Physics of the Earth and Planetary Interiors 236 (2014) 79–94

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

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

Extended and revised archaeomagnetic database and secular variation curves from Bulgaria for the last eight millennia

M. Kovacheva [a], M. Kostadinova-Avramova [a,*], N. Jordanova [a], Ph. Lanos [b], Y. Boyadzhiev [c]

[a] National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., bl.3, 1113 Sofia, Bulgaria
[b] Université de Rennes 1 "Géosciences-Rennes", Bât. 15, Equipe "Paléo-Archéomagnétisme" Campus scientifique de Beaulieu, CS 74205, 35042 RENNES Cedex, France
[c] National Institute of Archaeology and Museum, Bulgarian Academy of Sciences, Saborna Str. 2, 1000 Sofia, Bulgaria

A R T I C L E   I N F O

Article history:
Received 13 January 2014
Received in revised form 21 May 2014
Accepted 2 July 2014
Available online 15 July 2014

Keywords:
Archaeomagnetism
Database
Southeastern Europe
Reference curves

A B S T R A C T

The efforts of geophysicists to describe geomagnetic field behaviour in the past lead to creation of different geomagnetic field models. On the other hand, the established regional palaeosecular variations of geomagnetic elements are increasingly used for dating purposes in archaeology. Both of these goals can be achieved if sufficient amounts of long archaeomagnetic data sets exist for different geographical regions. The accumulation of archaeomagnetic determinations began at the middle of the last century, parallel with the progressive development of experimental methodology and acceptance criteria. The presence of great number of old determinations requires their critical assessment. The important question about the reliability of the associated dating intervals should be also re-assessed. All this requires the continuous refinement and extension of the accumulated databases. This paper presents the last synthesis of Bulgarian archaeomagnetic database and the local palaeosecular variation curves obtained using a statistical treatment based on Bayesian approach (RenCurve software). The rock-magnetic characteristics of the newly included, non-published results are summarized.

1. Introduction

Archaeological baked clay structures and volcanic rocks are the most valuable source of data bearing information about the past behaviour of full geomagnetic vector. On the basis of this kind of data, treated with Bayesian (Lanos, 2004; Lanos et al., 2005; Lanos et al., in preparation) or bivariate (Le Goff et al., 2002) statistics, enable secular variation curves (SVCs) to be built for a given territory. These curves should be created from sufficiently precise archaeomagnetic determinations obtained from well dated materials preferably by independent methods. In such cases, SVCs can be used in archaeology for dating purposes (Kovacheva et al., 2004; Lanos, 2004; Herve et al., 2011). The global and regional geomagnetic field modeling (Korte et al., 2009; Korte and Constable, 2011; Pavón-Carrasco et al., 2009) is the most important key for elucidating the geomagnetic field origin and fluid motions in the Earth's interior. These complicated geophysical problems can be solved on the basis of reliable data sets of archaeomagnetic and palaeomagnetic (volcanic and sedimentary environments) determinations of geomagnetic field elements. Each database compilation is a long, continuous process and periodical updates, revision or re-examinations are required. The accumulation of the Bulgarian data set started in 1967 and several updates have been published (Kovacheva, 1992, 1997; Kovacheva et al., 2009a). In previous compilations archaeomagnetic determination from all studied collections in Sofia Palaeomagnetic laboratory (Bulgarian, Serbian, Greek, etc) were included. Now the data from non-Bulgarian archaeological sites are excluded and those obtained after 2009 (28 different features) are added. Furthermore, in the present compilation, the dating intervals for some sites were corrected according to the new ^{14}C dates that are becoming available or last archeological conceptions. The aim of this paper is to communicate the enlarged and revised after 2009 local data set and the obtained from it local reference curves for the three geomagnetic field elements during the last 8000 years.

2. General description of the extended database

The basic feature of Bulgarian archaeomagnetic data set is that it summarizes the simultaneous determination of the geomagnetic field direction (D, I) and intensity (F) – both parameters being obtained from the same material. It covers almost the entire prehistoric and historic periods. The methodology applied in the

* Corresponding author. Tel.: +359 895 745 533; fax: +359 2 979 33 27.
E-mail addresses: marykov@abv.bg (M. Kovacheva), miki4740@abv.bg (M. Kostadinova-Avramova), vanedy@geophys.bas.bg (N. Jordanova), philippe.lanos@univ-rennes1.fr (Ph. Lanos), yavordb@abv.bg (Y. Boyadzhiev).

http://dx.doi.org/10.1016/j.pepi.2014.07.002
0031-9201/

Sofia Palaeomagnetic laboratory was gradually improved and optimized over the years. Detailed information about sampling technique, experimental protocols, selection and quality criteria can be found in Kovacheva and Toshkov (1994), Kovacheva et al. (1998, 2009a), Kostadinova-Avramova et al. (2014a). The archaeomagnetic determinations correspond to the feature's mean values as "the feature is a volume of material that can be considered to have been magnetized at the same time" (Tarling, 1983). In some cases (mainly for the historic periods) "feature" coincides with the studied site, but in other (e.g., for the prehistoric periods), several "features" corresponding to different layers are related to the same archaeological site. The feature's average values for the direction are calculated following the hierarchical approach (Lanos et al., 2005).

