxides in continental environments. She focused on the Chinese loess plateau (CLP) which both contains a great

cont'd. on pg. 7...

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.

Anisotropy/magnetic fabrics

Airoldi, G., J. Muirhead, E. Zanella, and J. White (2012), Emplacement process of Ferrar Dolerite sheets at Allan Hills (South Victoria Land, Antarctica) inferred from magnetic fabric, *Geophys. J. Int.*, 188(3), 1046-1060.

Hastie, W., M. Watkeys, and C. Aubourg (2011), Significance of magnetic and petrofabric in Karoo-feeder dykes, northern Lebombo, *Tectonophys*., 513, 96-111.

Humbert, F., P. Robion, L. Louis, D. Bartier, B. Ledesert, and S. Song (2012), Magnetic inference of in situ open microcracks in sandstone samples from the Taiwan Chelungpu Fault Drilling Project (TCDP), *J. Asian Earth Sci*., 45, 179-189.

Tang, Z., B. Huang, X. Dong, J. Ji, and Z. Ding (2012), Anisotropy of magnetic susceptibility of the Jingou River section: Implications for late Cenozoic uplift of the Tian Shan, *Geochem. Geophys. Geosys*., 13, doi:10.1029/2011GC003966.

Till, J., B. Moskowitz, and M. Jackson (2012), High-temperature magnetic fabric development from plastically deformed magnetite in experimental shear zones, *Geophys. J. Int*., 189, 229-239.

Zak, J., I. Soejono, V. Janousek, and Z. Venera (2012), Magnetic fabric and tectonic setting of the Early to Middle Jurassic felsic dykes at Pitt Point and Mount Reece, eastern Graham Land, Antarctica, *Antarctic Sci*., 24, 45-58.

Archeomagnetism

Catanzariti, G., M. Gomez-Paccard, G. Mcintosh, F. J. Pavon-Carrasco, A. Chauvin, and M. Osete (2012), New archaeomagnetic data recovered from the study of Roman and Visigothic remains from central Spain (3rd-7th centuries), *Geophys. J. Int.*, 188, 979-993.

Gomez-Paccard, M., G. Mcintosh, A. Chauvin, E. Beamud, F. J. Pavon-Carrasco, and J. Thiriot (2012), Archaeomagnetic and rock magnetic study of six kilns from North Africa (Tunisia and Morocco), *Geophys. J. Int*., 189, 169-186.

Environmental Magnetism/Paleoclimate Proxies

Badesab, F. K., T. von Dobeneck, K. R. Bryan, H. Müller, R. Briggs, T. Frederichs, and E. Kwoll (2012), Formation of magnetite-enriched zones in and offshore of a mesotidal estuarine lagoon: An environmental magnetic study of Tauranga Harbour and Bay of Plenty, New Zealand, *Geochem. Geophys. Geosyst*., doi:10.1029/2012GC004125.

Jiang, Z., and Q. Liu (2012), Magnetic characterization and paleoclimatic significances of late Pliocene-early Pleistocene sediments at site 882A, northwestern Pacific Ocean, *Sci. China - Earth Sci.*, 55, 323-331.

Kim, W., S. Doh, and Y. Yu (2012), Asian dust storm as conveyance media of anthropogenic pollutants, *Atmos. Enviorn*., 49, 41-50.

Yamazaki, T. (2012), Paleoposition of the Intertropical Convergence Zone in the eastern Pacific inferred from glacial-interglacial changes in terrigenous and biogenic magnetic mineral fractions, *Geology*, 40, 151-154.

Extraterrestrial Magnetism

Emmerton, S., A. Muxworthy, D. Hezel, and P. Bland (2011), Magnetic characteristics of CV chondrules with paleointensity implications, *J. Geophys. Res*., 116, doi:10.1029/2011JE003856.

Fu, R., and B. Weiss (2012), Detrital remanent magnetization in the solar nebula, *J. Geophys. Res*., 117, doi:10.1029/2011JE003925.

Shea, E., B. Weiss, W. Cassata, D. Shuster, S. Tikoo, J. Gattacceca, T. Grove, and M. Fuller (2012), A Long-Lived Lunar Core Dynamo, *Science*, 335, 453-456.

Geomagnetism and Geodynamo Studies

Gogorza, C., M. Irurzun, A. Sinito, A. Lise-Pronovost, G. St-Onge, T. Haberzettl, C. Ohlendorf, S. Kastner, B. Zolitschka (2012), High-resolution paleomagnetic records from Laguna Potrok Aike (Patagonia, Argentina) for the last 16,000 years, *Geochem. Geophys. Geosys*., 13, doi:10.1029/2011GC003900.

