Physics of the Earth and Planetary Interiors 241 (2015) 21–36

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Holocene archeointensities from mid European ceramics, slags, burned sediments and cherts

Kathrin Lisa Kapper [a,*], Fabio Donadini [b], Ann M. Hirt [a]

[a] Institute of Geophysics, ETH Zurich, Rämistr. 101, CH-8092 Zurich, Switzerland
[b] University Fribourg, Av. Europe 20, CH-1700 Fribourg, Switzerland

ARTICLE INFO

Article history:
Received 26 March 2014
Received in revised form 18 December 2014
Accepted 23 December 2014
Available online 3 January 2015

Keywords:
Archeointensity
Secular variation
Holocene
Ceramic
Slag
Burned chert
Burned sediments

ABSTRACT

The Earth's geomagnetic field intensity in the past can be determined from archeological artifacts. These archeointensity data are important inputs for geomagnetic field models and local reference curves of Earth's magnetic field. Although archeointensities have been measured on materials for more than half a century ago, data are still scarce before 1000 BC and for the Alpine area in general. This investigation presents new absolute archeointensity data from a time period of 5000–700 BC from Italy and Switzerland. The archeological materials that were studied are ceramics, copper slag, and burned sediments from fireplaces. In addition, we investigated archeointensities from burned cherts, in order to uncover if they are a suitable material for paleomagnetism. Rock magnetic properties of all samples indicate magnetite, and small amounts of maghemite and hematite in the pseudosingle domain range as the ferromagnetic carriers. The IZZI protocol was used for 96 specimens to obtain absolute intensities; 23 ceramics, slags and burned cherts passed the threshold criteria, which we applied. The choice of the threshold values allowed us to obtain the linear part in the Arai diagram, which corresponds to the characteristic remanent magnetization. Burned sediments did not pass the threshold criteria, most probably because they acquired a thermochemical remanent magnetization during their formation. We demonstrate that magnetic susceptibility and saturation isothermal remanent magnetization can be used to select cherts that are suitable for paleointensity determinations. After applying anisotropy and cooling rate corrections, the new archeointensity values are lower for some samples, but fit well with available models and other archeomagnetic data.

1. Introduction

Absolute intensities and directions, which can be determined from archeomagnetic samples, can improve our understanding of the Earth's magnetic field and how it has changed during the past millennia. They serve as the input in the construction of geomagnetic field models and for local reference curves. Present geomagnetic field models that employ archeomagnetic data have fairly good data coverage for the past 3000 years, particularly for Europe (e.g., Donadini et al., 2009, 2010; Pavón-Carrasco et al., 2010). Archeomagnetic data of older artifacts is rare, particularly intensity data. For this reason geomagnetic field models that extend further back into the Holocene are dependent on additional sources of data such as from lacustrine sediments (e.g., Pavón-Carrasco et al., 2010).

Geomagnetic field models that use stacking of available data sets display significant scatter between data sets, so that they cannot resolve accurately short term changes in field intensity and direction (e.g., Shaar et al., 2011). High frequency features, such as archeomagnetic jerks (Gallet et al., 2003) and geomagnetic spikes (Ben-Yosef et al., 2009) are smoothed out. For example, the large geomagnetic spikes, observed in the Levantine slags at around 900 BC that reach a maximum virtual axial dipole moment of $(204 \pm 12) \times 10^{21}$ Am^2, suggest the existence of local non–dipolar features that can rise and fall over a period of several decades. Resolution of such local, short–term features requires high quality data sets with high resolution, and therefore, stringent quality criteria are needed when evaluating archeomagnetic data sets (e.g., Shaar and Tauxe, 2013).

Various local studies on the behavior of the intensity of Earth's magnetic field before 0 AD have been made in France on hearths, baked clay and kilns (Gallet et al., 2002), in Germany on ovens, kilns or hearths (Schnepp and Lanos, 2005), in Turkey on burned mud bricks and kilns (Ertepinar et al., 2012), in Greece on ceramics

* Corresponding author.
E-mail address: klkapper@gmail.com (K.L. Kapper).

http://dx.doi.org/10.1016/j.pepi.2014.12.006
0031-9201/

and burned clay structures (Fanjat et al., 2013), in southern Israel on slags (Ben-Yosef et al., 2008b), and in the Balkan Peninsula (Tema and Kondopoulou, 2011). Little data are available from the Alpine region. This study examines archeointensity data obtained from ceramics, copper slag, and burned sediments from the Alpine region in Switzerland and northern Italy. It also investigates the suitability of burned cherts as a recorder of the past Earth's magnetic field and intensity and attempts to establish rock magnetic criteria to distinguish suitable burned cherts from unburned cherts. Results are evaluated in the context of field behavior for Central Europe over a time period from 5100 to 600 BC.

2. Materials

Ceramic or potsherds were one of the first archeological materials to be used as reliable magnetic field recorders of the Earth's magnetic field (e.g., Sternberg and Butler, 1974; Aitken et al., 1981; Tarling, 1975). Because these materials have been fired at high temperature they acquire a thermoremanent magnetization (TRM) over a short period of time. Ceramics can acquire a thermochemical remanent magnetization (TCRM), if heating temperatures were not high enough. In this case the magnetization is only partly or completely reset, which can lead to an incorrect determination of archeointensity (Morales et al., 2011). The Swiss ceramics used in this study were obtained from the Archeological Service of the Fribourg Canton, and were collected during various archeological excavations in the area east of Lake Neuchâtel and Lake Murten (Table B.1, Fig. A.1, pers. comm. M. Mauvilly). The Italian ceramics were donated by the Università degli Studi di Trento, and were collected in the Adige River valley in the region of Trento, Italy (Table B.1, Fig. A.1; pers. comm. Fabio Cavulli). The ceramics span a time period from about 5000 to 700 BC, and vary in color from red–brown to dark gray, and texture from fine to coarse.

