Journal of Archaeological Science 85 (2017) 66–82

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Advances in archaeomagnetic dating in Britain: New data, new approaches and a new calibration curve

Catherine M. Batt [a, *], Maxwell C. Brown [b, c], Sarah-Jane Clelland [a, d], Monika Korte [c], Paul Linford [e], Zoe Outram [a, f]

[a] School of Archaeological Sciences, University of Bradford, Bradford, BD7 1DP, UK
[b] Institute of Earth Sciences, University of Iceland, Sturlugata 7, 107, Reykjavík, Iceland
[c] GFZ German Research Centre for Geosciences, Telegrafenberg, 14473, Potsdam, Germany
[d] School of Materials, University of Manchester, Oxford Road, Manchester, M13 9PL, UK
[e] Historic England, Fort Cumberland, Eastney, Portsmouth, PO4 9LD, UK
[f] Historic England, 24 Brooklands Avenue, Cambridge, CB2 8BU, UK

ARTICLE INFO

Article history:
Received 28 March 2017
Received in revised form
6 July 2017
Accepted 7 July 2017

Keywords:
Archaeomagnetic dating
Secular variation
Britain
Geomagnetic field
Magnetic direction

ABSTRACT

Archaeomagnetic dating offers a valuable chronological tool for archaeological investigations, particularly for dating fired material. The method depends on the establishment of a dated record of secular variation of the Earth's magnetic field and this paper presents new and updated archaeomagnetic directional data from the UK and geomagnetic secular variation curves arising from them. The data are taken from publications from the 1950's to the present day; 422 dated entries derived from existing archaeo and geomagnetic databases are re-evaluated and 487 new directions added, resulting in 909 entries with corresponding dates, the largest collection of dated archaeomagnetic directions from a single country. An approach to improving the largest source of uncertainty, the independent dating, is proposed and applied to the British Iron Age, resulting in 145 directions from currently available databases being updated with revised ages and/or uncertainties, and a large scale reassessment of age assignments prior to inclusion into the Magnetic Moments of the Past and GEOMAGIA50 databases. From the significantly improved dataset a new archaeomagnetic dating curve for the UK is derived through the development of a temporally continuous geomagnetic field model, and is compared with previous UK archaeomagnetic dating curves and global field models. The new model, ARCH-UK.1 allows model predictions for any location in the UK with associated uncertainties. It is shown to improve precision and accuracy in archaeomagnetic dating, and to provide new insight into past geomagnetic field changes.

1. Introduction

The development of precise, robust site chronologies is a central concern in all archaeological work and there are a range of scientific dating methods available to address this issue. Archaeomagnetic dating is a valuable addition to the suite of chronological tools available to archaeologists working on both commercial and research excavations. Its particular strengths are the applicability to baked clays, fired stone and ceramic materials, which survive well in the archaeological record, and the clear relationship between the event dated, typically the last cooling of the material, and human activity. The method can be more precise than other techniques for certain periods of time and for specific situations (e.g. Outram and Batt, 2010); for example, it potentially has good precision in periods where radiocarbon dating has large errors, such as the British Iron Age and the Early Medieval period (Linford, 2006).

The method was first established in British archaeology by Aitken and colleagues (Aitken, 1958, 1960; Aitken and Weaver, 1962), building on an initial investigation by Cook and Belshé (1958). Following a period of development, the basis for its routine use was set out by Clark et al. (1988). Since then there have been significant developments to the method, both in the UK and

* Corresponding author.
E-mail addresses: c.m.batt@bradford.ac.uk (C.M. Batt), maxwell@hi.is (M.C. Brown), sarah-jane.clelland@manchester.ac.uk (S.-J. Clelland), monika@gfz-potsdam.de (M. Korte), Paul.Linford@HistoricEngland.org.uk (P. Linford), Zoe.Outram@HistoricEngland.org.uk (Z. Outram).

http://dx.doi.org/10.1016/j.jas.2017.07.002

internationally (Sternberg, 2008). The aim of this paper is to present new and re-evaluated UK archaeomagnetic data and the geomagnetic secular variation curves arising from them. Such discussions are uniquely important in archaeomagnetic dating as the precision and accuracy of dates provided by the method improve as more data are used in the construction of dating curves. Archaeomagnetic studies also have a wider significance as they provide the most detailed record of how the geomagnetic field has changed over recent millennia; crucial to understanding deep Earth processes, the space environment, palaeoclimate and volcanism (Brown et al., 2015a; Constable and Korte, 2015).

