

BEST PRACTICES OF
GEOINFORMATIC
TECHNOLOGIES FOR
THE MAPPING OF
ARCHAEOLANDSCAPES

Edited by

Apostolos Sarris

ARCHAEPRESS ARCHAEOLOGY

ARCHAEOPRESS PUBLISHING LTD

Gordon House
276 Banbury Road
Oxford OX2 7ED

www.archaeopress.com

ISBN 978 1 78491 162 1
ISBN 978 1 78491 163 8 (e-Pdf)

© Archaeopress and the authors 2015

Cover design by Meropi Manataki

All rights reserved. No part of this book may be reproduced, stored in retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of the copyright owners.

Printed in England by Oxuniprint, Oxford

This book is available direct from Archaeopress or from our website www.archaeopress.com

Table of Contents

Preface	iii
Images of the Past: Magnetic Prospection in Archaeology	1
Kayt L. Armstrong and Tuna Kalayci	
GPR: Theory and Practice in Archaeological Prospection	13
Meropi Manataki, Apostolos Sarris, Jamieson C. Donati, Carmen Cuenca Garcia and Tuna Kalayci	
Identification of Shapes and Uses of Past Landscapes through EMI Survey	25
François-Xavier Simon and Ian Moffat	
Seismic Geophysical Methods in Archaeological Prospection	35
Pantelis Soupios	
Locating Graves with Geophysics	45
Ian Moffat	
Exploring the Interior of Tumuli: Examples from Investigations in Macedonia and Thrace	55
Gregory N. Tsokas, Panagiotis I. Tsourlos and Georgios Vargemezis	
Off-Shore Archaeological Prospection Using Electrical Resistivity Tomography	63
Kleanthis Simyrdanis, Nikos Papadopoulos and Theotokis Theodoulou	
Data Integration in Archaeological Prospection	71
Tuna Kalayci	
Overview of Underwater Archaeological Research with Advanced Technologies in Greece	85
Theotokis Theodoulou	
Aerial Reconnaissance in Archaeology – from Archives to Digital Photogrammetry	103
Gianluca Cantoro	
On the Use of Satellite Remote Sensing in Archeology	115
Athos Agapiou, Dimitrios D. Alexakis, Apostolos Sarris and Diofantos G. Hadjimitsis	
Cities and Satellites: Discovering Ancient Urban Landscapes through Remote Sensing Applications	127
Jamieson C. Donati	
More Than Line of Sight and Least Cost Path. An Application of GIS to the Study of the Circular Tombs of South-Central Crete	137
Sylviane Déderix	
Mixed Reality Applications, Innovative 3d Reconstruction Techniques & Gis Data Integration for Cultural Heritage	149
Lemonia Argyriou and Nikos S. Papadopoulos	
Interpreting the Past through Agent-Based Modeling and GIS	159
Angelos Chliaoutakis and Georgios Chalkiadakis	
Geomorphometry, Multi-Criteria Decision Analysis and Archaeological Risk Assessment	171
Athanasios Argyriou, Apostolos Sarris and Richard Teeuw	
Adding a Geographical Component in Cultural Heritage Databases	181
Poulicos Prastacos and Eleni Gkadolou	
Historical Maps on the Semantic Web	189
Eleni Gkadolou and Emmanuel Stefanakis	
Archaeomagnetic Method as a Dating Tool: Application to Greek Archaeological Sites from Prehistoric to Byzantine Periods	199
Despina Kondopoulou and Elina Aidona	
Geoarchaeology: a Review in Techniques	209
Eleni Kokinou	
Inorganic Geochemical Methods in Archaeological Prospection	219
Carmen Cuenca-García	
Mineralogical and Petrographic Techniques in Archaeology	231
Georgia Karampatsou and Theodoros Markopoulos	
Provenance of Ceramics: Methods and Practices	239
Nikolaos A. Kazakis and Nestor C. Tsirliganis	

Sustainable Data Management in the Study of Ancient Materials – Using the Example of Archaeological Ceramics	251
Anno Hein and Vassilis Kilikoglou	
Laser Tools in Archaeology and Conservation How Far Can We Get?	261
A. Philippidis, P. Siozos, Z.E. Papiaka, K. Melessanaki, K. Hatzigiannakis, M. Vakondiou, G. Manganas, K. Diamanti, A. Giakoumaki and D. Anglos	

Preface

New geoinformatic technologies have recently had a transformative effect on landscape archaeology, particularly by facilitating the high resolution acquisition and analysis of data over large areas. These techniques have fundamentally changed the nature and scope of questions that can be addressed regarding the archaeological record. Despite this stimulating potential, many practising archaeologists were not trained in these methods and so are not fully aware of their capabilities or the most appropriate ways to apply them. This volume collates state of the art research in the fields of geophysics, geochemistry, aerial imaging, dating, digital archaeology, GIS and marine archaeology to present a comprehensive overview of the specialised techniques which can contribute to landscape scale archaeological investigations. It is hoped that it will serve as a 'best practice' guide for their use and encourage their widespread adoption by the archaeological community.

Geophysical survey has been revolutionised by the wide scale availability of high quality positioning systems such as differential GPS and the introduction of fast sampling multi-sensor arrays. These have freed geophysicists from traditional small and regularly spaced grids and allowed them to collect high density data over large areas extremely quickly. This significant increase in areal coverage, does not simply increase the amount of data available, but fundamentally revises the way in which these techniques can examine the spatial distribution of archaeological material. It moves geophysics from just being a technique of 'archaeological prospection' to being one that can answer nuanced questions about the interaction between the landscape and humans in ways that are impractical through conventional excavation and pedestrian survey techniques. Not to mention that the playground of the application of these techniques becomes even more challenging when the archaeological context is not the usual one (e.g. off-shore prospection). Another major advance in geophysical survey is the prospects offered by data fusion for quantitatively combining different geophysical data in a rigorous fashion, which is not coloured by preconceptions about the data or study area.

On a much larger scale, aerial and satellite imaging also provide important new insights into archaeological landscapes. A particularly popular approach in recent years is the use of structure from motion photogrammetry to create composite orthophotos and digital elevation models from aerial platforms such as kites, balloons and drones. This has been mainly driven by the widespread availability of cheap unmanned aerial platforms and high resolution, lightweight digital cameras. This advance has been augmented by the widespread availability of high resolution satellite imagery, allowing the subtle surface expression of archaeological features to be mapped remotely. The aerial and satellite perspective of the archaeological sites is particularly suited to the study of the archaeolandscape as it positions archaeological material in the context of the broader area, including the topography, geomorphology, vegetation and hydrology.

Other spatially based digital techniques such as GIS, visualisation and agent based modelling also provide new tools for the analysis and dissemination of archaeological information. GIS modelling of geomorphic, topographical and geological parameters coupled with the spatial distribution of the cultural residues provide alternative ways to model the interactive responses between humans and environment through time. This is especially obvious when agent based modelling (ABM) is used to simulate the interactions between individual and collective entities in the landscape. Additionally, digital techniques allow the archiving and analysis of historical information in ways that facilitate new interpretations and mixed reality approaches provide stimulating means to reconstruct monuments and interpret and represent sites.