The used ^{14}C dates (generally series of ^{14}C dates) were taken mainly from Görsdorf and Bojadžiev (1996). Most of these were obtained by the conventional method and OxCal 4.0 software was used for their calibration. The recently received ^{14}C dates for some prehistoric archaeological sites by the AMS method were compared with those obtained by the conventional method. The both methods give consistent results (Boyadzhiev, in press). The problems concerning ^{14}C dates related to Eneolithic period are described in Boyadziev (1995) and Kostadinova-Avramova et al. (2014a). When there are no ^{14}C, the archaeological assumption about the dating interval is based on stratigraphic constraints, e.g., the accumulation rate of layer and the cultural features found in it. Often, in addition to the existing ^{14}C dates, the mentioned archaeological evidences and the type of material (annual or perennial) used for ^{14}C dating were taken into account, which has led to better constraint of the dating intervals.

The archaeomagnetic data and all supporting information are given in a Table 1. For clarity the same format is kept as the Table 1 linked to Kovacheva et al. (2009a). The differences are listed below:

- 28 newly included Bulgarian sites (given in bold).
- All the data obtained from non-Bulgarian sites (Serbian, Greek, etc) but studied in Sofia laboratory were excluded. Thus the column "Country" becomes unnecessary and it is discarded. The Serbian data were used previously for the construction of first local SVCs in Kovacheva and Toshkov (1994) and Kovacheva et al. (1998).
- Another discarded column is "STEP" connected with the level of the thermal or alternating field cleaning. The normalized palaeointensity (PI) results corresponding to the site dipole field (PI_PIDIP) were also excluded.
- A new column for "K" was added. This column represents the grouping factor according to the Fisher (1953) statistics.
- When no data were available, the sign "*" was used in the Table 1.
- The results of inclination (I) of many sites represented only by brick materials were re-evaluated (e.g., Labnos 107, 108, 141) and some were discarded (e.g., these of Labnos 202, 230, 271) keeping only the intensity results.
- At the end there were 32 reference sites for which a new evaluation of the directional results (I and D) or only of the PI result had been performed (e.g., Labnos 36, 113, 156, 227, 311). The directional results for Labno 85 were discarded. This site has been studied at least 40 years ago and a doubt existed for the reliability of the results obtained on the basis of very limited number of independently oriented samples.
- Labno 97 (Kovacheva et al., 2009a) was entirely discarded because of its dubious results. Now the same Labno 97 was given to the results of one unused so far sector from the multilevel Bronze tell at Dyadovo.
- Two Labnos 10 and 294 from Kovacheva et al. (2009a), representing averaged results from successive layers in the sites Samovodene and Koprivetz, correspondingly were changed. They were both separated following the stratigraphy and the advices of archaeologists. Thus three new reference points: Labnos 354, 355 and 358 were obtained.
- For the prehistoric past the newly obtained ^{14}C dates were taken (e.g., Labnos 247, 261, 272). It should be noticed that for the sites dated on the basis of ^{14}C only, the dating intervals are now given exactly on the 95.4% probability level. This interval is often very large but is required for the subsequent mathematical applications. In some cases taking these large intervals, their midpoints are not always consistent with the stratigraphy (e.g., Labnos 306; 307; 295) Dating intervals of some prehistoric sites (layers) without ^{14}C were changed according to the last archaeological conceptions related to the stratigraphic constraints and cultural features (e.g., Labnos 50, 281, 295).
- For the prehistoric past the column showing the stratigraphic constraints is added (SC). Older/current Labno is after the «older» and before the «younger»/younger (e.g. 35/51/52) for Labno 51. The information in this column clarifies the above mention problem when considering only the midpoints.
- Besides the problems in prehistory, the dates of several Middle age sites were changed after new consultations with the archaeologists (e.g., Labnos 120, 159, 195, 314).

3. General magnetic characteristics of the unpublished sites, included after 2009

The new sites included in the last version of Bulgarian database are 28. The archaeomagnetic results from 11 of them are published (corresponding references are given in the last column of the Table 1 – the first reference corresponds to that of Geomagia 50.v3 (in preparation) and the second one corresponds to the original (detailed) publication). The main properties of the other 17 unpublished reference points are summarized in this section.

For all studied materials different types of magnetic cleaning were performed. Viscous cleaning was done for all specimens coming from the gathered hand samples. The viscosity coefficient Sv (%) was calculated for each specimen according to the relation $Sv = \{NRM_0 - NRMst)/NRM_0\} \times 100\%$, where NRM_0 is the initially measured remanence and NRMst is the stable component measured after the zero field storage. For the most of the studied collections acceptable ($\leqslant$8%) values for Sv were obtained (Fig. 1a). The exceptions are three collections (Labnos 353; 356 and 366). For these, the Sv values vary over a wide range and often exceed 8% (Fig 1b). For PI determinations only specimens with Sv less than 6% were used. There are two possible explanations for the observed high Sv values: (1) the insufficient heating in the antiquity and (2) the presence of significant amount of unstable superparamagnetic (SP) grains. The determined K_{FD} (%) for the studied materials are often more than 6% (Fig 1c). This indicates that magnetic grains with SP sizes are very common for baked clay materials (Jordanova et al., 2001). Insufficient heating in the antiquity also is not an uncommon affecting factor – for example Labnos 368 and Labno 369 are two kilns from a recently studied archaeological site Pliska which show high Sv and high K_{FD} values (Kostadinova-Avramova et al., 2014b). On the other hand the Arai plots and magnetic susceptibilities measured after each heating step (Fig 6c) indicate that both structures have been heated in the past to temperatures around 430–460 °C. Therefore, in this case combination of factors (1) and (2) are probably responsible for the observed high Sv values.

Magnetic cleaning with alternating field (AF) or temperature (Fig. 2) were applied for some selected specimens (from one to four per sample depending on the number of cut specimens). The final directional results were obtained only from the results after both AF and thermal cleanings.