Chapter 8
Archaeomagnetic Studies of the Material of the Archaeological Monument Dmitrievskaya Sloboda II of the Second Millennium B.C

O. V. Pilipenko, I. E. Nachasova, S. K. Gribov and O. V. Zelentsova

Abstract An archaeomagnetic study of ceramic material from the archaeological site Dmitrievskaya Sloboda II (Murom district, Vladimir region) was conducted. The site is archaeologically dated to the middle of II millennium B.C. Nine geomagnetic field intensity determinations were obtained. The geomagnetic field intensity varies between 40 and 75 μT with an average value of about 55 μT. Comparing the field intensity data sets obtained in this study and in that on the material from the Sakhtysh-I monument (IV-III millennium B.C., Nachasova et al. 2018) shows an increase in the geomagnetic field intensity variation and the mean value of the geomagnetic field intensity in the II millennium B.C. against the level of the field in the previous two millennia. This might be a manifestation of the 8-thousand-year cycle in the field intensity variation.

Keywords Archaeomagnetic intensity · Geomagnetic field variations
Thellier method · Arai-Nagata diagrams

Introduction

Acquisition of new data about the Earth's magnetic field makes it possible to advance the studies of geomagnetic variations and clarify their regularities, and thereby to determine the key elements in the process of generation of the geo-

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magnetic field. The study of the fine structure of the geomagnetic field, of its individual elements and their interrelations forms a natural part of comprehensive research of the processes taking place in the Earth's core and shells.

Archaeomagnetic research makes it possible to obtain data about the intensity of the geomagnetic field in recent millennia by studying thermoremanent magnetisation of burnt material from archaeological monuments. Most important, data on absolute intensity of the ancient geomagnetic field are recovered, which cannot be obtained by investigating other types of remanence.

Examination of geomagnetic field intensity variations carried out on the materials from archaeological monuments of Eurasia (in the south-east of Europe (Kovacheva 1980), in the Caucasus, in Central Asia and Siberia (Burlatskaya 1965; Nachasova 1998), in Japan (Sakai and Hirooka 1986) showed that a gradual change in the field intensity occurs with a characteristic time of about 8000 years.

An analysis of the world data of geomagnetic field intensity for the last eight millennia (Nachasova 1998) led to the conclusion that the change in the field intensity can be largely represented as a superposition of a number of oscillations with periods from ranging 300 to 8000 years. The characteristic feature of these oscillations is their drift; moreover, oscillations with different characteristic times show a drift in both western and eastern directions. At the same time, these studies led to a significant increase of the information about the geomagnetic field intensity for Eurasia.

The longest time series of archaeomagnetic intensity determinations for the last 13 ky (Nachasova et al. 2015), constructed for Siberia, reveals new peculiarities of the "basic" oscillation of the geomagnetic field intensity, suggesting the existence of its eastern drift.

The greatest amount of data on the geomagnetic field intensity was obtained for the latitudinal belt 40°–45°N. The distribution on the time scale of the data is very irregular, most of the determinations belonging to the last two millennia. Therefore the task of extending the archaeomagnetic database for the time B.C. is very relevant. This work is a part of the research aiming to obtain information about the geomagnetic field intensity in the European part of Russia, located to the north of the above mentioned latitudinal belt, in the time interval from the Neolithic to the boundary of eras. It is especially interesting to obtain data for the time interval between 4000 and 2000 years B.C., for which there are much less data for Eastern Europe (Tema and Kondopoulou 2011) compared to other time intervals. This work studies the material from the Dmitrievskaya Sloboda II archaeological monument dated at the second millennium B.C.

The Object of Study and Age Estimations

The Dmitrievskaya Sloboda II settlement was discovered in the Murom district of the Vladimir region on the northern periphery of the Murom town, Russia, (φ = 55° 34′, λ = 42° 03′), Fig. 8.1. It occupies a low-pitched side of the first terrace of the left bank of the Oka river, and it is single-layered. The ceramic fragments are well