Gomez-Paccard, M., J. Larrasoana, S. Giralt, and A. Roberts (2012), First paleomagnetic results of mid- to late Holocene sediments from Lake Issyk-Kul (Kyrgyzstan): Implications for paleosecular variation in central Asia, *Geochem. Geophys. Geosys*., 13, doi:10.1029/2011GC004015.

Granot, R., J. Dyment, and Y. Gallet (2012), Geomagnetic field variability during the Cretaceous Normal Superchron, *Nature Geosci*., 5, 220-223.

Hoffman, K., and N. Mochizuki (2012), Evidence of a partitioned dynamo reversal process from paleomagnetic recordings in Tahitian lavas, *Geophys. Res. Lett*., 39, doi:10.1029/2011GL050830 .

Korte, M., C. Constable, F. Donadini, and R. Holme (2011), Reconstructing the Holocene geomagnetic field, *Earth Planet. Sci. Lett*., 312, 497-505.

Linder, J., and S. Gilder (2012), Latitude dependency of the geomagnetic secular variation S parameter: A mathematical artifact, *Geophys. Res. Lett*., 39, doi:10.1029/2011GL050330.

Moulin, M., V. Courtillot, F. Fluteau, and J. Valet (2012), The "van Zijl" Jurassic geomagnetic reversal revisited, *Geochem. Geophys. Geosys*., 13, doi:10.1029/2011GC003910.

Nilsson, A., R. Muscheler, and I. Snowball (2011), Millennial scale cyclicity in the geodynamo inferred from a dipole tilt reconstruction, *Earth Planet. Sci. Lett*., 311, 299-305.

Olson, P., U. Christensen, and P. Driscoll (2012), From superchrons to secular variation: A broadband dynamo frequency spectrum for the geomagnetic dipole, *Earth Planet. Sci. Lett*., 319, 75-82.

Panovska, S., C. Finlay, F. Donadini, and A. Hirt (2012), Spline analysis of Holocene sediment magnetic records: Uncertainty estimates for field modeling, *J. Geophys. Res*., 117, doi:10.1029/2011JB008813,

Shcherbakov, V., and K. Fabian (2012), The geodynamo as a random walker: A view on reversal statistics, *J. Geophys. Res*., 117, doi:10.1029/2011JB008931.

Happy field trip participants near Cerrillos, New Mexico.

Tarduno, J. (2012), Geomagnetism: Hum from the quiet zone, *Nature Geosci.*, 5, 161-162.

Ziegler, L., and C. Constable (2011), Asymmetry in growth and decay of the geomagnetic dipole, *Earth Planet. Sci. Lett.*, 312, 300-304.

Magnetic Field Records and Paleointensity methods

Calvo-Rathert, M., A. Carrancho, F. Stark, J. Villalain, and M. Hill (2012), Are burnt sediments reliable recorders of geomagnetic field strength?, *Quat. Res.*, 77, 326-330.

Channell, J., D. Hodell, and J. Curtis (2012), ODP Site 1063 (Bermuda Rise) revisited: Oxygen isotopes, excursions and paleointensity in the Brunhes Chron, *Geochem. Geophys. Geosys.*, 13, doi:10.1029/2011GC003897.

Ferk, A., R. Leonhardt, F. W. Von Aulock, K. Hess, and D. Dingwell (2011), Paleointensities of phonolitic obsidian: Influence of emplacement rotations and devitrification, *J. Geophys. Res.*, 116, doi:10.1029/2011JB008397.

Shcherbakova, V., V. Bakhmutov, V. Shcherbakov, G. Zhidkov, and V. Shpyra (2012), Palaeointensity and palaeomagnetic study of Cretaceous and Palaeocene rocks from Western Antarctica, *Geophys. J. Int.*, 189, 204-228.

Xuan, C., J. Channell, L. Polyak, and D. Darby (2012), Paleomagnetism of Quaternary sediments from Lomonosov Ridge and Yermak Plateau: implications for age models in the Arctic Ocean, *Quat. Sci. Rev*., 32, 48-63.

Rock and Mineral Magnetism

Abdelmalak, M., C. Aubourg, L. Geoffroy, and F. Laggoun-Defarge (2012), A new oil-window indicator? The magnetic assemblage of claystones from the Baffin Bay volcanic margin (Greenland), *AAPG Bull*., 96, 205-215.

Bowles, J., L. Tatsumi-Petrochilos, J. Hammer, and S. Brachfeld (2012), Multicomponent cubic oxide exsolution in synthetic basalts: Temperature dependence and implications for magnetic properties, *J. Geophys. Res*., 117, doi:10.1029/2011JB008867.

