PALEOMAGNETISM: Magnetic Domains to Geologic Terranes

Electronic Edition, May 1998

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Preface to the Electronic Edition of

Paleomagnetism: Magnetic Domains to Geologic Terranes

This electronic version of **Paleomagnetism: Magnetic Domains to Geologic Terranes** is made available for the use of "students of paleomagnetism." In this context, "student" means anyone who has sufficient interest in paleomagnetism to read through this text in an effort to gain a basic understanding of the subject.

Following the decision by Blackwell Science Inc., the original publisher, to no longer make the text available in hardcopy, I obtained the copyright to the book in an effort to keep it available to interested parties. I was encouraged by several people, most notably Mark Besonen of the University of Massachusetts Amherst, to reformat the text into PDF files which could be accessed using the internet or via ftp. As with all such efforts, this operation took much longer than originally imagined, although it was relatively straightforward. As is also often the case, someone other than the author did most of the work. In this case, that someone was Norman Meader. Norm took on the task of learning PageMaker and Adobe Acrobat in order to transform the book from text and graphics files into PDF files. Many hours of Norm's time went into this effort. All I had to do was proof the chapters as he completed the conversions. I am very grateful to Norm for his major effort on this project and his careful attention to detail. I also thank Steve Sorenson for his management of the computer system on which the files for this electronic version of the book are maintained.

Because I now hold the copyright to **Paleomagnetism: Magnetic Domains to Geologic Terranes**, it is within my legal right to permit users to make copies of this electronic version for their personal use. I hereby grant permission to anyone making a hardcopy of these PDF files to make additional hardcopies by xerography or other means for noncommercial use. The obvious importance of this permission is to allow instructors of classes or groups of students to make as many hardcopies of this book as they wish at the lowest possible cost. If you wish to have hardcopies made by a commercial firm, I recommend that you show this page to the personnel at such firms to assure them that no copyright is being violated by making hardcopies for personal use or use in formal or informal classes.

If you wish to make a citation to **Paleomagnetism: Magnetic Domains to Geologic Terranes**, you should cite the original 1992 printed version using standard citation styles.

Sincerely,

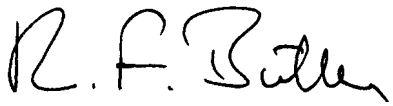

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TABLE OF CONTENTS

PREFACE

Terms such as continental drift, seafloor spreading, and plate tectonics are understood even by nongeologists to reflect the mobility of the Earth's lithospheric plates. The revolution in the Earth sciences that took place in the 1960s has changed our view of the Earth. The former view was that of a fairly static planet with occasional mountain-building episodes of uncertain origin. Our current view is that of a dynamic system of continental and oceanic lithospheric plates with frequently changing relative motions that are largely responsible for the structural evolution of the Earth. Paleomagnetism provided some of the quantitative data about past locations of continents and oceanic plates; these observations have become cornerstones of plate tectonic theory. Today paleomagnetism is providing evidence about motion histories of suspect terranes with respect to continental interiors and is enlightening the processes by which continents grow and mountain belts form. In addition, paleomagnetism has provided major refinement of stratigraphic correlations and geochronologic calibrations of both marine and nonmarine fossil zonations. These geochronologic advances have major implications for patterns and rates of biological evolution.

In both the tectonic and geochronologic applications of paleomagnetism, there has been an explosion in scientific literature over the past 20 years. Modern paleomagnetism was initiated in a few modestly equipped laboratories in England, France, the United States, and Japan with a world population of about a dozen paleomagnetists in the late 1950s. Paleomagnetism has now grown to be a technologically sophisticated research field with scores of laboratories and several hundred scientists with a research emphasis on paleomagnetism. Because of the wide and growing influence of paleomagnetism, many Earth scientists find themselves in need of basic knowledge of paleomagnetism. But without guidance by an instructor with research experience in paleomagnetism, it is difficult to build a basic knowledge base of the subject from the existing (and rather imposing) body of paleomagnetic and rock magnetic literature. This book is intended to teach the interested Earth scientist (student or otherwise) how paleomagnetism works. An introduction to the fundamental principles of paleomagnetism is provided along with examples of tectonic and geochronologic applications.

Emphasis is placed on providing a firm foundation in the basics of the paleomagnetic technique. The building blocks are geomagnetism, rock magnetism, and paleomagnetic methods. Chapters 1 through 7 build knowledge of the paleomagnetic method to an "intermediate" level. In the early chapters (especially Chapters 2 and 3), you must learn many new concepts about physics of magnetism without really knowing how this information will eventually apply to paleomagnetism. While the physics and mathematics required to understand each individual concept are not particularly difficult, the sum of these new concepts presented in rapid succession is indeed challenging. Effort and diligence invested in these early chapters will pay back major dividends in later chapters. Invariably, students who understand and appreciate paleomagnetism have an effective working knowledge of geomagnetism and rock magnetism.

Chapters 4 through 7 develop the methodology of paleomagnetism. These chapters are the "nuts and bolts" of the paleomagnetic technique. Topics include sampling schemes, basic laboratory procedures that put the rock magnetic principles to work, and statistical treatment of paleomagnetic data. Illustrations and real examples are emphasized because this material is largely geometrical, and pictures simply work better than words in developing an intuitive feel for the principles of paleomagnetism.