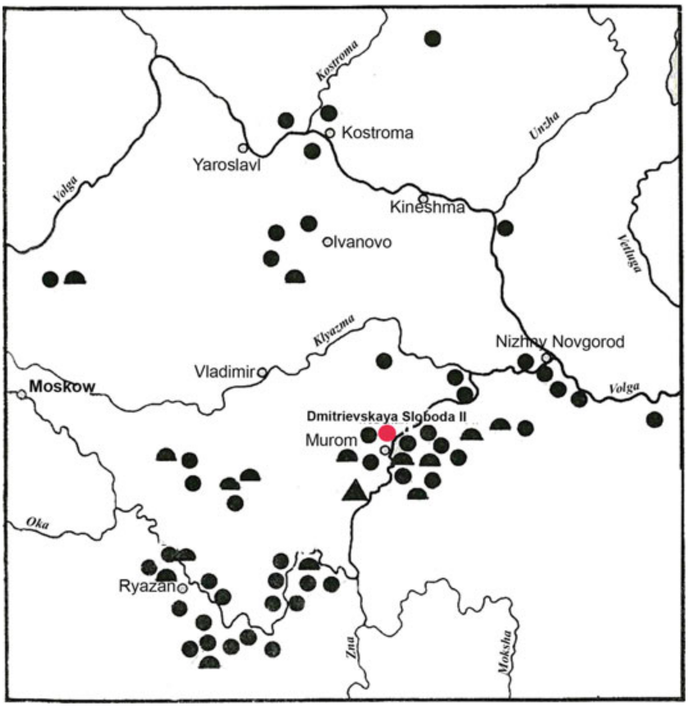


Fig. 8.1 Archaeological sites of Pozdnyakov culture (after Bader 1987). Bold circles are settlements, semicircles are burial mounds, triangles are archaeological sites, red circle is the Dmitrievskaya Sloboda II monument

burned pottery scraps, which are of brick or yellowish color outside, and dark brown or dark gray inside (Fig. 8.2). In general, the ceramic complex and implements look quite uniform in chronological and cultural terms. The monument belongs to the Pozdnyakov culture which dates to middle of II—beginning of I millennium B.C. (Sulerzhitsky 1993). For the dating of the monument, a series of radiocarbon dates were obtained for soil, coal and ceramics (Voronin 2013). The determinations made for coal have a calibrated age of ~1750–1500 years B.C. The dates obtained for ceramics are more variable (Saprykina et al. 2010). The most probable interval of the calibrated age of dates for ceramics is ~2050–1750 B.C. These dates correspond to the time of the transition from the Middle Bronze to the Late Bronze period and are related to the early stage of the formation of the Pozdnyakov culture.