A number of other scientific methods have made an important contribution to the documentation of archaeological landscapes. For example, maritime archaeology has benefited from the wide scale availability of geophysical equipment as well as new technologies that allow the inspection of archaeological features below the depth of conventional SCUBA investigation. This includes diving technology such as the Exosuit and unmanned underwater vehicles. The use of geochemical techniques in archaeology has been facilitated by the use of low cost, high throughput methods such as ICP-AES and essentially non-destructive methods such as laser ablation sampling. Also of great interest are new portable field techniques such as pXRF which allow immediate feedback on composition during archaeological investigations and facilitate the informed guidance of sampling for more elaborate analysis. The above techniques coupled with other approaches such as dating methods and provenance studies can create a more integrated framework for the study of the archaeolandscape.

In conclusion, new geoinformatic technologies provide exciting new tools for the investigation and documentation of archaeological landscapes. This volume summarises the current best practices to enable archaeologists and practitioners to gain a further understanding of the current 'state of the art' across a broad disciplinary range. These methods are rapidly evolving and many new developments are expected soon however it is hoped that this book will serve as an impetus for archaeologists and cultural heritage professionals to integrate these techniques within their own research in a useful and productive fashion.

The compilation of the articles and the publication of the volume was performed in the framework of the POLITEIA research project, Action KRIPIS, project No MIS-448300 (2013SE01380035) that was funded by the General Secretariat for Research and Technology, Ministry of Education, Greece and the European Regional Development Fund (Sectoral Operational Programme : Competitiveness and Entrepreneurship, NSRF 2007-2013)/ European Commission.

Dr Apostolos Sarris

Director of Research

Laboratory for Geophysical-Satellite Remote Sensing & Archaeo-environment (GeoSat ReSeArch LAB)

Institute for Mediterranean Studies

Foundation for Research and Technology, Hellas

Rethymno, Crete, Greece



Images of the Past: Magnetic Prospection in Archaeology

Kayt L. Armstrong and Tuna Kalayci

Laboratory of Geophysical-Satellite Remote Sensing & Archaeo-environment (GeoSat ReSeArch Lab),
Institute for Mediterranean Studies (IMS), Foundation for Research and Technology Hellas (FORTH), Greece.
k.l.armstrong@ims.forth.gr, tuna@ims.forth.gr

Abstract: This chapter introduces near-surface magnetic prospection as it is applied in archaeology. It contains a short overview of the history of the application of this technique to archaeological sites and landscapes, and a brief discussion of the basic scientific principles involved. It is not designed to teach in-depth these principles, but rather to outline the current state of the art, and accepted 'best practice' principles for those wishing to employ magnetic methods in their research. As such, it is vital that practitioners obtain hands-on training on the conduction, processing, interpretation and reporting of geophysical surveys. This document discusses the environments and site-types that are best suited to magnetic methods, and explains how to get the most archaeological information from the surveys. It specifically considers the issues of working in Mediterranean environments, and explores mitigation strategies for these issues. It also emphasizes that magnetometry is one geophysical technique within a wide range available to the researcher, and discourages reliance on magnetics alone for archaeological geophysical prospection. There is also a short discussion of data processing and reporting and archiving for magnetic data.

Keywords: *magnetometry, gradiometry, geophysics, magnetic susceptibility, multi sensor surveys, data processing, archaeology, landscape.*

Introduction

It is impossible in a manuscript of this length to cover all but the most essential introduction to the physics behind magnetic prospection in archaeology, or the history of this discipline. Readers are referred to two excellent introductory texts that go into detail on both of these topics (and for other geophysical methods applied to archaeology): 'Seeing Beneath the Soil' (Clark 1996) and 'Revealing the Buried Past' (Gaffney and Gater 2003). This guide also draws heavily on the format and philosophy of the English Heritage best practice guidelines contained in 'Geophysical Survey in Archaeological Field Evaluation', (English Heritage 2008), which were updated in 2008 and a new version of them is also expected in 2015. Technology in this area has moved quickly, and 7 years on, this text will contain specific guidance on working with the most recently developed multi-sensor cart based gradiometer systems.

Magnetic Survey In Archaeology

In short, magnetic prospection in archaeology is the mapping of surface and sub-soil variations in the magnetic properties of soils and buried materials, such as walls, pit and ditch fills, and surfaces like roads. In order for it to be successful, there needs to be a measureable magnetic contrast between the buried material of interest and its surrounding matrix (usually soil, but also for example, sand). In near surface geophysical surveys, two main methods of discovering magnetic contrasts are employed. The first, considered here, is the influence magnetized remains have on the magnetic field of the earth. The second, and related property is that of magnetic susceptibility, which is how magnetized a material becomes in the presence of

a magnetic field (see Simon & Moffat, this volume). The physics of magnetic susceptibility is explained below. What follows here is a short history of the use of near-surface magnetic prospection in archaeology.

The first archaeological applications of magnetic geophysics were early instances of metal detectors being employed on archaeological sites, as noted by Hesse (2000), most particularly Mesnil du Buisson, who noticed that the instruments also responded to ceramic tiles, and predicted the future development of a sub-discipline of 'geophysics' dealing with shallow / near surface anomalies, including archaeological ones, as early as 1934. During and immediately following WWII, instances of metal detectors being employed in more or less systematic ways continued, but it is not until the early 1960's that we see the development of magnetometers and their specific application to look for buried archaeological features, in the deployment of proton precession and caesium vapour instruments in the search for Sybaris conducted by the Leric Foundation (Rainey *et al.* 1967). At the same time, in the United Kingdom Atkinson was developing methods and instruments for electrical surveys in archaeology, which together with the work of the Leric Foundation prompted a period of exploration of various near-surface geophysical methodologies in the 1950's and '60's. These were largely reported in the (now defunct) journal, *Prospezioni Archeologiche*, where the development of the discipline of archaeological geophysics can be traced. This slowed down in the 1980's, and in the UK in particular, the discipline moved out of the research arena and into applied practice, particularly in rescue archaeology. From the mid 1980's onwards, this shift to a commercial footing drove instrument development; since then advances in computing (speed of processors, graphic display capabilities, GPS