Copper slags from as early as 4300 BC have also been shown to be good recorders of the Earth's magnetic field intensity and direction (e.g., Ben-Yosef et al., 2008a,b), because: (1) the samples acquire a TRM with a high intensity on the order of Am^2/kg; (2) they are cooled rapidly in air favoring the formation of magnetic grains in the single domain range of grain size; and (3) the cooling rate after smelting is similar to the cooling rate used in Thellier experiments, thus eliminating a correction for cooling rate (Shaar et al., 2010). Slag is a waste material that is produced in furnaces during the heating of copper ore up to 1200 °C. Metallic copper separates at the bottom of the furnace from the melt on the top, which makes up the slag. After removing the melt from the furnace, the slag cools in the ambient field to acquire a TRM. The slag samples that are used in this study were collected from the Transacqua excavation (TA) in northern Italy, ENE of Trento and originate from copper smelting production during the end of the Bronze Age (Table B.1, Fig. A.1). The ore was chalcopyrite, and the slag is mostly made up of fayalite with Cu and Cu–sulfide inclusions (pers. comm. E. Silvestri).

The third material, which we investigated in this study, is burned sediment from fireplaces. Le Borgne (1955) first noted that the magnetic susceptibility of burned soils is enhanced. Later studies showed that burned soils and sediments from archeological sites can preserve the ambient geomagnetic field through the acquisition of a TRM (e.g., Calvo-Rathert et al., 2012). Sediments and soils that acquire the most stable TRM are usually from the center of the fireplace and from the uppermost layer. Burned sediments were collected from two Holocene rock shelters, Arconciel, which is located in Canton Fribourg, Switzerland (ARC, Table B.1, Fig. A.1) and Riparo Gaban, which is in the Adige River Valley, Italy (RGB, Table B.1, Fig. A.1) The burned sediments span a time period from 6000 to 4600 BC. Rock magnetic properties and paleomagnetic directions of those samples are reported in Kapper et al. (2014a,b). Based on these investigations ash specimens were selected for archeointensity determinations.

Some of the oldest archeological artifacts are flaked stone tools, which have been produced for at least 2.5 Ma during the Paleolithic and Mesolithic periods. The most commonly used materials in the production of stone tools are the siliceous–rich sedimentary rocks, chert or flint. Chert is composed of cryptocrystalline quartz, chalcedony (microcrystalline compact quartz) or opal (colloidal, amorphous or semi–amorphous hydrated silica) (Angelucci, 2010). Cherts were heated to improve their flaking properties, because heating helps to propagate fractures in the material, making it easier for production of the stone tools (Domanski and Webb, 1992). Burned cherts were obtained from an excavation in Lugo (LU), and burned and unburned cherts from La Vela (LV), both in the vicinity of Trento, Italy (6800–4600 BC, Table B.1, Fig. A.1). These cherts were also donated by the Università degli studi di Trento, Italy; their color is dark red or gray.

Ceramic, slag and chert samples were dated with radiocarbon dating or dendrology of trees from the sample sites. Burned sediments were also dated by radiocarbon dating or by interpolation of radiocarbon ages, between hearth levels, when no direct dates were available (c.f., Kapper et al. (2014a,b), Table B.1).

3. Sample preparation and rock magnetic measurements

For the archeointensity experiments ceramic, slag or chert samples were glued with Omega high–temperature oven cement in non–magnetic ceramic cylinders with 2 cm diameter and height. The side of the cylinders was marked with a reference line so that the samples were always placed in a similar position in the oven during heating or in the magnetometer for measuring (Fig. A.2). Burned sediments were placed in cylindrical shaped cavities in cubes of plaster of Paris with a 2 cm edge length. All measurements were carried out at the Laboratory of Natural Magnetism of ETH Zurich, Switzerland.

Thermal reversibility of magnetization and ferromagnetic mineralogy were criteria used to judge whether a sample would be suitable for the determination of archeointensity. Thermomagnetic curves (magnetic bulk susceptibility versus temperature) were measured on an AGICO KLY-2 or MFK1.FA susceptibility bridge with a CS-2 or CS-4 heating system, respectively. Measurements were made with a heating/cooling rate of 11 °C/min. Reversibility of the heating and cooling curves indicates mineralogical stability during heating. These measurements also provide information on the Curie (T_c) or Néel (T_n) temperature of the dominant ferromagnetic minerals. Acquisition of isothermal remanent magnetization (IRM) in a backfield (backfield curve) was made using a Princeton Measurements Corporation vibrating sample magnetometer (VSM, Model 3900). The acquisition curves of IRM provide information on the ferromagnetic minerals in the samples, based on the field in which the magnetization is saturated, i.e., saturation IRM (SIRM), and the field needed to reduce the backfield magnetization to zero, which is known as the coercivity of remanence (B_{cr}). The natural remanent magnetization (NRM) and IRM were measured on a 2G Enterprises, DC-SQUID rock magnetometer (Model 755), which is equipped with a 2-axis alternating field (AF) demagnetizer. Bulk susceptibility and anisotropy of magnetic bulk susceptibility (AMS) were measured on the AGICO KLY-2 susceptibility bridge (applied field, $H_{app} = 300$ A/m, frequency, $v_{app} = 920$ Hz). Hysteresis loops were measured on the VSM with a field increment of 10 mT and averaging times of 100–500 ms. Hysteresis loops provide information on the saturation magnetization (M_s), remanent saturation magnetization (M_r), and coercivity (B_c). Two first–order reversal curves of burned cherts were measured on the VSM and