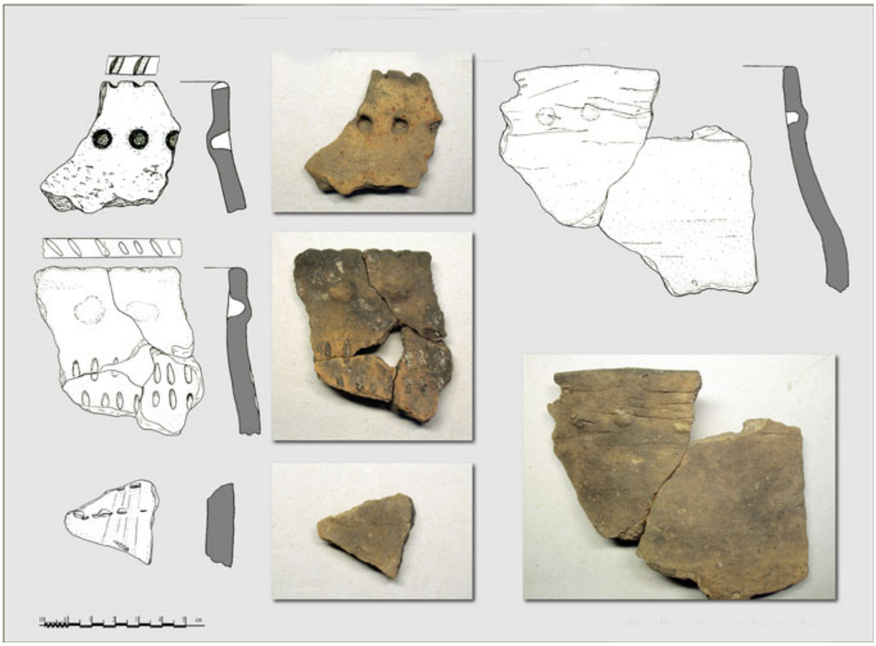


Fig. 8.2 Fragments of ceramics from the Dmitrievskaya Sloboda II settlement

Methods of Investigation and Equipment

Fourteen ceramic fragments were subjected to an archaeomagnetic study. The composition of the ferromagnetic fraction was studied on a pilot collection, consisting of seven samples (G-7/2-1694, B-6/3-2419, A-6/3-2639, A-5/3-2646, B-6-2667, $G_2$8-3922, VV10/1-4259) by the method of powder X-ray diffraction. Before X-ray diffractometry, we dispersed each sample in water by ultrasound and extracted a ferromagnetic fraction along the test tube wall with a neodymium magnet. We performed this procedure several times in order to improve separation. Since the initial data were inconclusive, we separated a sufficient amount of the magnetic fraction to reliably identify magnetic minerals by X-ray diffraction. The latter procedure was performed at room temperature with a STADI-MP multifunctional diffractometer (STOE, Germany) with an arched germanium monochromator crystal (reflection 111) which maintains a strictly monochromated CoK_α emission.

Thermomagnetic analysis (TMA) was carried out measuring the dependence of the saturation magnetization on temperature $Js(T)$ in the field of $\sim$0.4 T with an analyzer of ferromagnetic fraction (ORION, Russia).

The natural remanent magnetization (*NRM*) and thermoremanent magnetization (*TRM*) were measured on a spinner magnetometer JR-6 (AGICO, Czech Republic) in three rotation positions.

The intensity of the ancient geomagnetic field has been determined using the modified double heating Thellier method (Thellier and Thellier 1959; Coe 1978). For this purpose we used a non-magnetic oven MMTD80 (Magnetic Measurements, UK) and a DC magnetic field source. To exclude the effect of magnetic anisotropy, the samples in the furnace were placed with the maximum axes parallel to the direction of the magnetic field in the furnace. To eliminate the cooling rate effect, the samples in the furnace cooled at a natural rate, without turning on a cooling fan. For all samples, *pTRM* check-points were measured at temperatures of 300, 400 and 500 °C (Coe 1967; Paterson et al. 2014). Repeated field-free, *pTRM* tail-checks were also measured at temperatures of 150, 250, 350, 450 and 550 °C to test composition changes of magnetization carriers at blocking temperatures above the *TRM* creation temperature (Bolshakov and Shcherbakova 1979; Riisager and Riisager 2001; Shcherbakov and Shcherbakova 2002). For each sample, the Arai-Nagata diagram was used to determine the angular coefficient K of the slope of the straight line and to calculate the ancient geomagnetic field intensity according to the formula $B_{an} = K\, B_{lab}$, where B_{lab} = 50 μT (Fig. 8.3). We used for paleointensity estimations only that points, when difference between tail-check and *NRM* were less than or equal 10% and when difference between check-point and *pTRM* were less than or equal 10%.

The whole experiment was carried out at the Schmidt Institute of Physics of the Earth RAS and Geophysical observatory “Borok”.

Rock- and Archaeomagnetic Results

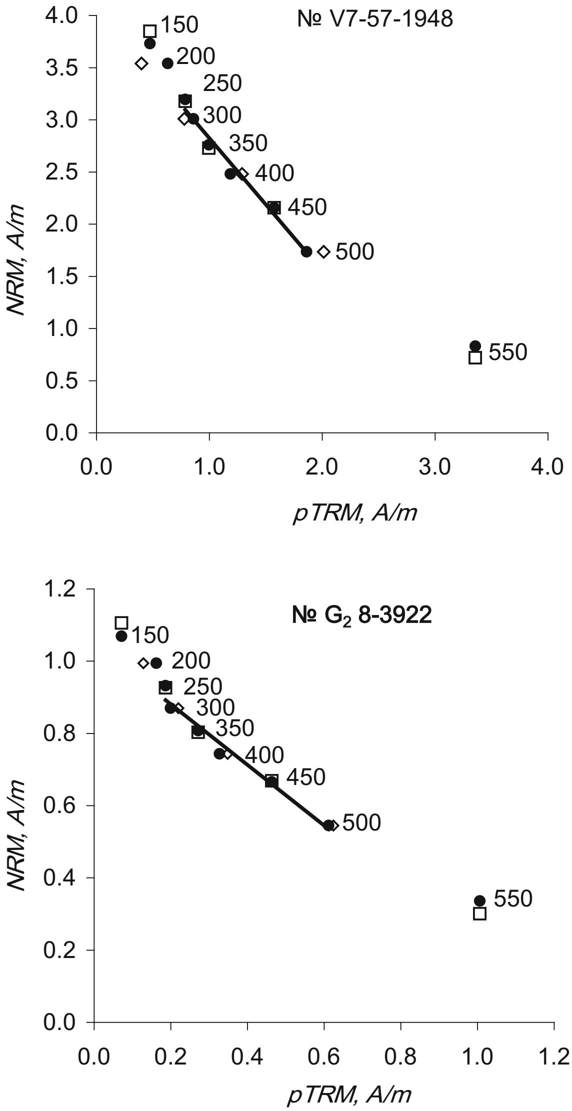
On the base of the powder X-ray diffraction method, the component analysis of spinel and hexagonal reflexes indicates that two phases are present in all cases. The elementary cell parameters calculated for both phases are given in Table 8.1. The period a of a spinel phase crystal lattice is close to those of magnetite (a = 8.396 Å) or maghemite (a = 8.33 Å). The parameters of a hexagonal phase correspond well to periods a and c of the hematite crystal lattice (a = 5.034 Å, c = 13.75 Å). We conclude therefore that in the investigated magnetic fraction the X-ray phase analysis shows the presence of magnetite, in most cases single-phase oxidized to maghemite, as well as of hematite.