Carporzen, L., B. Weiss, S. Gilder, A. Pommier, and R. Hart (2012), Lightning remagnetization of the Vredefort impact crater: No evidence for impact-generated magnetic fields, *J. Geophys. Res*., 117, doi:10.1029/2011JE003919.

Ferre, E., J. Geissman, and M. Zechmeister (2012), Magnetic properties of fault pseudotachylytes in granites, *J. Geophys. Res*., 117, doi:10.1029/2011JB008762.

Heslop, D., and A. Roberts (2012), A method for unmixing magnetic hysteresis loops, *J. Geophys. Res*., 117, doi:10.1029/2011JB008859.

Heslop, D., and A. Roberts (2012), Estimating best fit binary mixing lines in the Day plot, *J. Geophys. Res*., 117, doi:10.1029/2011JB008787.

Malvoisin, B., J. Carlut, and F. Brunet (2012), Serpentinization of oceanic peridotites: 1. A high-sensitivity method to monitor magnetite production in hydrothermal experiments, *J. Geophys. Res*., 117, doi:10.1029/2011JB008612.

Mang, C., A. Kontny, D. Harries, F. Langenhorst, and L. Hecht (2012), Iron deficiency in pyrrhotite of suevites from the Chesapeake Bay impact crater, USA-A consequence of shock metamorphism?, *Meteorit. Planet. Sci*., 47, 277-295.

Njanko, T., E. Fozing, M. Kwekam, A. Sandjo, and E. Njonfang (2012), Magnetic Characterization of Amphibolites from the Fomopea Pluton (West Cameroon): Their Implication in the Pan-African Deformation of the Central African Fold Belt, *Acta Geol. Sinica - Eng.*, 86, 73-84.

Reznicek, R., V. Chlan, H. Stepankova, P. Novak, and M. Marysko (2012), Magnetocrystalline anisotropy of magnetite, *J. Phys. - Condensed Matter,* 24, 055501, doi:10.1088/0953-8984/24/5/055501.

Robinson, P., R. Harrison, N. Miyajima, S. Mcenroe, and K. Fabian (2012), Chemical and magnetic properties of rapidly cooled metastable ferri-ilmenite solid solutions: implications for magnetic self-reversal and exchange biasuII. Chemical changes during quench and annealing, *Geophys. J. Int*., 188, 447-472.

Sorescu, M., T. Xu, A. Wise, M. Diaz-Michelena, and M. Mchenry (2012), Studies on Structural, Magnetic and Thermal Properties of xFe_2TiO_4-(1-x)Fe_3O_4 ($0 <= x <= 1$) Pseudo-binary System, *J. Magn. Mag. Mat*., 324, 1453-1462.

Tectonics/Paleomagnetism

Buchan, K., A. Lecheminant, and O. Van Breemen (2012), Malley diabase dykes of the Slave craton, Canadian Shield: U-Pb age, paleomagnetism, and implications for continental reconstructions in the early Paleoproterozoic, *Can. J. Earth Sci.*, 49(2), 435-454.

Domeier, M., R. Van Der Voo, R. Tomezzoli, E. Tohver, B. Hendriks, T. Torsvik, H. Vizan, and A. Dominguez (2011), Support for an "A-type" Pangea reconstruction from high-fidelity Late Permian and Early to Middle Triassic paleomagnetic data from

