Environmental MAGNETISM

ROY THOMPSON
Department of Geophysics, University of Edinburgh
and
FRANK OLDFIELD
Department of Geography, University of Liverpool

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Preface

The scientist will be forced, in the unenthusiastic words of one of my scientific colleagues, 'to slosh about in the primordial ooze known as inter-disciplinary studies'.

John Passmore
Man's responsibility for nature

The present text has arisen from some thirteen years of collaboration between the two authors. During that period, upwards of a dozen postgraduates in Edinburgh, the New University of Ulster and Liverpool have been closely involved in exploring many of the applications of magnetic measurements described in the second half of the book. Much of the text is based on their work, both published and unpublished. A great deal of the work summarised reflects extensive co-operation not only between the authors and among their postgraduate groups, but also involving colleagues in geology, geography, ecology, hydrology, meteorology, glaciology, archaeology, limnology, oceanography, chemistry and physics. It is from this wide range of collaborative, interdisciplinary work that the concept of the book has arisen. If indeed, as we hope to have shown, magnetic measurements have a growing rôle to play in many diverse and important areas of the environmental sciences, then there is a case for trying to bring together and present in an organised way, illustrations of as many applications as possible. The text also includes enough grounding in principles and techniques to encourage the interested research worker in any of the potential 'user' disciplines to understand the methods and results more fully as well as to approach the practical use of the techniques with more background, insight and confidence.

Progress in empirical science often grows from advances in our perception, appraisal and creative use of order in natural systems. Out of this can come enhanced insight into processes, structures and systems interactions on all temporal and spatial scales and at all integrative levels from subatomic to cosmic. In the environment, elements of order are often difficult to appraise and analyse, not only because of intrinsic complexity, but as a consequence of our lack of techniques, instrumentation and suitable methodologies. Magnetic properties, whether natural or induced, reflect forms of order which, in recent years, have become dramatically more accessible to a growing range of instruments and techniques. Developments in electronics and computing have been vital elements in this trend, complementing and, at times, stimulating growing interest in and concern for the environmental studies to which magnetic measurements can contribute. Thus methodological advance, problem definition and hypothesis development have been mutually interactive at all stages in the work, each aspect giving the lead from time to time.

Much of the second half of the book has arisen out of work stimulated by the late F. J. H. Mackereth of the Freshwater Biological Association Laboratories in the English Lake District. His studies of the Flandrian sediments of Windermere showed that the stable natural remanent magnetisation locked into them gave a consistent record of secular variation which, once calibrated by ^{14}C dating and through comparison

with Observatory records and archaeomagnetic evidence, could provide a chronological framework for palaeolimnological studies. At the same time, studies there and elsewhere were showing that lake sediment chronologies for the last few millenia, based on ^{14}C dates alone, almost always involved large errors arising from the inwash of old particulate carbon from persistent organic residues in terrestrial soils as a result of erosion following human activity. In the Lough Neagh sediments, which were the subject of a research project arising from serious aquatic pollution problems in the late 1960s, the 'old particulate carbon' error led to stratigraphically inverted ^{14}C dates over the past 2000 years. Consequently, much of the initial palaeolimnological work designed to reconstruct the historical background for assessing the present problems of cultural eutrophication in the lake was vitiated by lack of a chronology of sedimentation for the period of maximum human impact. The possibility of identifying the 1820 AD westerly declination maximum in the recent sediments prompted the application of Mackereth's palaeomagnetic approach to Lough Neagh. Not only did this exercise provide a suite of cores with stable, consistent and repeatable secular variation from a second lake (Thompson 1973), it played a crucial rôle in the development of the chronology of sedimentation (O'Sullivan *et al.* 1973) and led to a growing interest in the mineral magnetic properties of the sediment (Thompson *et al.* 1975). The realisation that the magnetic susceptibility variations provided a basis for rapid correlation and were a response to forest clearing and agriculture prompted first, a much wider range of catchment studies, and subsequently the extension of the approach to marine sediments and an interest in the magnetic properties of atmospheric particulates. Thus in a very real and direct sense, much of the work outlined in the second half of the book is a sequel to and consequence of the pioneering work of John Mackereth.

