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A broad band magnetic susceptibility test study — The magnetic spectroscopy of a Neolithic ditch

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ABSTRACT

The magnetic characteristics of soil, sediments and archaeological deposits are environmentally sensitive, and can therefore be used to understand formation processes at archaeological sites. The magnetic susceptibility (MS) of a material indicates the concentration of magnetic inclusions of a sample. This depends on the concentration of magnetic grains but also on the composition of the magnetic mineralogy as the size of those grains. The grain size relates to the size-dependent magnetic domain state, which vary from thermally unstable ultrafine superparamagnetic (SP) grains to stable single-domain (SD) and pseudo-single-domain (PSD) grains to large multi-domain (MD) grains. Standard dual frequency measurements (χ_{FD}), magnetic susceptibility measurements at two different frequencies, are applied to semi-quantitatively evaluate a sample's SP inclusion. Other methods are used to quantitatively evaluate the magnetic grain size distribution (GSD) of a sample. Recently, magnetic susceptibility meters are available permitting broad-band magnetic susceptibility (BBMS) measurements to be made over a large spectrum of frequencies. This allows quantifying a narrow GSD of SP grains based on their frequency-dependency. Although novel in archaeology, such measurements have been applied in a handful of environmental studies in recent years concerning loess deposits in China and Bulgaria as well as ceramics in a study from the Czech Republic. To assess the applicability of BBMS in archaeology, soil samples were taken from a ditch at the middle-Neolithic Circular Ditched Enclosure, Hornsburg I, Lower Austria. The samples were measured with the University of Toronto Electromagnetic Induction Spectrometer (UTEMIS II). Measurements at different frequencies, ranging between 140 Hz to 63 kHz, allowed the calculation of the samples' GSD's, the grain sizes' mean, standard deviation and range as well as the frequency dependence. These can be used to understand a sites or features soil formation history, as archaeological deposits often exhibit enhanced magnetic properties that are distinct from surrounding non-anthropogenic soils, sediments and deposits. Therefore understanding how these contrasts relate to the changes in magnetic concentration, composition and grain size can provide indispensable information towards the formation processes and post-depositional changes at an archaeological site. The results of the study show promise for BBMS studies being a useful tool for differentiating different soils, sediments and archaeological deposits and thus reflecting the different archaeological phases and soil formation processes within the examined ditch. This provides for a better understanding of the depositional and post-depositional processes of the ditch deposits allowing for further archaeological assessment and offering additional applicability for a wide range of archaeological fields.

1. Introduction

Low field magnetic susceptibility (MS) measurements are a common technique used in geological, rock, palaeomagnetic, environmental and archaeological studies (Mullins, 1977; Thompson and Oldfield, 1986; Verosub and Roberts, 1995; Dalan and Banerjee, 1998; Evans and Heller, 2003; Maher, 2007; Liu et al., 2012; Kodama et al., 2014; Dalan et al., 2017), as they are a convenient indicator of the concentration of magnetic minerals in rocks, sediments, soils and archaeological deposits (Thompson and Oldfield, 1986; Verosub and Roberts, 1995; Dalan and Banerjee, 1998; Maher and Thompson, 1999; Evans and Heller, 2003). Low field MS measurements reflect the concentration of ferromagnetic particles within a sample and can therefore be used to gain insight into the formation processes (Mullins, 1977; Dalan and Banerjee, 1998; Dalan, 2006, 2008; Evans and Heller, 2003; Kodama et al., 2014).

Typically, low field MS measurements are performed using

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commercially available equipment, which enables large quantities of material to be studied rapidly. Such measurements are non-destructive, allowing samples to be examined by additional studies, which can help define other magnetic parameters (Dearing et al., 1996; Dalan and Banerjee, 1998; Evans and Heller, 2003; Dalan et al., 2017). A material's magnetic grain size distribution (GSD) or its magnetic minerals can be investigated using a variety of methods, however these are not always non-destructive (Banerjee et al., 1981; King et al., 1982; Fassbinder, 1993; Fassbinder and Stanjek, 1993; Dalan and Banerjee, 1998; Evans and Heller, 2003; Kodama et al., 2014). The GSD provides useful information relating to the ultrafine magnetic particles, known as superparamagnetic (SP) grains, which contribute most to a material's magnetic properties.

In previous studies, the relative frequency dependent MS (χ_{FD}) (Clark, 1996; Dearing, 1994), calculated from a low frequency (χ_{LF}) and a high frequency (χ_{HF}) MS measurements, has been used to indicate the concentration of fine grained SP particles (Eyre, 1997; Worm, 1998). These measurements provide useful information about the environments in which soils, sediments and archaeological deposits have formed (Maher, 1986; Thompson and Oldfield, 1986; Heller et al., 1991; Dearing, 1994; Maher and Thompson, 1995; Dearing et al., 1996; Evans and Heller, 2003; Sartori et al., 2005; Dalan, 2006; Kodama et al., 2014). The low and high frequency MS measurements are typically recorded at 0.465 kHz and 4.65 kHz, respectively, defined by the operating bandwidth of the most commonly used susceptibility meters (Bartington MS2 or MS3). The resultant χ_{FD} indicates the concentration of SP particles and is influenced by various magnetic properties, especially the applied frequencies (Muxworthy, 2001; Kodama, 2010; Hrouda, 2011).