2. Context of investigation

In common with many dating methods, the development of archaeomagnetic dating requires expertise from both natural sciences and archaeology. However, in archaeomagnetic dating, archaeological input is particularly crucial. The principles of the method are well-established (Linford, 2006; Clark et al., 1988). The Earth's magnetic field in the past can be recorded by fired archaeological materials or sediments and a date is obtained for this geomagnetic record by comparison with a dated record of changes in the geomagnetic field over time, known as the secular variation (SV) record. Scientists have directly recorded changes in the Earth's field in the UK since the 16th century CE (Malin and Bullard, 1981; Jonkers et al., 2003); prior to this the SV record is obtained from magnetic measurements on materials with an independent date established using other scientific techniques (such as radiocarbon or luminescence), documentary sources or the archaeological information (Clark et al., 1988). The SV record is only as good as the independent dating evidence on which it is based. Hence, key to the method's development, is a good understanding of the challenges of archaeological chronologies and the interpretation of cultural remains, requiring excellent communication with archaeologists in the assessment of supporting dating evidence. The initial development of the method is slow and laborious, as it requires large numbers of measurements on materials of known date. It is also important that the independent dates are re-evaluated regularly, as more evidence becomes available and archaeological understanding develops. Lanos et al. (1999) describe SV records as 'living organisms' which evolve with the addition of new data; this development also extends to new archaeological approaches, new typological sequences and new theoretical paradigms that affect the independent dates. SV is specific to a region (c. 1000 km in diameter) as the geomagnetic field changes spatially as well as with time (Jackson and Finlay, 2015) and so the data need to be considered on a regional basis.

The mechanism by which fired materials acquire a thermoremanent magnetisation (TRM) which reflects the field at the time of last high temperature heating (over c. 580 °C) are well-understood (e.g., Tauxe, 2002) and such materials form the majority of archaeomagnetic studies. The acquisition of remanent magnetisation by sediments is still a subject of debate and different mechanisms have been proposed (see reviews by Tauxe and Yamazaki, 2007; Roberts et al., 2013). In essence, magnetic grains align with the geomagnetic field either during or after deposition. In some instances, remanence acquisition can be delayed and may not represent the time of deposition. Hence, there may be difficulty in associating depositional remanences with a specific archaeological event (Batt, 1999). Sediments are also more prone to bioturbation and disturbance after deposition, and such changes are harder to detect than they would be with fired structures. For these reasons, and because of their availability on archaeological sites, archaeomagnetic studies are dominated by the investigation of fired materials. However, sediments can provide a continuous record of SV, rather than the single magnetic direction typically available from a fired structure and studies have shown that fine grained, undisturbed sediments in archaeological environments can provide reliable archaeomagnetic directions (Batt, 1999; Ellis and Brown, 1998).

Archaeomagnetic dating can be based on variations in the direction (that is declination and inclination) or the intensity of the past geomagnetic field or, ideally, both. Estimates of intensity have the advantage that they can be obtained from fired materials that are not *in situ* and require very small samples, vastly increasing the range of materials investigated. However, intensity experiments on fired materials are challenging, with alteration and magnetic domain state effects potentially biasing estimates of past intensity (Thomas, 1983; Aitken et al., 1988; Valet, 2003; Tauxe and Yamazaki, 2007; Genevey et al., 2008; Brown et al., 2015a). In contrast, directions are experimentally straightforward to obtain, but require *in situ* material, with precise orientation during excavation (Clark et al., 1988). In many regions of Europe all three components of the magnetic field are routinely analysed and many countries have their own SV curves (e.g. Gómez-Paccard et al., 2006; Schnepp and Lanos, 2005; Lanos et al., 1999; Kovacheva et al., 2009, 2014; Tema and Kondopoulou, 2011). In addition Kostadinova-Avramova et al. (2014) have demonstrated the value of using stratigraphic constraints alongside all three components. Although ceramics are commonly available, intensity analyses have yet to be widely adopted in the UK, mainly because of the experimentally challenging nature of intensity determination. This leads to limited precision available in dating using intensity, as there are fewer data with which to build calibration curves and the data often have large uncertainties. There have been significant developments in the methods used to obtain estimates of intensity, which have now been applied to archaeological materials. These include the microwave method (e.g., Shaw et al., 1999; Hill and Shaw, 1999; Stark et al., 2010); the Triaxe method (Le Goff and Gallet, 2004; Gallet et al., 2015); the multi-specimen method (e.g., Ertepinar et al., 2016; Schnepp et al., 2016); modifications to the Thellier-Thellier method, e.g., the IZZI protocol (Shaar et al., 2011) and extended versions of the Shaw technique (e.g. Yamamoto et al., 2015). However, so far there are only a limited number of studies of intensities on UK samples (e.g. Casas et al., 2005; Suttie, 2010). None of the previous UK SV curves considered intensities, so updating these data was beyond the scope of the present work. Common practice in many other regions argues strongly for the routine measurement of the full magnetic vector in future UK studies, or at least the retention of suitable samples from directional investigations to allow intensity studies in future.

3. UK archaeomagnetic data

3.1. Databases

As discussed above, the biggest limitations to archaeomagnetic dating are the precision and accuracy of the SV curves. This can be addressed by increasing the amount of reliable data used to construct them, as well as improving the precision of the independent age estimates associated with each magnetic measurement. It is therefore vital to collate and evaluate all existing archaeomagnetic data in the UK. Such a compilation also allows regular review and can easily provide data for construction of SV curves.

3.1.1. The Magnetic Moments in the Past database

The 'Magnetic Moments in the Past' project (University of Bradford/English Heritage now Historic England) was initiated to develop archaeomagnetic dating in the UK, partly through