F. Oldfield
R. Thompson

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The broad range of topics and disciplines covered in this book has been made possible by the help, advice and stimulation we have received from many friends and associates over the past two decades. Numerous colleagues have generously provided hard won, well characterised field samples for us to indulge our magnetic whims on; others have unselfishly supplied us with their unpublished data; while others have patiently donated their time in order to guide us through the intricacies of their own disciplines and to reduce our confusions and misapprehensions. To all these friends, companies and colleagues we are extremely grateful. Sections of text have been read and much improved by the constructive comments of Rick Battarbee, Jan Bloemendal, David Collinson, John Dearing, Ed Deevey, Ken Gregory, Roy Gill, Andy Hunt, Jen Jones, Norman Hamilton, Barbara Maher, Malcolm Newson, Bill O'Reilly, Simon Robinson, Don Tarling and Des Walling. Our technical helpers and assistants have developed and maintained our field and laboratory equipment despite (intermittent) abuses while new or rushed experiments have been attempted, and have striven to sustain high levels of 'quality control' over the hundreds of thousands of magnetic measurements made at Edinburgh and Liverpool during the course of the past years. Our students in particular have generated much of the data described in the book, and provoked and vitalised new lines of enquiry, and to them special thanks are due.

We also wish to thank Janet Hurst for her typing and mastery of the Liverpool University Faculty of Social and Environmental Studies word processor, and the staff of the drawing office in the Liverpool University Geography Department for their help in preparing the diagrams of the book.

Finally, we owe a great debt to our wives, not only for foregoing scrambling and skiing weekends in the Scottish mountains or days in the garden, but also for an acumen in spotting split infinitives and 'sentences that are not sentences'. Above all, we thank them for their continued support and encouragement. We dedicate this book to Mary and Christine.

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Introduction

Its purpose is to be suggestive to him rather than didactic; to put him in the way of intelligently observing for himself.

Archibald Geikie 1879
Outlines of field geology
London: Macmillan

Such is the scope and versatility of magnetic studies that the same apparatus can be used, within the span of a single day, to probe the orienting behaviour of living organisms, trace the origin of suspended stream sediments, provide estimates of particulate pollution, and explore, through measurements of palaeomagnetic intensities and pole positions, the dynamics of the Earth's fluid core. This very diversity presents us with a formidable challenge at the outset, the more so since in most of the disciplines touched on, few workers are familiar with either the principles of magnetism involved or with the methods of study employed.

The text of this book seeks to introduce research workers and advanced students to the range of applications of magnetic measurements in their own and related disciplines, as well as to provide a theoretical and practical background should this be required. Chapters 2–5 are concerned mostly with the properties, definitions, concepts, principles and theories which are used in later chapters. In so far as possible, the level of explanation and discussion chosen has been designed to allow non-physicists to understand and appreciate the magnetic properties which are inherent or may be induced in natural materials, and which form the basis for the wide range of applications illustrated later. For any interested readers unfamiliar with basic concepts in physics, we hope in the early chapters to raise their knowledge of magnetism, at least in an intuitive or qualitative sense, to the minimum level needed for making use of either the techniques directly or the results arising from their use.