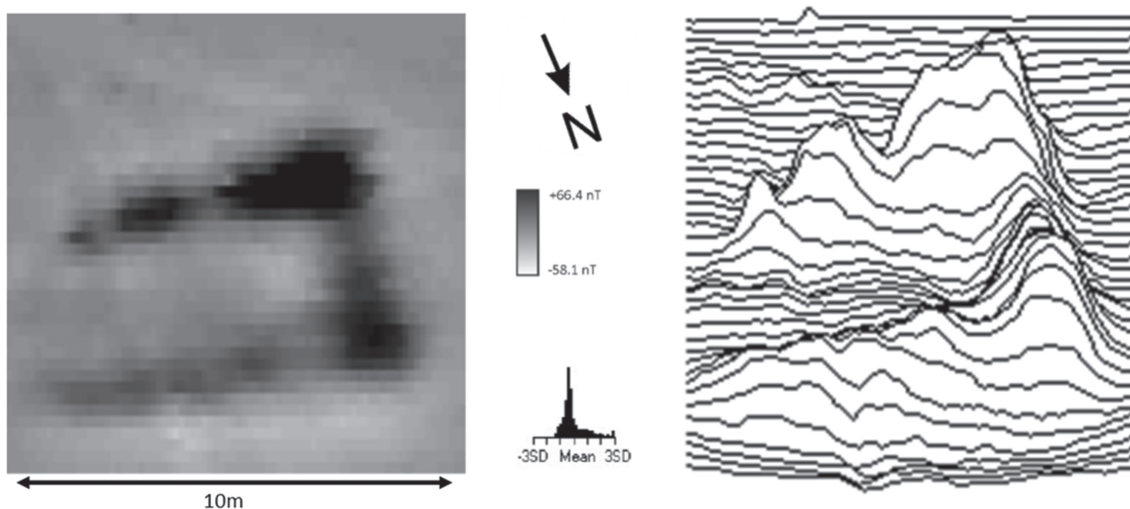


FIGURE 1. GREYSCALE RASTER PLOT (LEFT) AND TRACE PLOT (RIGHT) OF A GRADIOMETER SURVEY OVER SMALL BRONZE AGE STRUCTURE AT CONTRADA DAMALE, NORTHERN CALABRIA, ITALY. THE GREYSCALE DATA IS PLOTTED USING 55 SHADES OF GREY, WITH A SPREAD OF 3 STANDARD DEVIATIONS FROM THE MEAN. THE SURVEY WAS CONDUCTED WITH A RESOLUTION OF 0.25M X 0.125M.

improvements, and memory capacity) have all allowed the development of instruments and methodologies. The basic physics remains unchanged, but now we use multi-sensor platforms, located by differential-GPS or robotic total station, and towed from quad bikes, to cover huge areas: this has been made possible by changes in computing rather than fundamental developments in sensor technology or core methods.

The Physical Principles

Earth has an electromagnetic field that is generated by complex interactions in the molten metals in the planet's core. Circular currents exist at the core-mantle boundary and these act as a solenoid, generating the field. Important characteristics of this field are the distinctive changes in the angle of dip between the poles and the equator; which impacts on the magnitude and appearance of anomalies (Clark, 1996:64). In geomagnetic survey, the measurement unit is normally nT – nano Tesla ($= 10 \times 10^{-9}$ tesla), which is a measurement of magnetic flux density, or the strength of the magnetic field. The reason we normally work with such small units is because we are measuring very small changes in the local strength of the magnetic field of the Earth being caused (in archaeological surveys at least) by buried deposits or features that lead to small but detectable changes by one of two mechanisms. The strongest effects on the field come from remnant magnetization: this is when materials have been permanently magnetized by exposure to high temperatures (beyond their Curie point). These effects produce a small local magnetic field, which distorts the field produced by the earth. Typical archaeological examples include kilns and furnaces, but also buildings and features constructed from igneous rocks with remnant magnetism, such as basalt. Deposits with a contrast in magnetic susceptibility also have an effect on the Earth's magnetic field that we can measure, despite

being magnetized only in the presence of a magnetic field. In general, areas with enhanced magnetic susceptibility (with respect to the one of the surrounding soil) are represented as positive anomalies, whereas areas with smaller percentage content in iron oxides (i.e. smaller values of the magnetic susceptibility) are represented as negative magnetic anomalies. Both kinds of anomalies are interesting in the process of interpretation of the magnetic data.

This means that as we move over a magnetic anomaly we see a change in the local field strength. This can be either measured directly, with a magnetometer that measures the total field, or with a gradiometer which measures the difference in field strength over a fixed distance (in other words, the gradient): this is because the steepness of the magnetic gradient is affected by the magnetic anomaly. Gradiometers have frequently been employed in archaeological surveys as they are cheaper to build than total field strength magnetometers, and have some other useful advantages, to be discussed below. Typically, whichever instrument is used, readings of either the gradient or the total field strength are taken along transects and displayed to show the relative changes over the survey area. These measurements can be presented as raster data, or less commonly, as trace plots of each traverse (Fig. 1).

There are multiple factors that have an influence on the final appearance of the anomaly in the data; the depth of burial, the type of magnetization, the instrument properties, the degree of contrast between the anomaly and the soil matrix, and the local topography all play a part. What is important to recognize here is that the dimensions and position of the anomaly in the data cannot be assumed to have a 1:1 relationship with a buried archaeological feature. In geophysical survey we map anomalies, which then need to be carefully interpreted as features using a

combination of knowledge and experience. Practitioners should consult the following references for the applied archaeological perspective on magnetic prospection: Clark (1996 Chapter 3), Gaffney and Gater (2003, in particular pages 36-42). The Gaffney & Gater volume in particular has a very useful section full of examples of surveys of different types of sites, which despite a slight bias towards the UK, gives a good idea of the range of responses that can be expected. For more discussion of the physics behind the detection of these anomalies, the geological literature should be consulted. In this respect, a useful volume is Kearey *et al.* (2002), which has a chapter dedicated to magnetism.

Instrumentation

Two general families of magnetometers are usually employed aiming toward the measurement of the total intensity of the magnetic field or its vertical or horizontal components. Proton magnetometers calculate the total field intensity through the measurement of the free-precession frequency (Larmor precession frequency) of protons aligned in a direction perpendicular to the Earth's magnetic field. Proton magnetometers may be used either in differential mode (using one rover and one base station sensors) or in gradiometer mode and have a sensitivity of about 0.1 nT.

As a further development of the proton magnetometers, modern total field instruments use alkali vapour based sensors. These are composed of a system of a vapour chamber, a photon emitter and detectors. Light excites the caesium atoms and polarises them. Changes in the local magnetic field will cause changes in the polarisation, allowing the atoms to intercept photons and this 'dimming' will be picked up by the detector. The detection is omnidirectional, allowing the total field to be measured. In practice, this means there is a period where the lamps need to warm up and allow the vapour to become fully polarised. Commonly, two sensors are used together, either arranged one above the other (allowing the calculation of the gradient of the field), or side-by side to allow more dense coverage or to measure the horizontal gradient. The sensors can be carried by an operator or mounted onto a cart.

Fluxgate gradiometers are widely employed in archaeological surveys for a number of reasons, but primarily because they are considerably cheaper than alkali vapour sensors (Fig. 2). Highly magnetically susceptible cores (often mumetal) are wrapped in two coils, a drive coil and a detection coil. The drive coil rapidly cycles, driving the solenoid effect and bringing the core in and out of saturation. Every time they come out of saturation, external fields (i.e. the field of the earth) can enter them, causing an electrical pulse in the detection coil. Two strips are used, with the cores wound in such a way that the drive coil has no net magnetic effect on the detector coil. The fluxgate can only measure the field parallel to the axis of symmetry of the core. Any tilt will cause a large change

in the observed readings. For this reason, the cores are always used in pairs, mounted a fixed distance (usually either 0.5m, 0.75m or 1m) apart. One measurement is subtracted from the other, giving the gradient of the vertical component of the field. It isn't possible to measure the total field strength with a fluxgate instrument. Greater sensor separation in theory increases the depth of investigation, but again in practice this is a minor distinction. For both methods, the typical depth of investigation for features with archaeological signal strengths (typically 5-20nT for anything other than remnant objects) is 0.5m to 1m (Clark 1996).

