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First directional European palaeosecular variation curve for the Neolithic based on archaeomagnetic data

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ABSTRACT

Neolithic, Chalcolithic and Bronze Age anthropogenic cave sediments from three caves from northern Spain have been palaeomagnetically investigated. 662 oriented specimens corresponding to 39 burning events (ash–carbonaceous couplets) from the three sites with an average of 16 samples per fire were collected. 26 new archaeomagnetic directions have been obtained for the time period ranging from 5500 to 2000 yr cal. BC. These results represent the oldest archaeomagnetic directions obtained from burnt archaeological materials throughout all Western Europe. Magnetisation is carried by pseudo-single domain low-coercivity ferromagnetic minerals (magnetite, magnetite with no significant isomorphous substitution and/or maghaemite). Rock-magnetic experiments indicate a thermoremanent origin of the magnetisation although a thermochemical magnetisation cannot be excluded. Combination of the new data presented here and the recent updated Bulgarian database allows us to propose the first European palaeosecular variation (PSV) curve for the Neolithic. A bootstrap method was applied for the curve construction using penalised cubic B-splines in time. The new palaeosecular variation curve is well constrained from 6000 BC to 3700 BC, the period with the highest density of data, showing a declination maximum around 4700 BC and a minimum in inclination at 4300 BC, which are not recorded by the recent global CALS10K.1b and regional SCHA.DIF.8K models due to the use of lake sediment data. Dating resolution by using the proposed PSV curve oscillates from approximately ±30 yr to ±200 yr for the period 6000 to 1000 yr BC, reaching similar resolution as radiocarbon dating. Considering the good preservation, age-control and widespread occurrence of burnt archaeological materials across Southern Europe, they represent a new source of data for geomagnetic field modelling, as well as for archaeomagnetic dating.

1. Introduction

Knowledge of long-term variation of the Earth's magnetic field (palaeosecular variation) is a forefront research area in Solid Earth Sciences. Determinations of the palaeofield are necessary to expand global and regional geomagnetic field models, whose applications range from the reconstruction of field geometry to

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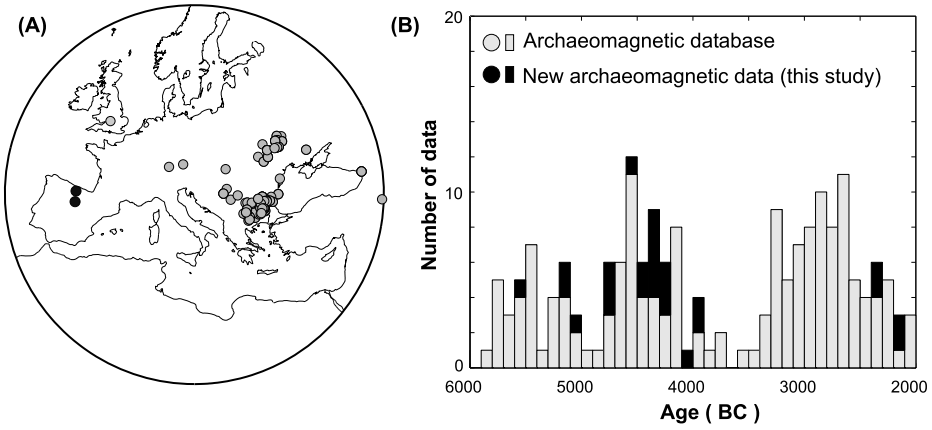

Fig. 1. (A–B) Spatial and temporal distribution of archaeomagnetic directions in Europe (6000–2000 yr BC). Archaeomagnetic database in grey (after Kovacheva et al., 2009; Korte et al., 2011).

archaeomagnetic dating. Reconstruction of geomagnetic field variations prior to instrumental measurements (last few centuries, e.g. Alexandrescu et al., 1997; Jonkers et al., 2003), has been traditionally addressed through the analysis of well-dated magnetised sediments, lavas or archaeological burnt material. Sedimentary sequences provide relatively long and continuous palaeomagnetic records with broad geographical distribution. However, their magnetisation lock-in is delayed, due to the mechanism of remanence acquisition. Moreover, the magnetisation in sedimentary contexts is subjected to several factors that could cause errors in the palaeomagnetic record such as *flattening* or bioturbation, among others. Consequently, geomagnetic models that incorporate sedimentary data introduce a "smoothing effect" producing low resolution reconstructions of geomagnetic field variations (e.g. Donadini et al., 2009; Korte et al., 2011; Pavón-Carrasco et al., 2010). In contrast, burnt archaeological materials and lava flows usually carry a stable thermoremanence which gives spot information of the palaeofield and are thus considered the best records of the geomagnetic field.