Argentina, *J. Geophys. Res.*, 116, doi:10.1029/2011JB008495.
Domeier, M., R. Van Der Voo, and T. Torsvik (2012), Paleomagnetism and Pangea: The road to reconciliation, *Tectonophys.*, 514, 14-43.
Mitchell, R., T. Kilian, T. Raub, D. Evans, W. Bleeker, and A. Maloof (2011), Sutton hotspot: Resolving Ediacaran-Cambrian tectonics and true polar wander for Laurentia, *Am. J. Sci.*, 311, 651-663.
Oliva-Urcia, B., E. Pueyo, J. Larrasoana, A. Casas, T. Roman-Berdiel, R. Van Der Voo, and R. Scholger (2012), New and revisited paleomagnetic data from Permian-Triassic red beds: Two kinematic domains in the west-central Pyrenees, *Tectonophys.*, 522, 158-175.
Panaiotu, C., M. Visan, A. Tugui, I. Seghedi, and A. Panaiotu (2012), Palaeomagnetism of the South Harghita volcanic rocks of the East Carpathians: implications for tectonic rotations and palaeosecular variation in the past 5 Ma, *Geophys. J. Int.*, 189, 369-382.
Pisarevsky, S., P. Mccausland, J. Hodych, S. J. O'Brien, J. Tait, and J. Murphy (2012), Paleomagnetic study of the late Neoproterozoic Bull Arm and Crown Hill formations (Musgravetown Group) of eastern Newfoundland: implications for Avalonia and West Gondwana paleogeography, *Can. J. Earth Sci.*, 49, 308-327.
Radhakrishna, T., and M. Joseph (2012), Geochemistry and paleomagnetism of Late Cretaceous mafic dikes in Kerala, southwest coast of India in relation to large igneous provinces and mantle plumes in the Indian Ocean region, *Geol. Soc. Am. Bull.*, 124, 240-255.
Shephard, G., H. Bunge, B. Schuberth, R. Muller, A. Talsma, C. Moder, and T. Landgrebe (2012), Testing absolute plate reference frames and the implications for the generation of geodynamic mantle heterogeneity structure, *Earth Planet. Sci. Lett.*, 317, 204-217.
Silva, P., B. Henry, F. Marques, A. Hildenbrand, P. Madureira, C. Meriaux, and Z. Kratinova (2012), Palaeomagnetic study of a subaerial volcanic ridge (Sao Jorge Island, Azores) for the past 1.3 Myr: evidence for the Cobb Mountain Subchron, volcano flank instability and tectonomagmatic implications, *Geophys. J. Int.*, 188, 959-978.
Speranza, F., A. Di Chiara, and S. Rotolo (2012), Correlation of welded ignimbrites on Pantelleria (Strait of Sicily) using paleomagnetism, *Bull. Volcanol.*, 74, 341-357.

Chronostratigraphy/Magnetostratigraphy

He, H., C. Deng, P. Wang, Y. Pan, and R. Zhu (2012), Toward age determination of the termination of the Cretaceous Normal Superchron, *Geochem. Geophys. Geosys.*, 13, doi:10.1029/2011GC003901.
Schwartz, H., P. Renne, L. Morgan, M. Wildgoose, P. Lippert, S. Frost, K. Harvati, F. Schrenk, and C. Saanane (2012), Geochronology of the Manyara Beds, northern Tanzania: New tephrostratigraphy, magnetostratigraphy and $^{40}Ar/^{39}Ar$ ages, *Quat. Geochron.*, 7, 48-66.
Sevin, B., C. Ricordel-Prognon, F. Quesnel, D. Cluzel, S. Lesimple, and P. Maurizot (2012), First palaeomagnetic dating of ferricrete in New Caledonia: new insight on the morphogenesis and palaeoweathering of Grande Terre', *Terra Nova*, 24, 77-85.
Szurlies, M., M. Geluk, W. Krijgsman, and W. Kurschner (2012), The continental Permian-Triassic boundary in the Netherlands: Implications for the geomagnetic polarity time scale, *Earth Planet. Sci. Lett.*, 317, 165-176.
Xiao, G. et al. (2012), Evidence for northeastern Tibetan Plateau uplift between 25 and 20 Ma in the sedimentary archive of the Xining Basin, Northwestern China, *Earth Planet. Sci. Lett.*, 317, 185-195.

Visiting Fellows

January - June, 2012

Stacey Emmerton
Imperial College London
Magnetic characterization of oil sands

Pinar Ertepinar Kaymakci
Utrecht University
Archaeomagnetism of Turkey: Establishing a record of geomagnetic secular variation for the last 7000 years

Karl Fabian
Norwegian Geological Survey
Atomic structure and magnetic order in natural pyrrhotite, hematite-ilmenite compounds, and synthetic analogues

Tom Haerinck
K.U.Leuven
The anisotropy of magnetic susceptibility of chloritoid crystals

Paul Kelso
Lake Superior State University
Rock Magnetic characterization of samples from two magnetic anisotropy studies (NW USA and Australia) and two paleomagnetic studies (Nevada and Oregon)

Belén Oliva-Urcia
Pyrenean Institute of Ecology-CSIC
Testing the reliability of the magnetic signature of lake sediments as proxy for environmental changes (last deglaciation in northern Spain, Enol and Sanabri mountain lakes)

Dana M. Smith *
University of Wisconsin- Madison
Resolving seismogenic normal fault geometries using the paleomagnetic signature of pseudotachylyte

Basil Tikoff
University of Wisconsin - Madison
Paleomagnetic analysis on the edge: Testing tectonic models for the western margin of North America in western Idaho

Elif Uz *
Southern Illinois University
Thermal history of intracratonic basins constrained by magnetic studies of the Illinois and Karoo sedimentary rocks

Huapei Wang *
Rutgers, the State University of New Jersey
Thermal fluctuation tomography on bulk sediment samples across the Paleocene/Eocene boundary recorded in an Atlantic Coastal Plain core from New Jersey: Are the nanoparticles impact condensates or magnetosomes?