The two models of handheld gradiometers commonly used in archaeology (Geoscan FM series, Bartington Grad601 / DualGrad601) need to be hand trimmed prior to each episode of survey, to ensure the optimal alignment of the two sensors. Small changes from heating caused by operation or temperature shifts in the environment can cause 'drift' in the positions of the cores/coils and so the data. Mounting multiple gradiometers onto a cart system allows for very rapid area coverage while maintaining dense traverses. The mounted sensors cannot be manually trimmed like the handheld sensors: instead special tensor-alignment is required and a software routine calculates the adjustments needed to the readings to 'balance' the signal.

In theory, alkali vapour instruments are more sensitive than fluxgates, but actual field conditions mean this is rarely achieved, though a study by English Heritage did show they were better at detecting low amplitude (less than 0.5nT in peak amplitude) on soils with good magnetic contrasts (Linford *et al.* 2007). The main difference between the two instruments is that total field measurements cannot be made with a gradiometer, and in some situations these are necessary or preferable. There are also advantages to the fluxgate systems. Operating as a gradiometer, rather than measuring the total field, it is less subjected to the diurnal variations of the total magnetic field or to the geological trends caused by the bedrock (though igneous geology causes problems generally for magnetic data). These issues complicate the interpretation of total field data, but can be dealt with by the use of a base station magnetometer (in the case of diurnal shift) or with filtering (in the case of gradual background changes in geology). Instrument choice is therefore governed by the budget, by the size of the survey area, and by the terrain: cart systems cannot be used on steep slopes or where there is significant ground vegetation. They are also difficult to use on soft ground and ploughed fields, whereas instruments held by a walker are more versatile.

Where and how is magnetometry useful?

First of all, before deciding to use magnetometry as a geophysical method on your site, you need to consider what type of archaeological features you expect. Broadly speaking, you will be conducting research on a site where archaeological remains are known or suspected, to find out more about them (site elaboration surveys), or, perhaps



FIGURE 2A. LEFT: A SENSYS 8 FLUXGATE GRADIOMETER ARRAY CART SYSTEM, NAVIGATED BY DGPS (SEE BELOW), AND SET UP WITH A 4m SURVEY SWATH, WITH 0.25m TRAVERSE SEPARATION. RIGHT: BARTINGTON DUALGRAD 601, 1m SENSOR SEPARATION FLUXGATE GRADIOMETER WITH 1m TRAVERSE INTERVAL FOR HAND HELD SURVEYS



FIGURE 2B. LEFT: PAIR OF GEONICS G-858 CESIUM VAPOUR MAGNETOMETERS SET UP AS A 1m VERTICAL GRADIOMETER. RIGHT: GEOSCAN RESEARCH FM256 0.5m SENSOR SEPARATION FLUXGATE GRADIOMETER (CAN ALSO BE MOUNTED ON A FRAME WITH A SECOND INSTRUMENT, WITH A 1m TRAVERSE INTERVAL) FOR HANDHELD SURVEYS.

in a Cultural Resource Management (CRM) context, you need to check whether archaeology is present in an area, prior to some destructive or disruptive activity (site detection surveys). In both cases, because of the wide variety of archaeological features that cause magnetic anomalies, magnetometry is a good ‘first pass’ technique, but it should not be used as a sole method, especially in CRM site detection surveys.

As has been previously stated, magnetometer surveys allow the mapping of materials with contrasting magnetic properties to their surrounding matrix. On archaeological

sites, we are typically interested in anthropogenic anomalies rather than natural ones. This includes features with different magnetic susceptibilities as well as remnant magnetised material.

Anthropogenic features such as pits, ditches, post-holes (if large enough) and building fills often contain material with enhanced magnetic susceptibility, and so show as positive anomalies in magnetometer surveys. The process by which they gain enhanced susceptibility is mostly due to the Le Borgne effect (see Gaffney and Gater 2003:38), whereby repeated heating (in hearths and ovens) converts

Table 1. Suitable and unsuitable geologies for magnetic prospection

Suitable / favourable	Unsuitable/problematic
Sedimentary parents including limestone, most sandstone	Igneous geology
Metamorphic geologies including slate, despite elevated background readings	Waterlogged soils
A few surveys have succeeded on basic igneous parents	Alluvium can be problematic, but depends heavily on local conditions: same for coversands, and clays
	Marine deposits such as old lagoons (good results from relict marine terraces however)

iron minerals into more susceptible forms, but processes of fermentation by magnetobacteria may also occur, particularly in the organic-rich deposits on settlement sites.

Built structures are more often visible thanks to remnant magnetization, either from fired components such as brick and tile, or due to the use of stone with remnant magnetism, such as basalt in Roman roads. Structures built from non-magnetic stone may appear as negative anomalies, in contrast with more magnetic fills and surrounding soils. Industrial features such as ovens, furnaces and kilns respond well to this method, and can produce very distinctive anomalies allowing robust interpretations. Transient occupation sites rarely leave enough contrasts, and dry-stone walls of non-magnetic rock that do not contrast well with the surrounding soils are also problematic. Similarly, field boundaries away from settlement sites will only be detected if the disturbed soil in the ditch fills has developed enhanced magnetic susceptibility: this will not always be the case.

As well as the type of archaeology you need to detect, you also need to know about the geology and pedology of the survey area. Whilst there are always exceptions, generally speaking, the conditions summarized in Table 1 need to be taken into account.

Waterlogging is a particular problem for magnetometry, as wet soils inhibit the enhancement of magnetic susceptibility (Thompson and Oldfield 1986), or in some environments, redistribute magnetic minerals within the soil (Kattenberg and Aalbersberg 2004). Igneous geology is also a major problem, with the remnant magnetism of the parent rocks swamping and overwhelming the responses from archaeological features, but with careful interpretation these environments can produce useful surveys. The English Heritage (2008) guidelines contain a useful detailed matrix of different geologies with suggested survey methods. These guidelines are free to download from <https://www.english-heritage.org.uk/publications/geophysical-survey-in-archaeological-field-evaluation/>

Magnetometry in the Mediterranean

In their review of geophysical surveys for archaeological purposes in the Mediterranean, Sarris and Jones (2000)

identified a series of challenges the Mediterranean environment specifically poses for geophysical surveys. These all have an impact on magnetic prospection. They are:

- Fragmentation of the landscape
- Terrain
- Effects of weather and climate
- Geology
- Site longevity

Mediterranean landscapes are often characterised by *fragmentation*, either by the physiography of the region, with coastal zones that transition rapidly to mountainous interiors, or by social factors such as inheritance practices, which have led to a patchwork of smaller fields and terraces. Mixed crop regimes mean that even in flat areas, large contiguous fields under the same cover are rare. The mountainous *terrain* of the Mediterranean region doesn't just fragment the landscape, the steep and often rocky ground also poses logistical and practical problems for surveys. Larger cart-based systems can operate on rough and sloping ground, but only up to a point: then, handheld instruments must be used, costing time. The steep terrain also means terracing is common. Terraces are both difficult to survey and difficult to interpret because of the way slope-processes and terraces combine to simultaneously erode and bury layers following the original slope profile.

