Quaternary Climates, Environments and Magnetism

The Quaternary has been a period of major climatic and environmental oscillations and our knowledge of these past variations is important for our understanding of the possible impact of human activity on the present-day environment.

*Quaternary Climates, Environments and Magnetism* presents an up-to-date account of the rich variety of uses of magnetic measurements in the environmental geosciences. It focuses on the Quaternary geological period, and reviews the application of magnetic studies to climatic and environmental problems. Ten chapters by leading world authorities describe the highlights of environmental magnetic work during the last decade and identify directions for future research. Emphasis is placed on a multidisciplinary approach to achieve a more thorough understanding of the environmental processes involved.

This volume will be of interest to research scientists from a wide range of disciplines working on Quaternary environments, including earth and environmental sciences, physical geology, geography and palaeoclimatology. It will also be valuable as a supplementary text for graduates and advanced undergraduates.

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Quaternary Climates, Environments and Magnetism

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‘One machine can do the work of fifty ordinary men. No machine can do the work of one extraordinary man’. E. Hubbard.

Preface

Raymond S. Bradley and Friedrich Heller

The use of magnetism in the study of Quaternary sediments began in the summer of 1926 when Gustav Ising (Fig. 1) made measurements of magnetic susceptibility and natural remanence on varved lake sediments from Sweden. His pioneering studies were finally published in 1942. Ising showed how the magnetic properties of the lake sediments varied with distance from the source (i.e. the ice margin) and identified a yearly periodicity in magnetic content – the varves deposited in spring were several times more magnetic than those deposited in winter. He explained these relationships

Figure 1. Gustav Ising, pioneer of magnetic susceptibility and remanence studies of Recent sediments.
in terms of the high specific weight of magnetite grains and their hydro-
logical response to the varying flows of glacial rivers. He also recognized
that in addition to a remanent moment and a reliable magnetic declination,
the lake clays had a considerable anisotropy of susceptibility which gave
rise to an inclination error. Another important date in the development of
magnetic studies of Recent sediments is Thursday 21 September 1967 – the
day that John Mackereth first measured the magnetic properties of sedi-
ments from Lake Windermere, UK (Fig. 2). His studies were pivotal in lead-
ing to a renewed interest in the origins of magnetic minerals in lakes and
soils and in recovering geomagnetic secular variation from Quaternary
sediments.

Frank Oldfield (Fig. 3) is a worthy successor to these two founding
fathers of environmental magnetism. Over a career of 35 years, Frank has

Figure 2. Excerpt from John Mackereth’s laboratory notebook of the first
magnetic declination measurements of Holocene sediments from Lake
Windermere, UK. Each sample was measured three times in four orienta-
tions on an astatic magnetometer.
published more than 140 scientific papers. Throughout his career, Frank has been fascinated by changes in ecosystems wrought by ‘natural’ climatic and environmental changes, and by the effects of human activities. Distinguishing these often intertwined effects in the palynological record of sediments is complex and difficult. Frank recognized that a multidisciplinary approach to deciphering landscape change would pay big dividends, and that, as part of such an effort, magnetic studies had much to offer. This approach culminated in his establishing the Radiometric, Mineral Magnetic and Palaeoenvironmental Research Centre at Liverpool University. Frank first became involved in magnetic studies while Professor of Geography and Dean of the School of Biological and Environmental Studies at the New University of Ulster (1967–1972). After a year as Deputy and Acting Vice-Chancellor at the University of Papua New Guinea in 1973, he returned to the UK to a Personal Chair in Geography, and the Directorship of the School of Independent Studies, Lancaster. In 1975 he moved again to become the John Rankin Professor of Geography, at Liverpool University. There he cultivated a stream of talented Ph.D. stu-
dents who specialized in a diverse range of topics using magnetic methods. In his early studies of the magnetic characteristics of sediments, Frank was constrained by the lack of appropriate instrumentation and depended on measurements made in the major palaeomagnetic laboratories. However, the 1970s saw the development of fluxgate magnetometers and pulse discharge magnetizers which Frank demonstrated could be profitably exploited by geography and environmental groups that were previously unused to laboratory magnetic measurements. Through a series of serendipitous events, he later met and began collaborating with Geoff Bartington who was able to design and extend the range of magnetic equipment. This fruitful collaboration was instrumental (so to speak) in helping to launch a company which now supplies equipment for magnetic studies world-wide. Frank applied Bartington’s instruments in numerous studies, demonstrating the important role that humans have played in the modification of the European landscape, in some cases for several millennia.