* US Student Fellowship

9th Santa Fe Meeting, cont'd. from pg. 1

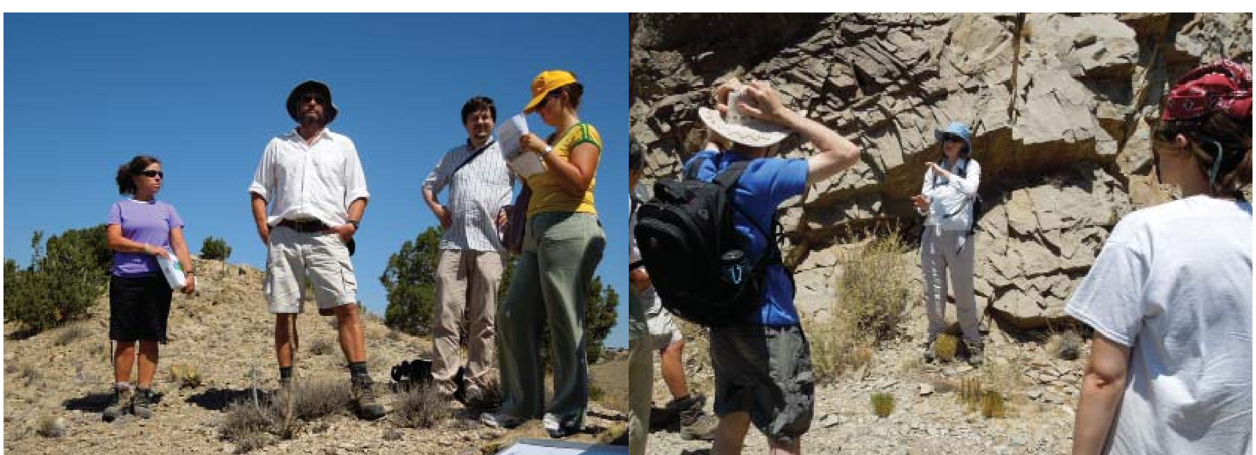
record of climate change, and is also potentially an agent of climate change, as dust from the plateau is mobilized into the atmosphere. Much of the talk and the discussion centered on the question of how to identify where atmospheric dust comes from, especially if it is chemically altered during transport, which makes fingerprinting a source especially difficult. Surface sediments from all of the potential source areas studied to date are significantly more magnetic than the CLP loess. To get around this, Barbara jointly uses 6-8 different magnetic properties in a fuzzy cluster analysis to test which deserts are too statistically distinct to be the source for the dust.

Barbara's talk about continental dust was followed by Andrew Roberts' (Australian National University) thoughts about the implications of dust deposition in the oceans. In addition to the radiative effects of particulates in the atmosphere, dust deposited in the oceans can induce phytoplankton productivity when Fe is a limiting micronutrient, leading to carbon export to the seafloor. Andrew identified some urgent issues for further research, including a better understanding of how cation substitution in hematite and goethite (common dust-borne minerals) affects the resulting magnetic properties. This bears strongly on our ability to translate magnetic properties into mass fraction hematite (for example). Other questions include: Can we use magnetic proxies (such as HIRM) of dust in marine sediments to make climate interpretations? What are the links between Fe fertilization and magnetotactic bacteria?