The ruggedness of the *terrain* in Mediterranean landscapes also causes other problems. Typically, settlements tend to be *long lived* due to the scarcity of suitable land near cultivable soils. This means that archaeological sites are often within or in close proximity to modern settlements, and often exist as palimpsests of traces built up over millennia. This causes a number of problems for magnetic prospection. First of all, modern buildings and urban areas disrupt magnetic surveys a great deal, thanks to the use of large amounts of metal in construction and utility pipes and cables. There comes a point where an area is too built up for magnetic surveys to be useful, as the noise from the modern materials drowns out any useful archaeological response. Secondly, magnetic surveys lack a depth element. They record only two-dimensional information. Where there is a palimpsest of features, sorting out the tangle of responses from different depths and phases of

the site becomes quite difficult, rendering archaeological interpretations uncertain.

The Mediterranean *climate* is favourable to magnetic surveys in terms of the formation of magnetic contrasts. The humid winters give rise to reducing conditions, and the hot dry summers to oxidizing conditions, meaning that soils in the region generally have a high in-situ conversion rate for the iron oxides (i.e. they have high magnetic susceptibilities), leading to strong contrasts that are readily detectable, especially on well drained limestone geologies, which occur over much of the region (Sarris and Jones, 2000:23). However, in some areas, the natural soil enhancement can reach a similar or larger magnitude than the archaeological features, especially on more ephemeral sites. This can cause problems for survey interpretation. Furthermore, the dryness of the soils for much of the year causes problems for electrical and ground penetrating radar surveys, which rely to some degree on moisture contrasts. This means it can be difficult to obtain comparison data from other methodologies to improve interpretations and check the magnetic surveys didn't miss something crucial due to a lack of magnetic contrasts.

In the field: preparation, survey and common pitfalls

General principles

All instruments require different set up procedures. Ensure you are familiar with the process for your specific instrument, and the detection implications of any options you select (such as the sensitivity settings, and any pre-processing of the signal). Remember that different soils and site-types might require different settings and approaches. A key element in obtaining good data is to be flexible and responsive to the specific conditions of your site, rather than following a 'one size fits all' approach. Bearing this in mind, what follows are general principles for obtaining the best data possible, regardless of instrument type or site type.

First of all, some (usually fluxgate) instruments require a balancing routine, whether manual or software driven. This should be done in an area of the site which is known or reasonably assumed to be free of large magnetic contrasts. The better an instrument is balanced, the better the initial result will be, reducing the need for data processing. Balancing and zeroing a machine over an anomaly can skew the results of the survey so badly as to render it uninterpretable. Handheld instruments can be used to 'scout' for quiet spots even before the have been balanced. Larger systems usually need to be balanced 'blind' without a scouting phase. In this instance, be sure to select a location away from modern disturbances (such as the fieldwork van and other instruments in use) and away from any known archaeological remains, on flat ground.

Whether working in grids, or using ungridded methods, you should aim to hit known linear archaeological features at an angle. On sites with orthogonal remains, such as urban

area with gridded street plans, this means approaching them on a diagonal, to avoid traverses running along linear anomalies. The reason for this is two-fold. First, it prevents linear anomalies falling between traverses and remaining undetected, and generally allows them to be better visualised. Secondly, some commonly employed filters (especially for gridded data) can process out anomalies that run along a traverse. Where the orientation of the archaeology is unknown, it is better to plan the grids (if used) and traverses to allow maximum coverage.

For hand held instruments, operator gait is very important. New operators should be monitored, their data frequently checked and fed back to them to improve their technique. Operators must be always checked to be magnetically clean (not having any metals on them during the acquisition of the measurements). Ideally, the instrument should move very little relative to the soil surface, and the pace should be stable for the entire traverse. The operator needs to be careful to avoid orientation errors (twisting the instrument), particularly at the starts and ends of lines. Further, for gridded surveys the operator needs to be able to calculate accurately the dummy readings needed to navigate obstacles in the survey, and how to correct their mistakes.

When surveying on sloping sites, additional care must be taken. It is usually best for traverses to run up and down slopes, especially when using multi-sensor equipment, rather than along contours, to ensure both/ all sensors remain a consistent height above the soil surface. If you are using a gridded methodology that relies on operator pacing for the reading locations, and you are zig-zagging back and forth, taking data in both directions, on steep slopes it may be worth switching to parallel traverses as the difference in pace on the up and down traverses can be difficult for even experienced operators to compensate for, leading to staggering errors in the data. See the section below for further information.

In general, the larger the area that can be surveyed the better. If time and budget constraints allow for it, always capture more than the immediate area of interest. This has several advantages. First of all, it allows for clearer interpretation as the difference between on-site and off-site signals will be clearer. It is very hard on certain types of site to distinguish anomalies of interest from the background if you don't have a clear idea of what the undisturbed background looks like. Furthermore, site extents can be difficult to ascertain a-priori and it is better to maximise the probability that you have covered the entire site. Given what we have said about the Mediterranean landscape above, this can be tricky given field divisions and terracing. It's therefore important to also maximise the coverage by surveying right up to these boundaries, working in irregular areas, even on gridded surveys. Only surveying in square/rectangular blocks leaves large amounts of the landscape uncovered at the edges of irregular fields and terraces, and it is well worth the extra time it takes in the field to obtain the most comprehensive coverage possible.

This gives a much greater chance for the recognition of features that cross underneath modern landscape divisions.

On a similar principle, where possible work outside walls, ditches and other obvious site boundaries as well as on the interior as useful information can be recovered about extra mural activities. It is possible that obvious surface boundaries only reflect one particular phase of a site and that information will be lost if the survey is confined to just that area.

Finally, as with the point above about instrument settings, always adapt your survey strategy (including resolutions, see below) to the specific case at hand. For example, a compromise may have to be made between approaching the archaeology at a specific angle and adapting to a steeply sloping site. Record the choices you make (perhaps with the help of a form) and explain them in your reporting so subsequent users of your data can follow your reasoning.

Gridded vs ungridded

The choice between gridded and ungridded methods will usually be instrument based. Handheld fluxgate systems (at time of writing) require grids to be set up in advance of the survey, whereas cart-based systems are typically located by GPS or robotic Total Station, allowing 'freeform' surveys. Caesium and other alkali vapour systems can use a variety of navigation methods, depending on the manufacturer and the instrument settings. This is a general discussion of the specific considerations for the two approaches, regardless of manufacturer or intended processing software.