Chapters 8 through 11 are the applications chapters, the rewards for learning the principles of paleomagnetism. These chapters employ a "case example" approach. A small number of research applications are discussed in some detail rather than attempting to provide a complete summary of all past and present

applications. Chapter 8 explores several topics in rock magnetism that expand on the basic rock magnetic principles introduced in Chapter 3. The development of the geomagnetic polarity time scale is briefly reviewed in Chapter 9. This review is followed by example applications of magnetic polarity stratigraphy to a variety of geochronologic problems. Chapter 10 introduces principles of paleomagnetic applications to paleogeography and investigates formation and dispersal of supercontinents during the Phanerozoic. In Chapter 11, applications to regional tectonics are introduced with emphasis on the role of paleomagnetism in the developing views of crustal mobility. In these applications chapters, special note is made of how the principles presented in early chapters are critical to classic and current applications of paleomagnetism.

In the early chapters, in which the emphasis is on developing fundamental concepts, suggested readings are listed at the ends of the chapters rather than including references within the text. But in the applications chapters, references are included to provide the accurate impression of an evolving paleomagnetic database and differences in interpretations of the observations. These references can also serve as a guide to specific research topics that the reader may wish to explore. An appendix provides the details of mathematical derivations that lead to results used in the main text. Very little about the history of paleomagnetism is presented here, mostly because others have provided excellent personal accounts (see Suggested Readings).

Throughout the text, the first occurrences of important terms or key concepts are printed in italics. This draws special attention to the definitions and concepts that must be mastered to understand paleomagnetism. At least the first occurrences of vector quantities are printed in bold type to emphasize that these quantities have both direction and magnitude. Although subsequent occurrences of these vector quantities are usually printed in regular type, it is important to keep the vector nature of these quantities in mind. A few problems are included at the ends of Chapters 1 through 7. Working these problems will help you grasp the fundamentals presented in these chapters. A solutions manual is available from the publisher to instructors adopting this book for their courses.

Given this introduction to the game plan of the book, you understand the approach that we will take. With a working knowledge of the material presented in this book, you will be able to read current paleomagnetic research articles and understand the basic objectives, methodology, and results. Now let's just do it.

SUGGESTED READINGS

W. Glen, *The Road to Jaramillo*, Stanford Univ. Press, Stanford, 459 pp., 1982.
This book covers the development of the time scale of geomagnetic polarity reversals and its role in plate tectonic theory. Excellent history of science with the personalities of the scientists left in.

E. Irving, The paleomagnetic confirmation of continental drift, *Eos Trans. AGU*, v. 69, 1001–1014, 1988.
An excellent personal account of the paleomagnetic research leading to the confirmation of Wegener's continental drift hypothesis.

R. T. Merrill and M. W. McElhinny, *The Earth's Magnetic Field*, Academic Press, London, 401 pp., 1983.
Chapter 1 provides a thorough history of geomagnetism and paleomagnetism.

N. D. Opdyke, Reversals of the Earth's magnetic field and the acceptance of crustal mobility in North America: A view from the trenches, *Eos Trans. AGU*, v. 66, 1177–1182, 1985.
A personal account of the discovery of magnetic polarity reversals in deep-sea sediment cores and events leading to acceptance of seafloor spreading by Lamont Observatory personnel.

D. H. Tarling, *Paleomagnetism*, Chapman and Hall, London, 397 pp., 1983.
Chapter 1 provides a thorough account of the history of paleomagnetism. Covers many subjects that are not treated in this book.

ACKNOWLEDGMENTS

This book could not have been completed without considerable assistance from colleagues and family. Myrl Beck is at the top of the list of helpful colleagues. Myrl arranged for my sabbatical leave at Western Washington University, which provided the time for a good start on this project. Myrl also contributed significantly to the substance of the book. He provided very thorough editing of early chapters and contributed early versions of some of the derivations that appear in the appendix. Myrl's major contribution is gratefully acknowledged.

Many colleagues read portions of the text and provided important feedback. Steve May deserves special mention for contributing editorial comments and suggestions on the entire text. Very helpful formal reviews of portions of the book were provided by Ken Kodama, Rob Coe, Jim Diehl, and Peter Shive. Numerous colleagues provided important reviews of selected chapters. These include Dave Bazard, Sue Beske-Diehl, Peter Coney, Bill Dickinson, Tekla Harms, Jack Hillhouse, Bill Lowrie, Paul Riley, Rob Van der Voo, and Ray Wells. Special contributions of photomicrographs or data for figures were provided by Steve Haggerty, Chad McCabe, Hojatollah Vali, Ken Verosub, and Ted Walker. Gary Calderone contributed several computer programs that were instrumental in producing the figures in Chapter 6.

All of the figures were prepared on Apple® Macintosh™ computers. Most of the figures were done by the author using MacDraw® II, TerraMobilis™, Stereo™, Cricketgraph™, and Wingz™ software. Paul Mirocha masterfully prepared Figures 1.4, 1.6, 1.11, 2.6, 2.9, 4.3, 5.3, and 7.1, which were beyond my capabilities. The text was prepared using Microsoft® Word™ with MathType™ 2.0 used for equation setting. I owe special thanks to Norm Meader for his meticulous assistance with text preparation.

Simon Rallison helped tremendously in his capacity as editor for Blackwell Scientific Publications. His constant encouragement and gentle reminders of things that needed attention provided me with just the right guidance.

This book is dedicated to my wife Patricia for her unfailing encouragement and support throughout the duration of this project. Expertly dealing with the logistics of a sabbatical leave and keeping the family ship afloat were just part of her contribution. In small compensation for my absences during the preparation of the manuscript, our family decided that we should take a trip in celebration of completing this book. I was hoping to see Hawaiian volcanoes. However, my son David decided that Disneyland was the place for us. I don't know what others do when they complete a book, but I'm going to Disneyland.