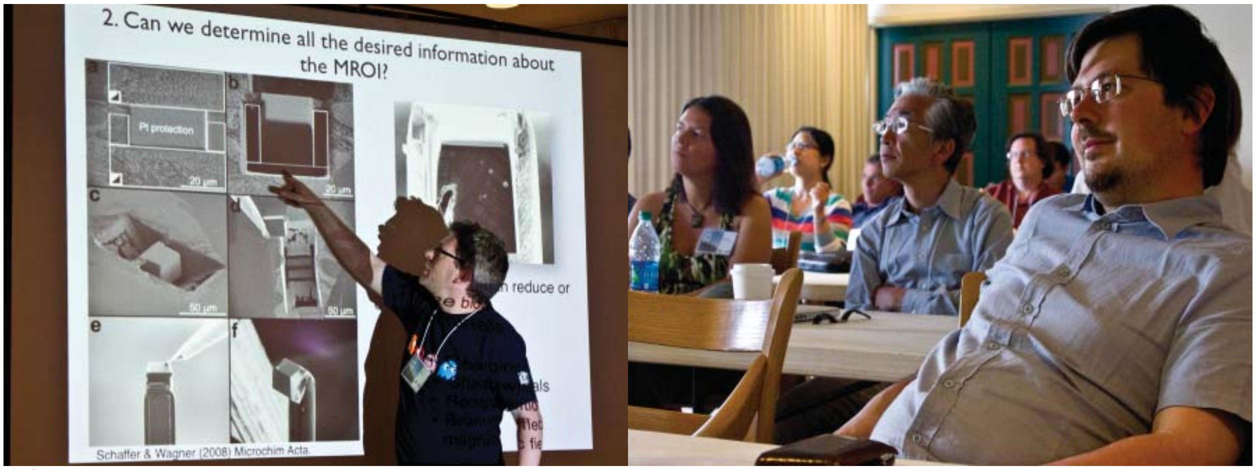
After breaking for lunch, the afternoon began with the meeting's second keynote lecture, given by Dennis Bazylinski from University of Nevada, Las Vegas. Titled "Small Magnetism, Big Attraction: The Magnetotactic Bacteria", Dennis talked about our current understanding of magnetotactic bacteria (MTB) from a biological perspective. Different strains of the bacteria produce magnetite or greigite crystals of high structural perfection, and some may produce both depending on their external chemical and redox environment. Because the bacteria live just below the oxic-anoxic transition zone (OATZ), it is thought that the purpose of the magnetosomes is to increase the efficiency of chemotaxis in locating the OATZ. The MTB are ubiquitous globally, and it has long been known that they occur in both oceanic and fresh-water environments. More recently, extremophilic MTB have been found in hot springs (up to 60°C) and in alkaline lakes. Because the genes responsible for biomineralization are grouped together, gene transfer is more likely and may explain the wide variety and global ubiquity of MTB. Finally, Dennis speculated based on the genetic analysis that tooth-shaped, magnetite magnetosomes may be the primordial magnetosome archetype. Dennis's presentation can be found on the meeting website: www.irm.umn.edu/SantaFe9/ .

The keynote lecture was followed by a working session on geomicrobiology and the magnetic signature of biogenic iron minerals (Chairs: Ramon Egli, Austrian Institute for Meteorology and Geodynamics; Bob Kopp, Rutgers University). Andrew Roberts (Australian National University) spoke about the survivability of magnetite and greigite magnetosomes in differing diagenetic environments and the abundance of magnetofossils in the geological record. Using detection techniques including transmission electron microscopy, FORC analysis, and ferromagnetic resonance, magnetofossils are inferred to be ubiquitous in pelagic carbonates as well as present in many lake and terrigenous marine sediments. There are some indications of an increase in both size and abundance of biogenic magnetite during paleo-warming events such as the Paleocene-Eocene thermal maximum (PETM) and the mid-Eocene climatic optimum (MECO) suggesting a link between climatic events and the type and abundance of MTB. Andrew also presented data suggesting that greigite-producing bacteria may be growing at depths of ~3 m in the sediment column, which would have obvious implications for magnetization lock-in depth and magnetostratigraphic dating. He suggested that we need to work on developing some kind of paleo-redox indicators to help constrain the depth of signal acquisition.

Kathie Thomas-Keprta (Johnson Space Center) returned to the ongoing debate about the possible origin of magnetite crystals in Martian meteorite ALH84001. Once thought to be biogenic in origin due to their similarity to magnetofossils observed on Earth, this was taken as evi-



(left photo) *Our fearless leaders, Mike Petronis (center) and Jennifer Lindline (left) from New Mexico Highlands University.* **(right photo)** *Laurie Brown (University of Massachusetts) describes some of the paleomagnetic work she and others have done at this location and in the area.*



(left) *Richard Harrison (University of Cambridge) provides a lively overview of a "microscale region of interest", while the crowd* **(right)** *watches with interest.*

dence for life on Mars. Because the crystals are embedded in carbonates, however, another hypothesis held that the crystals formed from thermal decomposition of Fe-rich carbonate. To test this, Kathie examined the composition and zoning of the carbonates as well as the composition of the magnetites. Based on experimental evidence and thermodynamic calculations, Kathie demonstrated the extremely low likelihood that the magnetite could have formed by thermal decomposition, thus leaving open the possibility that the crystals are indeed biogenic in origin.