From 1994 to 1996, Frank led the international effort to understand palaeoenvironmental changes in southern Europe (PALICLAS – Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments; Guilizzoni & Oldfield, 1996). This effort involved nine research groups in several countries, each focused on a distinct area of geochronological and palaeoecological research. The result was, in Frank’s own words, ‘very much greater than the sum of its parts’. This, in no small way, was due to Frank’s leadership and vision of the overall effort. In 1996, Frank became Executive Director of the International Geosphere–Biosphere Programme’s Past Global Changes Project (IGBP–PAGES) based in Berne, Switzerland. This is a position that is ideally suited to his talents, involving the coordination and promotion of interdisciplinary research into climatic and environmental changes on a global scale. Frank’s effectiveness in this role has helped PAGES move from its initial planning phase into a full-fledged international science effort.

In essence, environmental magnetism investigates the magnetic properties of materials which have been formed under the influence of environmental processes. Magnetic measurements of soils, dusts and other sediments provide powerful and effective tools for analysing problems and questions related to environmental and climate change, including anthropogenic pollution. The methods of environmental magnetism have been applied on all scales: global palaeoclimatic variability has been recon-
constructed from the magnetism of well-dated and widely separated marine sediments of variable age; submicroscopically fine magnetic iron oxide particles have provided insight into iron mobilization, migration and precipitation during soil formation; and regional pollution by strongly magnetic spherical particles produced during fossil fuel combustion has been surveyed in industrialized areas. Due to the relatively simple measurement techniques involved, magnetic properties can be measured rapidly, at low cost and in a non-destructive manner, and they may be conducted in the laboratory as well as in the field.

The chapters presented in this book describe some of the major fields where magnetic methods have been successful in reconstructing detailed histories of Quaternary climate, in unravelling the formation of magnetic minerals in sediments, in tracing anthropogenic pollutants and in developing high resolution time-scales which are based on periodically changing sediment magnetic properties. The extraordinary sensitivity of magnetic proxies with respect to various environmental processes of sediment formation is clearly demonstrated.

Evidence is assembled to show how many processes such as diageneisis, dissolution, biological productivity, iron mobilization and precipitation, wind activity, erosion or rain fall – to mention only a few – control the development of magnetic signatures observed in deposits of marine and terrestrial provenance.

The authors of this book identify future research directions and also emphasize the multidisciplinary approach for a better and quantitative understanding of the environmental processes involved; they especially urge for progress in analytical and statistical techniques for quantifying the magnetic properties of mixed magnetic mineral assemblages. High-resolution dating is a pre-requisite for the correlation of sediments formed in different environments. It will also aid in analysing the formation time of the magnetic sediment signals and will provide the means for obtaining well-dated environmental records throughout the entire Quaternary which can be compared on millennial and finer time scales, thus providing data relevant to present-day changes. The knowledge of the chemical stability fields of ferromagnetic minerals should be further developed. This applies for instance to the frequently occurring ferrihydrite mineral system which is the precursor source of many well known ferromagnetic minerals. The fundamental magnetic properties (e.g. grain size dependence) and environ-
mental formation conditions of some ferromagnetic minerals such as goethite or greigite are still poorly known.

The build-up and/or destruction of ferromagnetic minerals may be further elucidated by micromagnetic field studies in combination with geochemical iron migration investigations, thus establishing pathways for the in situ production by abiotic and biological or biologically induced processes. Magnetic pollution studies and surveys have great potential because hazardous heavy metals are often adsorbed to the surface of ferromagnetic minerals. Such examples of potential future environmental magnetism research illustrate the wealth of possible applications of the method.

In recognition of his vital and energetic contributions to the field of environmental magnetism, this book is dedicated as a Festschrift to Frank Oldfield. It aims to bring together, for both the Quaternary and the magnetic communities, the wide-ranging and exciting results and ideas gained during the rapid expansion of the field over the last decade.