Gridded methods

On flat sites, use a Total Station or GPS system to set out grids wherever possible. You should know the absolute location of the grid pegs to within 10cm, so navigation grade GPS is not accurate enough and another method must be used. For small sites, setting out the grids using optical squares, or with lines and tapes using Pythagorean triples to create right angles is acceptable, but the resulting grid pegs must then be recorded with high accuracy. If this method is used, then grids should not be set out more than two steps away from the original baseline, to avoid error propagation. Tapes and Pythagoras or optical squares is actually a better method for setting out grids on steeply sloping sites. Where there is a significant slope, the on-the-ground distance can be considerably more than the planar distance used by a total station or dGPS, creating larger grids in terms of the area to be walked than the planned grid sizes. Running tapes along the ground surface cancels this effect, but the resulting pegs must be correctly recorded and the data fitted to them. Measurements of anomalies should be made on data that hasn't been 'squeezed' to fit a flat surface, such as in a 2D GIS representation of the data.

Instruments designed for gridded surveys (particularly Geoscan instruments and the Bartington Grad601 systems) come loaded with firmware that presupposes the data will

be collected in grids, and specific modifications must be made to collect data in other ways. The firmware typically contains navigation aids that tell the operator where they are in the grid (i.e. what line, and which position or reading they are about to obtain or have just obtained). The firmware also allows for some mistakes during the acquisition of the data to be corrected, such as being able to delete a line and re-take the data if a pacing or heading error occurred. The firmware also usually allows dummy data points to be inserted at the time of the survey, such as when there is an obstacle within the traverse or the grid is incomplete due to a field boundary. Usually with such systems, a whole grid of data (including any dummy readings) is assembled and stored during the survey process, allowing the data to be downloaded and immediately visualised with no or limited pre-editing. Data is typically stored on resilient flash memory systems in real time, and survives accidental switch-offs and other operator errors, but the specific manufactures instructions should always be adhered to prevent data loss. This does mean however that if a mistake is made (such as a missed traverse) it isn't usually possible in the field to manually go in and add in the missing data; instead, data must be deleted back to the relevant point and then re-collected. For this reason, frequent checks on the position the instrument shows and the real position in the grid are vital as they allow errors to be corrected easily and efficiently. Finally, bear in mind that some processing software (and instrument firmware) assumes a particular and consistent approach to the grid, for example, assuming that all surveys begin in the bottom left hand corner of the grid (based on the direction of the first traverse). Check the instructions for your chosen software and hardware carefully when planning and setting up the grids, as this constraint on starting corner affects choice of grid layout and traverse direction. Typically, with gridded surveys you want your 'starting' baseline to be the most complete edge of your grid (if the grid is partial or disrupted). This means that sometimes, the optimal gridding approach can only be decided in the field after a site inspection, to take into account slopes and obstacles. This should be taken into account when pre-digitising grids using aerial photographs or topographic maps for set out with differential GPS or Total Station.

Ungridded surveys

Typically, survey systems that allow the use of GPS for locating the data points will have a navigation system to monitor the survey tracks and instruments swaths in real time, to allow monitoring of the coverage obtained. If this isn't the case, some control system to space the traverses should be adopted, such as a tape at each end of the survey area with a sighting pole or flag, to allow straight traverses with correct spacing to be maintained. Follow the manufacturer's instructions to obtain best possible position solutions and ensure you have correctly understood and accounted for any offset between the sensor(s) and the antenna. Make frequent backups (i.e. as one contiguous area is finished) of the survey data.

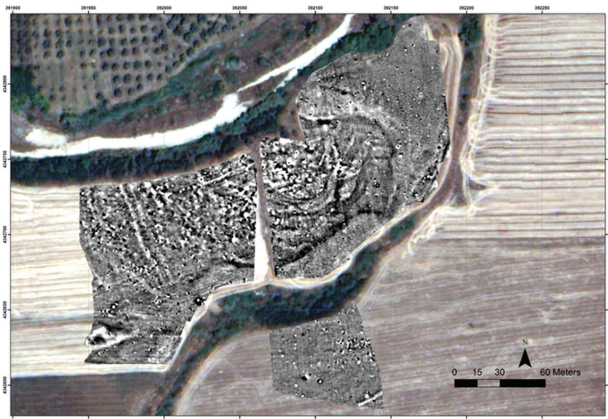


FIGURE 3. GEOMAGNETIC DATA COLLECTED WITH THE MULTI-SENSOR SENSYS SYSTEM. THE EIGHT SENSORS WERE SEPARATED WITH 0.5 METERS, BUT ALONG TRANSECTS THE DATA IS COLLECTED WITH HIGH SPATIAL FREQUENCY (~10 cm) RESULTING IN A DENSE POINT CLOUD OF MAGNETIC READINGS.

One of the main advantages of an ungridded survey is that minimal time is spent for the survey logistics (e.g. setting up the grids, strictly following transects, etc). Especially, if a multi-sensor system is used in an ungridded fashion survey coverage increases drastically. In one of such instances, at Karatsangliou — a Neolithic site in Thessaly, Greece—, researchers were able to survey 1.5 hectares a day in high resolution (Fig. 3). Correct this sentence to read: Achieving the same coverage with a gridded survey would have required setting out 38 20m x 20m grids, in addition to the extra time needed for surveying with fewer sensors.

Resolutions and Thresholds

Unless your survey is heavily time constricted and looking for large targets only (roads, public buildings of classical or later date), you should use a maximum of 0.5m transect separation and 0.25 in-line or better sampling resolution. Older guidelines and manuals suggest 1x1 or 1x0.5 is OK but this is due to historical processor & memory constraints, which meant that survey resolution was a trade-off between obtaining enough detail without creating unmanageably large datasets. Processor speeds and hard-disk sizes have improved to the point where this is no longer an issue. In almost all cases, the higher resolution data you are able to collect the better. However, for most archaeological features, transect separations of 0.25m or smaller are only useful where very fine detail is needed (and you expect the site to produce good enough contrasts at that scale), either for complex architecture, or on more ephemeral sites where small features like postholes are anticipated.

Surveys with a large difference in the resolution between transect intervals and reading intervals (such as 0.5 x 0.125) can run into problems when processing data due to the difference in detail obtained on the y and x axis, with anomalies appearing to be elongated over the traverse

and truncated between traverses. Also, bear in mind that although magnetometry (especially GPS located multi-sensor systems) is the fastest method in terms of area coverage, some targets may be poorly defined: therefore a ‘negative’ result should always be checked with another (non-magnetic) method like earth resistance or GPR.

Most instruments have a setting that governs the sensitivity of the readings taken. Generally speaking you should use the most sensitive option possible, as the less sensitive options are designed for use in highly magnetised environments with a large range in the expected values (say, on igneous geology). Similarly, there is usually a threshold setting, at which values that exceed a set range will either be recorded as dummy values or as the maximum or minimum set. This can be useful in noisy environments, constraining the dataset to a reasonable range of values which minimises the amount of processing needed to remove large responses from the dataset during processing, as these are rarely archaeological in origin. On most soils and sites, a typical sensitivity is 0.1 nT (recording variations of 0.1nT in amplitude and higher – the limit of most fluxgate systems), with thresholds of 1000 nT above and below the background. Most archaeological anomalies should be observable at this sensitivity and within this range of values.

