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Introduction to the special section on Fundamental and Frontier Research in Rock Magnetism

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[1] Many of the papers in this special section were first presented in the session "Rock Magnetism: Fundamentals and Frontiers" at the 2005 Fall AGU meeting. Collectively, they represent the leading edge of research in mineral magnetism and its applications to Earth and planetary sciences, as well as a tribute to Professor D. J. Dunlop, who has made profound contributions to the field.

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[2] It is now 25 years since *Dunlop*'s [1981] significant review paper appeared as part of a special publication commemorating the pioneering career of T. Nagata. In his concluding remarks, *Dunlop* [1981] wrote "Although it is now almost 30 years since the first edition of Nagata's classic 'Rock Magnetism' appeared in 1953, rock magnetism today is being pursued as vigorously as it was then. It is heartening to see that Professor Nagata does not regard the subject as laid to rest and is himself a contributor to this volume in his honor."

[3] As this special section demonstrates, rock magnetism today is still being pursued as vigorously as ever. It is heartening to see that Dunlop does not regard the subject as laid to rest and is himself a major contributor to this volume in his honor.

[4] In the energetic pursuit of rock magnetic research, *Dunlop*'s [1981] review article has since been superseded, first by his monumental review [*Dunlop*, 1990] and ultimately by the authoritative tome *Rock Magnetism: Fundamentals and Frontiers* [*Dunlop and Özdemir*, 1997]. Still it is both interesting and instructive to revisit *Dunlop*'s [1981] review, to highlight the sweeping progress of the field over the past quarter century, and to recognize some of the central problems that remain unsolved.

[5] Perhaps the most critical of these central problems involves the organization of magnetic moments on spatial scales intermediate between the nanometer scale on which magnetic ordering occurs and the micrometer scale of individual mineral grains at which the macroscopic magnetic effects are observed. It is this subgrain-scale organization into magnetic domains, walls, and more intricate structures that records information about past geomagnetic field directions and intensities and preserves this information through the eons. A complete understanding of how these structures develop and evolve in response to changing external fields and temperature and how they interact with the crystal microstructure, such as defects and their localized stress fields, would be a Rosetta stone for translating measured natural remanences into past geomagnetic field behavior. Needless to say, our understanding of these matters remains incomplete, but substantial progress continues to be made, as evidenced by a number of papers in this volume.

[6] *Dunlop* [1981] emphasized the well-established but still incompletely understood observation that magnetic properties vary continuously with increasing grain size, from the fine, uniformly magnetized ideal stable single-domain (SSD) end-member, all the way to large grains containing many body and surface domains and walls. The high SSD-like magnetic stability exhibited by multidomained grains remains a challenging problem in rock-magnetism, but significant progress has been made. *Dunlop* [1981] mentioned metastable single-domain states in large grains [e.g., *Halgedahl and Fuller*, 1980] and SD-like moments of domain walls (psarks [*Dunlop*, 1977]) as potential "remanence bridges" across the SD-MD transition.

[7] It is precisely in this enigmatic size range that a dramatic convergence of theory, experiment, and observation has been developing in recent years. Micromagnetic modeling of the organization and behavior of magnetic spin clusters has steadily increased in sophistication, both in the range of phenomena/experiments that can be simulated, and in the sheer number of cells that can be modeled [e.g., *Fukuma and Dunlop*, 2006; *Williams et al.*, 2006]. Simultaneously, imaging techniques such as magnetic force microscopy and electron holography [e.g., *Feinberg et al.*, 2006] have evolved to probe subgrain magnetization structures with ever finer scales of resolution. The nexus of modeling, observation, and experiment has brought us to the verge of a real understanding of pseudosingle-domain (PSD) behavior.

[8] Although low-temperature phenomena have long been used for identification of magnetic minerals [*Nagata et al.*, 1964] and for removal of unstable components of remanence [*Ozima et al.*, 1964; *Merrill*, 1970; *Dunlop and*

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Argyle, 1991], they play a much larger role in contemporary rock magnetic research than they have previously. Some of this growth is attributable to an increased emphasis on the study of sediments and sedimentary rocks that are not amenable to high-temperature study. Mostly, however, low-temperature phenomena are of vital interest because they provide additional means of probing the influence of magnetocrystalline anisotropy, phase transitions, transformational twinning, and other controls on magnetic properties such as remanence and hysteresis [e.g., *Carter-Stiglitz et al.*, 2006; *Özdemir and Dunlop*, 2006; *Smirnov*, 2006]. Moreover, low-temperature magnetic behavior is of direct potential relevance to the increasingly important investigation of paleomagnetic records preserved in meteorites [*Dunlop*, 2006].

[9] High-temperature measurements and thermoremanence (TRM) of course retain a central position in rock magnetism, both for paleofield/tectonic applications and for their experimental/theoretical foundations. All absolute paleointensity methods are based on total and/or partial TRM, and it is only for single-domain grains that we have a relatively complete theoretical foundation to work from. When methods based on SD theory (e.g., the standard Thellier-Thellier approach) are extended to rocks with MD carriers, it is critical to evaluate the extent to which the theory is violated and the effects on paleointensity determinations [e.g., *Yu and Dunlop*, 2006]. Alteration and thermochemical remanence acquisition in nature and in the laboratory are also near-universal concerns, and partial self-reversal is being more commonly recognized [e.g., *Doubrovine and Tarduno*, 2006; *Pan et al.*, 2006].

[10] Magnetostatic interactions provide one mechanism for generating partial or complete self-reversals [*Krasa et al.*, 2005; *Evans et al.*, 2006], but they also generate a wide variety of more subtle effects, particularly in connection with weak field properties such as AC susceptibility and anhysteretic remanence [*Egli*, 2006b] and their anisotropies. First-order reversal curve (FORC) analysis has been intensively studied of late, because it offers a possible means of quantifying mean interaction fields and the distribution of local interaction fields [e.g., *Egli*, 2006a; A. P. Chen et al., First-order reversal curve diagrams of natural and cultured biogenic magnetic particles, submitted to *Journal of Geophysical Research*, 2006].

[11] In this brief introduction we have sketched only some of the larger currents in modern rock magnetic research. They are well represented in this special section, as are a wide variety of other active research frontiers in rock and mineral magnetism, collectively being pursued as vigorously as ever.

[12] **Acknowledgments.** As individuals and as members of the global paleomagnetic/rock magnetic research community, we thank David Dunlop for leadership, insight, and inspiration. We appreciate the contributions of all the authors and reviewers, and we thank the JGR editors and staff for helping make this special publication a reality. This is IRM contribution 0612. The IRM is supported by the Instruments and Facilities Program of the Earth Science Division of the National Science Foundation.

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