In order to obtain a detailed picture of the geomagnetic field variation, the classical approach is to develop local palaeosecular variation (PSV) curves from well-dated, *in situ* archaeomagnetic materials carrying a thermoremanence. In recent years, new or updated PSV curves have been published in different European regions covering reasonably well the last 2–3 millennia (Gallet et al., 2002; Gómez-Paccard et al., 2006; Hervé et al., 2013; Kovacheva et al., 2009; Marton and Ferencz, 2006; Schnepp and Lanos, 2005, 2006; Tema et al., 2006; Tema and Kondopoulou, 2012; Zananiri et al., 2007). In spite of great advances, at present, very few archaeomagnetic directions are available in Europe before the third millennium BC (Fig. 1A–B). No archaeomagnetic information from Western Europe are provided by the global database, with the only exception of a study in the UK carried out during the 1960s (Aitken and Hawley, 1967) and one direction from the fourth millennium BC from France (Hervé et al., 2013). The only directional data currently available in Europe prior to this age come from Eastern Europe (Aidona and Kondopoulou, 2012; Burlatskaya et al., 1986; Márton, 2009; Kovacheva et al., 2009). One of the reasons that explain this lack of data is the unknown of well-dated materials suitable for these chronologies. It is therefore necessary to explore new materials meeting the necessary requirements in order to extend temporally and geographically the existing secular variations records.

We present here the first archaeomagnetic directions obtained from a new geomagnetic field recorder: anthropogenic cave sediments. These materials are known in the archaeological literature as *fumiers* and refer to stratigraphic sequences composed of ash, straw and dung (Brochier, 1983). They are produced by the periodic combustion of domestic livestock dung and consist of alternating burnt dung layers with unburnt dung levels (Fig. 2). By burning, the caves were cleaned from parasites arising from livestock penning, a common practice that is widely documented in the Mediterranean region since the Neolithic (e.g. Angelucci et al., 2009; Boschian, 1997; Boschian and Montagnari-Kokelj, 2000; Brochier, 1983; Brochier et al., 1992; Karkanas, 2006; Macphail et al., 1997; Straus and González Morales, 2012; Vergés et al., 2002, 2008). These layers have been traditionally studied from sedimentological and archaeobotanical perspectives. However, with the exception of our previous works (Carrancho et al., 2009, 2012), their suitability as geomagnetic field recorders has not been yet fully explored. The objective of this work is twofold. First, to show the suitability of anthropogenic cave sediments to obtain archaeomagnetic data through a comprehensive palaeomagnetic and rock-magnetic study. Second, to design a European PSV curve for the 6000–1000 yr BC time period exclusively based on archaeomagnetic data. The results obtained and their potential application to dating (Lanos, 2004; Pavón-Carrasco et al., 2011) are discussed.

2. Materials and methods

2.1. Description of anthropogenic cave sediments

Anthropogenic cave sediments are known in the French archaeological literature as *fumiers* or "burnt animal dung layers" (English) and are interpreted as a product of pastoral activities (Brochier, 2002). The main goal of these practices was to disinfest the space and reduce the volume of residues generated by the livestock. The Holocene stratigraphy of these sites exhibits a characteristic succession of burnt levels alternating with other few (or un-)burnt layers, generating sequences of rather variable texture and colour (Fig. 2A–B). This alternation between combustion episodes and unburnt levels generates facies' groups whose transition may be gradual or abrupt. As a whole they make up thin facies successions of centimetre and even millimetre scale, with sub-horizontal stratification or following the topography of the substrate. Slightly convex morphologies are occasionally observed probably related to the accumulation of waste to be burned. The dimensions, morphology and thickness of the ashes are somewhat variable, reaching up to 2–3 meters long and several centimetres of thickness. In section, they are occasionally observed as lenses with abrupt and/or wedged-shape contours and in most cases as horizontal and regular sheets. The presence of archaeological artefacts (generally poor) within these sequences derived from domestic activities (e.g. pottery) suggests that humans lived with the animals in the caves, although occupying differentiated areas. Most