Geolocation and topographic information

As well as the actual data, other information should also always be recorded for every geophysical survey. For gridded surveys, the location of all grid pegs must be recorded with a method that allows for better than 10cm accuracy on the ground. You need to be confident that you could return to site and re-establish the exact same grid, or navigate to a known anomaly or point with centimetre accuracy. This can be achieved using standard survey methodologies using local grids or surveying directly into projected systems, such as UTM. Whether the survey is gridded or not, major topographic features should be recorded (if gridded, in the same system as the grid pegs); this should include (but is not limited to): standing archaeology, field boundaries, breaks of slope, changes in the surface conditions (e.g. ploughed/unploughed) and any obstacles to the survey. This can greatly assist with the interpretation of the data, and placing any findings in their topographic context. Sketch maps of the site with major buildings, roads, surface changes should also be made, along with a record of what order the grids were surveyed (using a standard reference) and by whom. These sketch maps should also note any vegetation, the field state, weather conditions and any other pertinent facts about the survey. The use of standardised forms for this is encouraged for projects that involve multiple surveys. If the survey is gridded, sketch the grids and record the point ID’s for surveyed pegs, and note the order of grids in instrument.

The geolocation of any observed anomalies is only going to be as good as your recording of the survey location,

either directly, when working ungridded, or indirectly with gridded surveys. Furthermore, with gridded surveys, the location of the data points relative to the grid pegs depends entirely on good survey practice and the skill of the operator in being able to position themselves and thus the readings consistently along the traverse. The use of survey lines with navigation markers (typically at 1m intervals) is strongly recommended, even for experienced surveyors. The use of sighting flags for paced surveys is only advisable for experienced operators working on flatter sites with consistent ground cover.

Zig-zag traverses in gridded surveyors can be problematic. Even experienced surveys can have problems shifting between the up-and down lines in terms of instrument positioning. This can lead to ‘stagger’ errors in the final dataset due to mismatches in the assumed locations of the readings along the traverses. The corrections needed for these errors can shift the apparent location of an anomaly, enough to cause problems for targeted corings or test pits if the corrections are not properly understood. Therefore, the zig-zag approach should only be used by experienced operators, and even they may be better using a parallel method on steeply sloping sites, or sites with difficult/rugged terrain. Your aim should always be to collect the best raw data possible, rather than relying on processing to clean up or compensate for poorly acquired datasets.

After the field: processing, interpreting, reporting and archiving

Data processing

Despite the fact that different geophysical methodologies investigate different physical characteristics of the phenomenon they also have considerable common points in their workflows. In this respect, magnetic prospection is not an exception. Without going into details, we provide a typical workflow one might follow after collecting magnetic data. Good data processing is a mixture of technical skill / understanding and experience, and should only be carried out by sufficiently experienced operators.

1. Downloading data from the instrument: Most sensors keep data in their internal memories. Therefore, it is necessary to download data to dedicated computers for processing, interpretation, and archiving. In some cases, sensors might be directly connected to computers, and thus, data is transferred to these computers on-the-fly during the survey. Regardless of the way data is collected, it is strongly advisable that a backup copy of the data is retained in the original format. Standard operating procedures should be adopted in the field to reduce the chances of data loss, such as retaining the data on the instrument until a backup has been made of the initial download.
2. Conversion of data formats: If the researcher does not have access to dedicated processing software or he/she wants to use another platform, it becomes necessary to transform data from its native format. It is of vital

importance that metadata should be also transferred with the new format and that the raw and meta data are securely archived.

3. Creating mosaics: Whether data has been collected on grids or following an ungridded method, it is usually desirable to create mosaics of magnetic data. Obtaining a larger coverage within one data file not only provides a more representative picture of the anomalies in their wider contexts, but also helps researcher to accomplish a better data processing routine.
4. Data processing: Processing magnetic data usually requires specialized software, often provided by the vendor of the instruments. Proprietary geophysics software is becoming more accessible to archaeologists and more user-friendly day by day. However, they also remain, to some extent ‘black-boxes’ and only in some rare cases give the user full access to the parameters of routines and functions. Therefore, it is still necessary to have some degree of specialty in data processing. Without paying special attention to underlying principles of the process, erroneous results can be easily reached. In some other cases, researchers may need to develop their own specialized software. In such cases, it is important that developer pays particular attention to assumptions behind methodologies and that the new software/routine-package is bug-free as much as possible.

Geomagnetic data processing usually involves algebraic and statistical methods in order to improve data quality and make interpretation easier. As for other geophysical data processing techniques, the basic rule of thumb for magnetic data processing can be stated as ‘if the anomaly is not immediately visible in the raw data, do not create it.’ Data processing can be simplistic; just to ‘clean’ data or it can attain sophisticated levels. Considering the variety and complexity in magnetic data processing, we will only here briefly evaluate the four most common techniques.

1. Spike removal: Magnetic data may include artificial data spikes due to instrumental noise, or modern ferrous material may interfere with the readings and suppress signals from archaeological features. To reduce (or even sometimes cancel out) these noises, a basic statistical method can be used. The idea is based on comparing each data value with a threshold value and replace data which are falling above (or below) this with statistically sound data. Generically, the determination of the threshold is based on the distribution of data and replacement is provided after an evaluation of data values around the ‘spiked’ value.
2. Destaggering: Staggering is observed if the instrument data logs are not well aligned with predetermined spatial markers of the survey area. This is especially the case when the survey is conducted in a zigzag mode; the user may experience a systematic displacement at each transect. This problem can be solved by determining a representative value of displacement and iterating survey transects according to this value. Almost all

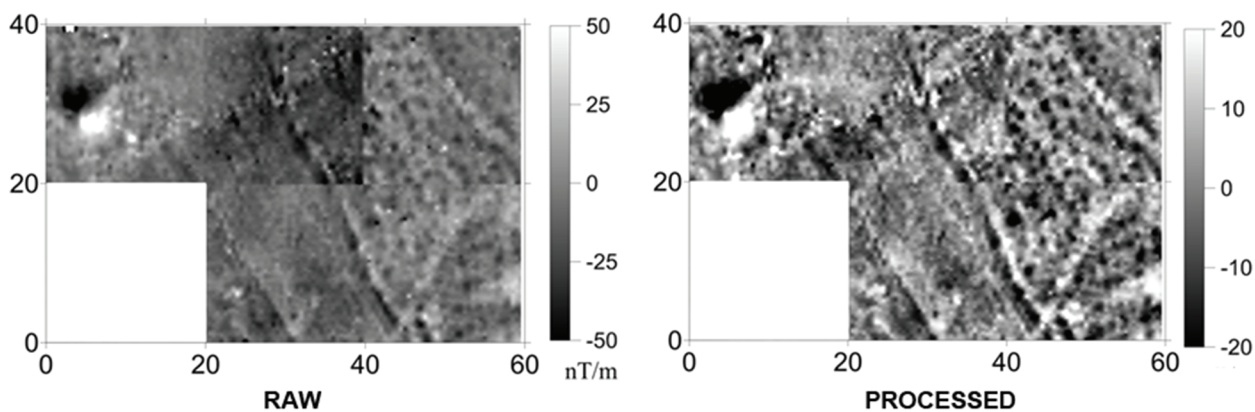


FIGURE 4. GEOMAGNETIC DATA COLLECTED WITH GEOSCAN FM256 ON 5 GRIDS WITH DIMENSIONS 20X20M.

geophysical data processing software provides a solution for this as a built-in function.