The session wrapped up with Michael Winklhofer (Ludwig-Maximilians Universität München) in a discussion of magnetoreception in higher organisms (no offense to MTB). A variety of migrating animals such as birds and fish possess magnetic sensory organs, allowing them to detect the orientation and strength of the ambient geomagnetic field and use this information in migratory navigation. However the biophysical and physiological nature of magnetoreception remain incompletely understood, and the sensory organs have proven difficult to identify and extract for study. Michael reviewed different aspects of the search for magnetic sensing organs, including: (1) identifying and isolating cells connected to nerve terminations which contain magnetic minerals (for example, trout olfactory epithelium); (2) estimating the magnetic properties of those cells (superparamagnetic, single-domain), for instance with rotating magnetic fields under the microscope; and (3) implementing a biophysical model for how the magnetic signal is transmitted to the nervous system (e.g. opening/closing of ion channels).

Saturday morning began with a special presentation by Robin Reichlin from the U.S. National Science Foundation (NSF). Robin is a Program Director for the Geophysics program in the Earth Sciences Division at NSF. Robin talked about the opportunities for disciplinary, cross-disciplinary and international research at NSF. She gave an overview of the different funding opportunities at NSF, as well as tips for writing a successful cross-disciplinary proposal. Robin's presentation can be found on the meeting website: www.irm.umn.edu/SantaFe9/ .

Chairs Maxwell Brown, (Helmholtz Centre Potsdam - GFZ) and Jeff Gee (Scripps Institution of Oceanography) led us in the first working session of the day focused on paleointensity. Unfortunately for all involved, Aleksey Smirnov (Michigan Technological University) was unable to attend due to a cycling accident the day before the meeting, and we missed his talk entitled: "Long-term trends in absolute paleointensity as a proxy for the deep Earth's processes: Are we there yet?" Leah Ziegler (Oregon State University) fortunately arrived intact and spoke about "Insights and challenges in million-year views of paleointensity variations recorded in deep-sea sediments." Leah highlighted the difficulties involved in extracting and interpreting long-period paleointensity trends from marine sediments and focused on three major problems/opportunities. First, it has been observed that the average paleointensity is higher during the Bruhnes compared to the Matuyama chron, but it is much less clear whether there is a discrete change at the chron boundary or whether this is just a manifestation of a longer-period variation. Second, there appears to be an asymmetry in dipole growth and decay that is not restricted to reversals. What causes this asymmetry and how far back in time does it persist? Finally, what are the timescales for geocentric axial dipole (GAD) vs. non-GAD behavior? Are there long-lived or recurring flux patches that are not directly related to core flow but instead to boundary conditions.

Leah's talk was followed by two short contributions. Lisa Tauxe (Scripps Institution of Oceanography) updated us on progress and problems in trying to understand and model detrital remanent magnetization (DRM). Lisa has been working on modeling DRM, combined with laboratory experiments, which show that floc size and shape have strong impacts on DRM intensity and direction. Cathy Constable (Scripps Institution of Oceanography) presented recent work on modeling field behavior. She pointed out that you can't use intensity-only or direction-only data in producing models of the field at the core mantle boundary (CMB). Near the equator, for example, intensity measurements made at Earth's surface are "blind" to the CMB directly below, and are instead influenced more strongly by the CMB further poleward. In contrast, intensity data are particularly important in constraining models near the poles, where directional data are less sensitive. In this sense, directional and intensity data are complementary.

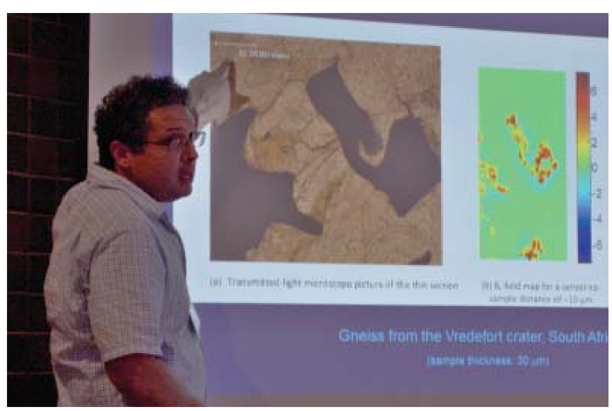
The final working session focused on fundamental rock magnetism (Chairs: Aleksey Smirnov, Michigan Technological University; Richard Harrison, University of Cambridge). In order to deepen our understanding of the messy materials produced in nature by a myriad of complex processes, it is extremely useful to work with synthetic analogues produced in the laboratory under controlled conditions and having controlled compositions, as shown by Julie Bowles (University of Minnesota) in her session-opening talk “Contributions of experimental petrology and mineralogy to rock magnetism: From rock squeezing to home-made magma.” In the ongoing search for ideal natural recording media, much attention has focused on glassy materials hosting magnetic oxide nanoparticles, and on silicate grains containing oxides formed by exsolution. Important questions still need to be resolved concerning the nature of the remanence carried by such phases and the reliability of paleomagnetic records obtained from them. A key area for future synthetic work was highlighted by new results from natural volcanic samples from Mt. St. Helens, containing titanomagnetites with moderate degrees of substitution by Al, Mg and other cations . These titanomagnetites exhibit strongly time- and temperature-dependent degrees of cation ordering (the distribution of cations on the octahedral and tetrahedral sites in the inverse spinel structure). Curie temperatures (T_c) vary by over 100° and are systematically related to emplacement temperature and cooling rate, which together determine the degree of ordering. The cation ordering can be changed in the laboratory by annealing, producing large changes in T_c without any change in chemical composition or crystal structure, but further work is required to determine the roles of the substitution cations in the phenomenon.