New developments in MS meters, such as the University of Toronto Electromagnetic Induction Spectrometer (UTEMIS II) used in this study, allow measurements over a large spectrum, 0.14 to 63 kHz. Other studies have used frequencies up to 250 kHz (Hrouda, 2011) and 512 kHz (Kodama, 2013), allowing SP particle concentrations to be measured across a wider spectrum. Due to the various frequencies used it is important to indicate which frequency has been used. Therefore the measurement frequency is indicated in the brackets, i.e. $\chi_{LF(0.14)}$ for 0.14 kHz and similarly the frequencies used in the frequency dependence calculations, i.e. $\chi_{FD(0.14,\ 64)}$ for 0.14 kHz and 64 kHz.

Prior BBMS studies have largely been applied to the study of loess and palaeosol sequences. The reconstruction of the GSD's for such a sequence in China revealed that the mean volume of SP particles tended to increase during the transition from loess to weak palaeosols to palaeosols indicating a change in grain size during pedogenesis (Kodama et al., 2014). Necula et al. (2015) reconstructed the GSD's of SP particles for Romanian loess deposits and compared these to results obtained from low temperature Mössbauer spectroscopy, showing that the GSD's in loess have higher diameters than palaeosols with the latter having higher concentrations of SP grains than loess deposits. Chlupáčová et al. (2012) investigated the magnetic properties of ceramics through a variety of measurements as frequency dependent magnetic susceptibility of the anisotropic and thermal characteristics of the magnetic particles, the natural remanent magnetisation, the time-dependent isothermal remanent magnetisation and Mössbauer spectroscopy. The optical microscope identified no ferri-magnetic minerals although these were confirmed by the bulk magnetic susceptibility and frequency dependence calculations. This indicated that all grains, both ultrafine and coarser ones, were orientated in the same direction concluding that a pottery wheel had been used for their production (Chlupáčová et al., 2012).

2. The site

The Hornsburg I circular ditched enclosure (Kreisgrabenanlagen in German, henceforth KGA) (Fig. 1) lies on a ridge to the west of the village of Hornsburg in the Kreuttal area, Lower Austria. The site lies within the Kreuttal case study area of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI Arch Pro; http://lbi-archpro.org/cs/kreuttal/), approximately 20 km to the north of Vienna. The case study area is mostly covered in forest and is comprised of brown earth on loess deposits, with the remnants of a multiperiod landscape, dating from the Neolithic to modern times.

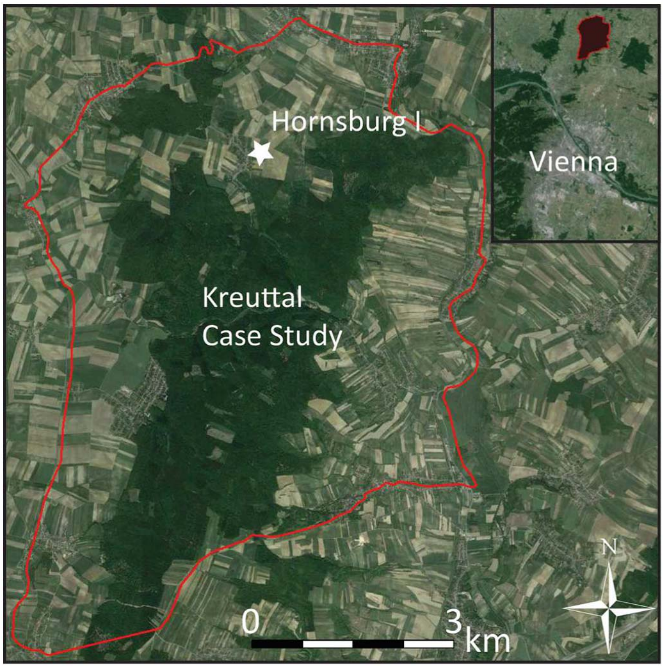

Fig. 1. The LBI ArchPro Kreuttal case study area and location of the Kreisgrabenanlage Hornsburg I and the case studies location (red polygon) in relation to Vienna is shown in the inset. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The KGA's of Central Europe date to the Middle Neolithic period (4800–4500 BC). Amongst the oldest monumental structures known in Central Europe, they represent one of the earliest forms of large transcultural ritual monuments in Europe (Neubauer, 2012), which can be seen as a reinterpretation of social organisation caused by an increase in social complexity (Ridky et al., 2014). These monuments can be found throughout Central Europe; in Austria, Czechia, Slovakia, west Hungary, Germany and Poland (Melichar and Neubauer, 2010; Ridky et al., 2014). KGAs in Austria consist of one to three concentric V-shaped ditches, ranging from 45 to 180 m in diameter, with at least two, but as many as five entrances. The interior is encircled by one or two wooden palisades creating a defined space for communal events but no obvious defensive function has been identified. KGAs could serve various functions, ranging from meeting places to ritual centres; astronomical characteristics indicate a possible calendrical use (Petrasch, 1990; Trnka, 1991; Becker, 1996c; Podborský, 1999; Neubauer, 2012). Often these monuments have related settlements in close proximity but show no evidence of being used for habitation themselves, however forming an integral part of these. Nonetheless, the KGA phenomenon has not been explained fully, with their function still open to debate, and it disappears as rapidly as it starts, lasting only 200–300 years.

Hornsburg I lies on a ridge to the east of the village of Hornsburg, which itself lies on a plateau between the watershed of the Haselauer and Hautzendorfer streams. These flow into the Rußbach stream which runs through the Kreuttal valley to the south of the site. Another KGA, Hornsburg II, is situated to the west of the village of Hornsburg, on the opposite ridge of Hornsburg I, and evidence from extensive magnetometry surveys carried out by the Zentral Anstalt für Metrologie und Geodynamik (ZAMG), Archaeo Prospections® and the LBI Arch Pro show an adjoining settlement to the north-west of the KGA (Melichar