Chapter 2 describes the various types of magnetic behaviour characteristic of natural materials. These categories of behaviour can be identified from relatively simple experiments which involve recording the response of specimens to changes in variables such as magnetic field and temperature. Many of the responses can be related to the properties of crystal structure and to the effects of crystal size and shape. These properties, along with others related to the concentration of magnetic minerals, form the basis for the magnetic differentiation of soils, sediments, peats and dusts (Chs 8–12 & 16) as well as for the property of natural magnetic remanence upon which magnetostratigraphy depends (Chs 13 & 14). Chapter 3 concentrates on naturally occurring minerals and sets out their different magnetic characteristics in terms of the magnetic properties and categories of behaviour outlined in Chapter 2. Chapter 4 deals with the magnetic parameters which we actually measure and use in the later chapters of the book in more detail. Some of these parameters are related to properties of the Earth's magnetic field, past or present (4.3.1), and others are quite independent of this and are instead a function of magnetic mineralogy, grain size and shape (4.3.2–4.8). These magnetic parameters can be diagnostic of mineral type and origin; they are sensitive to chemical and thermal transformations and

can reflect the ambient magnetic field at certain critical stages in processes such as sediment deposition, rock cooling or crystal growth. Used in combination, they provide a powerful new approach to the study of environmental systems. Chapter 5 considers the Earth's magnetic field at the present day and in the past. The definition of terms and concepts, the brief outline of sources of evidence and the introduction to the nature of variation in the Earth's field on a wide range of timescales all form a link with Chapters 13 and 14 dealing with magnetostratigraphy. Chapter 6 is devoted to methods of measurement and hence to instrumentation. Its main sections are designed to provide a practical guide to available techniques and appropriate equipment, largely for the benefit of prospective practitioners inexperienced in magnetic measurements. Chapters 2–6 as a whole serve both as an introduction to essential aspects of theory and practice and as a reference text once magnetic measurements and the appraisal of results are under way.

Chapter 7 introduces in general terms those environmental systems which involve the movement of material, including magnetic minerals. It develops the linking concept of particulate flux and foreshadows the use of magnetic minerals to explore, quantify and characterise this flux. In addition, some general points are noted regarding methods of sampling and sample preparation. In Chapters 8–12, the magnetic characterisation of particulate flux is considered in the full range of environmental contexts studied so far. Each chapter first considers the nature of mineral particles in general and magnetic minerals in particular in the environmental system considered, then briefly outlines their origin, movement and transformation. Suitable methods of sampling and measurement particular to the problems and processes involved are also outlined. Finally, case studies are summarised and these are designed to illustrate the applications of mineral magnetic studies, discuss areas of particular interest or future relevance, and identify crucial problems and uncertainties for further study. The range of mineral magnetic studies completed so far varies very much with the environmental system under consideration and this is reflected in the chapters themselves. Some are based on a wide range of empirical studies (e.g. Ch. 10) and others are necessarily more speculative (e.g. Ch. 11). Whereas Chapters 8–12 deal with 'artificial' *mineral* magnetic properties and their uses, Chapters 13 and 14 deal with natural remanent magnetisation and attempt to summarise the full range of palaeomagnetic measurements in the many environmental contexts where they have been studied. Chapter 15, on Biomagnetism, is concerned with the way in which animals make use of iron minerals, with emphasis on detecting the Earth's magnetic field as a directional aid. Chapter 16 is an integrative study based on the Rhode River, a tidal arm of Chesapeake Bay. It provides, amongst other things, an opportunity to develop more fully the themes of systems linkage and the scope for integrated magnetic studies especially within watershed-based interdisciplinary research programmes. The final chapter attempts a preliminary appraisal of the future rôle of magnetic measurements in environmental science.

Depending on initial training, experience and motivation, the reader may either begin with the early Chapters (2–6) or any one of the later ones (7–16) most closely related to his or her academic interests and research programme. We hope that for the geophysicist/palaeomagnetist approaching the book, the later chapters will encourage an interest in the wide range of only partly explored and potentially exciting environmental applications of magnetic measurements touched on. Perhaps in this way more scholars with the appropriate geophysical background and expertise will become interested in collaboration with non-geophysicists in other disciplines. Equally, we hope that the non-geophysicist, led to the book by an interest in particular areas of application, will feel stimulated to seek out opportunities to develop and extend the contribution of magnetic measurements to studies in his own field, through collaboration and a growing direct personal involvement in the techniques and the results obtained.