Richard Harrison asked us to consider a microscale region of interest (MROI) in a rock sample, whose remanence can be measured by scanning SQUID microscopy, and posed the question: what’s inside the box? In order to understand the origins and significance of the measured remanence, there are many things that we would like to know, including the mineralogy of the remanence-carrying grains, their sizes, 3D shapes and positions, their crystallographic orientations, domain configurations and internal microstructures. He then proceeded to show how most of this information can in fact be obtained by advanced methods of analytical electron microscopy (including electron holography and EBSD) in combination with focused ion-beam milling to remove successive layers, thereby producing a stack of 2D images which can be combined to obtain a full 3D micromagnetic and microstructural view of the original MROI in amazing detail. Still greater definition is attainable through the use of x-ray methods for magnetic imaging at nanometer and picosecond scales, and higher-resolution techniques of scanning microscopy (e.g., using a magnetic tunnel junction sensor). One of the grand challenges in rock magnetism is the development of a theoretical approach that can use such detailed information for quantitative prediction of magnetic behavior in populations of nonuniformly magnetized particles, in the same way that Néel theory works for noninteracting populations of single-domain grains.

An insightful review of scanning SQUID microscopy by Eduardo Lima (MIT) focused on the mathematical problem of inverting a set of measured magnetic fields to obtain the magnetization distribution in a sample. For practical reasons the measurements typically contain only the vertical component of the magnetic field vector at each mapped point, but (somewhat surprisingly) this is theoretically sufficient to reconstruct the full-vector field map. In some cases it is possible to invert for isolated dipole sources, but more often it is necessary to solve simultaneously for the entire source vector map. The well-known nonuniqueness problem arises because some source distributions (‘silent sources’) produce no measurable external field (e.g., a closed flux loop in the horizontal sample plane generates no vertical field above the sample). Various techniques can be applied to mitigate the non-uniqueness problem. For example it sometimes makes sense to assume a unidirectional magnetization distribution, in which only the intensity varies spatially (e.g., in the saturated remanent state). Although Fourier transform techniques are very fast, calculations in the spatial domain allow incorporation of additional information and constraints. The current state of the art makes it possible to obtain relatively clean demagnetization plots of individual sources down to moments of about 10^{-14} Am^2. Future improvements may be based on new non-superconducting sensors (e.g., using magnetic tunnel junctions) which can be used to map fields at a height of only 10 micrometers above the sample surface.

Sunday morning, we closed with a discussion of a white paper draft on “Mineral, Rock, and Paleomagnetism: 21st Century Strengths and Directions.” Cathy Constable (Scripps Institution of Oceanography and Chair of the IRM’s Review and Advisory Committee) led the discussion and was also largely responsible for coordinating and shepherding the draft into its present form. The document is intended to identify major challenges and opportunities in our field that also have potential impact across other disciplines. The goal is to serve as discussion points within our community, an “advertisement” for magnetism outside our community, and to excite and entice the next generation of scientists to enter our amazing, multi-disciplinary field.

Note: Thanks to Ramon Egli for input and suggestions.



Eduardo Lima, Massachusetts Institute of Technology.

University of Minnesota
291 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455-0128
phone: (612) 624-5274
fax: (612) 625-7502
e-mail: irm@umn.edu
www.irm.umn.edu

NONPROFIT ORG.
U.S. POSTAGE
PAID
TWIN CITIES, MN
PERMIT NO. 90155

The IRM Quarterly

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

Funding for the *IRM* is provided by the **National Science Foundation**, the **W. M. Keck Foundation**, and the **University of Minnesota**.

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

Julie Bowles
Institute for Rock Magnetism
University of Minnesota
291 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455-0128
phone: (612) 624-5274
fax: (612) 625-7502
e-mail: jbowles@umn.edu
www.irm.umn.edu

IRM

UNIVERSITY OF MINNESOTA

Keep current with IRM sponsored events and opportunities by following us on Facebook and Twitter.

www.irm.umn.edu