3. **Destriping:** Striping in magnetic data is visible when survey transects have significant disagreements for their average values. Striping might have different sources; surveyor might have kept the instrument at alternating levels over the ground, or might have tilted the instrument at alternating transects, etc. Likewise, instrumental drift may cause striping effects in the data. Basic statistical functions, such as pulling the average of magnetic values at each transect to a predetermined value (often zero) can solve the striping effect.
4. **Edge matching:** If the surveyor is following a gridded survey methodology, it is likely that grids have contrast differences between them. Edge discontinuities will happen if the instrument is aligned at a different base station or instrument drifted significantly during the survey. Dedicated built-in functions usually exist to correct for edge discontinuities. It is also very likely that destriping process provides satisfactory edge matching. In order to avoid edge mismatches, the best practice would be to align sensors after each grid over a magnetically quiet location, preferably returning to the same location throughout the survey.

As an example, magnetic survey at Therasia Island (Fig.4) reveals the power of data processing for a better interpretation of archaeological data. Mismatches between grid edges are immediately visible in the raw data. These mismatches not only create unappealing datasets, but they also make archaeological interpretation harder as some archaeological features may be obscured at the edges. The other problem lies in the range of the data. Through statistical operations, data ranges can be matched in such a way that features become more visible, and thus, their interpretations to become easier. Spike removal in this survey cluster also resulted in an increase in the signal to noise ratio.

Interpretation, reporting and archival of magnetic data

Interpretation: Maybe one of the most important steps in the geomagnetic prospection is the accuracy of the interpretation of data. Interpreting results not only requires

knowledge of the archaeology of the area, but also necessitates some working experience with geomagnetic prospection and how each specific instrument behaves under certain environmental conditions. If the magnetic prospection is outsourced, it might be crucial to team up with a geophysicist. Remember that good interpretation relies on both geophysical and archaeological understanding and is rooted in experience. Interpretation of all forms of geophysical data is greatly improved by feedback from archaeological excavations and other forms of ground truthing: seek feedback from the end-users of your data in order to improve interpretations of future surveys.

Reports on magnetic surveys should include as a minimum: Information about the site and its context: date/period, what we already know about archaeology on the site, the land use, geology, and survey conditions; Technical information regarding the instrumentation and settings, with short explanation / justification for the particular methods employed; Raw data & processed data plots with any additional topographical and archaeological information relevant (paths, infrastructure, upstanding remains etc) marked out; Interpretation drawings of any anomalies presented separately from the data, ideally using either CAD or GIS; A discussion of the data obtained, with a clear separation between description of the anomalies and any archaeological interpretation possible / offered; If needed, suggestions for further work.

Metadata and Archiving: Upon the completion of magnetic prospection and interpretation of results, generating metadata and creating an archive is necessary. Accessing metadata (the name of the surveyor, his/her contact address, processing steps, parameters used in the process, and many others) can be of crucial importance if the data needs to be re-examined by future researchers and heritage professionals. Archiving data in both the native format and other basic interchangeable formats will help future researchers to analyze and interpret magnetic data in their own ways. Keeping data only in native format may hinder future use if proprietary software ceases to exist and/or does not support older formats. Excellent guidelines for the archival of geophysical data have been published by the Archaeology Data Service in the UK, and can be

downloaded from http://guides.archaeologydataservice.ac.uk/g2gp/Geophysics_Toc, or in the publication by Schmidt (2013). Bear in mind that there may be local legal obligations for filing reports and / or data with a state archaeological service, within set timeframes.

Concluding remarks

Due to its high efficiency, magnetic prospection is usually considered as the 'first option' among other geophysical survey techniques. In comparison to resistivity surveys, more area can be covered in unit time. Magnetic prospection usually provides better data resolution in comparison to electromagnetic surveys. Finally, these instruments are more user-friendly than GPR. New generation multi-sensor systems, equipped with GPS provide additional capacity though with increased instrument cost. Thanks to its historicity there are now well-established algorithms, routines, and data processing workflows for geomagnetic data. Easy-to-use software also increases the number of researchers who are willing to adopt magnetic prospection in their studies. The transition from gridded to ungridded surveys has been an added value for this technique.

Despite such advantages, magnetic prospection usually fails in urban environments where metallic clutters distort data. Fences, power lines, underground pipes also cause problems in collecting and interpreting geomagnetic data. Therefore, researchers are usually advised to employ other techniques alongside magnetic prospection to fully exploit the arsenal of archaeogeophysicists.

References

- Clark, A., 1996. *Seeing Beneath the Soil: prospecting methods in archaeology*. Routledge, London.
- English Heritage, 2008. *Geophysical Survey in Archaeological Field Evaluation* (2nd Edition). English Heritage, Swindon.
- Gaffney, C., Gater, J., 2003. *Revealing the Buried Past: geophysics for archaeologists*. Tempus, Stroud.
- Hesse, A., 2000. Count Robert du Mesnil du Buisson (1895–1986), a French Precursor in Geophysical Survey for Archaeology. *Archaeological Prospection* 7, 43–49.
- Kattenberg, A., Aalbersberg, G., 2004. *Archaeological Prospection of the Dutch perimarine landscape by means of magnetic methods*. *Archaeological Prospection* 11, 227–235.
- Kearey, P., Brooks, M., Hill, I., 2002. *An Introduction to Geophysical Exploration*. Blackwell Publishing, Oxford.
- Linford, N., Linford, P., Martin, L., Payne, A., 2007. Recent Results from the English Heritage Caesium Magnetometer System in Comparison with Recent Fluxgate Gradiometers. *Archaeological Prospection* 14, 151–166.
- Rainey, F.G., Lericci, C.M., Bullitt, O.H., Milan, Politecnico, Istituto di geofisica applicata, University of Pennsylvania, University Museum, 1967. *The Search for Sybaris, 1960-1965*, Lericci Editori, Roma.
- Sarris, A., Jones, R.E., 2000. Geophysical and Related Techniques Applied to Archaeological Survey in the Mediterranean: A Review. *Journal of Mediterranean Archaeology* 13, 3–75.
- Schmidt, A., 2013. *Geophysical data in archaeology: a guide to good practice*. 2nd fully revised edition. Print Version. Oxbow Books, Oxford.
- Thompson, R., Oldfield, F., 1986. *Environmental Magnetism*. Allen & Unwin, London.