Thermomagnetic analysis shows that the $Js(T)$ curves of the first and second heating have a bend in the temperature interval of ~570–600 °C (Fig. 8.4) suggesting that the main carriers of magnetization in the studied samples are magnetite and/or maghemite. The mineralogical composition does not change much after the heating.

Attempt to determine the geomagnetic field intensity has been carried out for fourteen ceramic fragments. After applying the “*pTRM* check-point” and “*pTRM* tail-check” criteria five ceramic fragments, whose experiments results do not satisfy these criteria, were excluded. Thus, the archaeointensity data obtained from the rest nine ceramic fragments were taken into consideration (Table 8.2).

The obtained geomagnetic field intensity data vary from 39 to 77 μT, with the average value of 54.6 ± 5.1 μT.

Fig. 8.3 The Arai-Nagata diagrams. Circles denote the results of studies using the modified Thellier method, hollow diamonds—*pTRM* check-points, hollow squares—*pTRM* tail-checks. The numbers near the symbols indicate the heating temperatures



Discussion and Conclusions

Data of the geomagnetic field intensity in the past obtained for different regions of Eurasia (Spain, the Caucasus, Central Asia and Siberia) for the last 7000–8000 years (Nachasova 1998; Nachasova and Akimova 2015; Nachasova et al. 2015) allowed us to obtain a picture of the magnetic field intensity variations in time and in space. The minimum of the "basic" variation (8 thousand years) falls at

Table 8.1 Crystallographic parameters of the magnetic fraction separated from the samples of the pilot collection

No. of the sample	Spinel phase	Hexagonal phase
G-7/2-1694	*a* = 8,41(3) Å *V* = 593.8(37) $Å^3$	*a* = 5026(7) Å *c* = 13.73(3) Å *V* = 300.5(10) $Å^3$
B-6/3-2419	*a* = 8.357(5) Å *V* = 583.7(6) $Å^3$	*a* = 5.029(5) Å *c* = 13.71(3) Å *V* = 300.3(9) $Å^3$
A-6/3-2639	*a* = 8.33(3) Å *V* = 578.1(34) $Å^3$	*a* = 5.03(3) Å *c* = 13.70(10) Å *V* = 300.2(39) $Å^3$
A-5/3-2646	*a* = 8.349(8) Å *V* = 581.9(10) $Å^3$	*a* = 5.031(4) Å *c* = 13.728(15) Å *V* = 300.9(5) $Å^3$
B-6-2667	*a* = 8.340(8) Å *V* = 580.0(9) $Å^3$	*a* = 5.0344(20) Å *c* = 13.747(7) Å *V* = 301.7(3) $Å^3$
$G_2$8-3922	*a* = 8.341(4) Å *V* = 580.2(5) $Å^3$	*a* = 5.033(4) Å *c* = 13.752(8) Å *V* = 301.7(4) $Å^3$
VV10/1-4259	*a* = 8.323(11) Å *V* = 576.5(14) $Å^3$	*a* = 5.0360(13) Å *c* = 13.7550(20) Å *V* = 302.11(13) $Å^3$

Note *a, c* are the periods of the crystal lattice; *V*—volume of the crystal lattice, numbers in the brackets show the experimental error

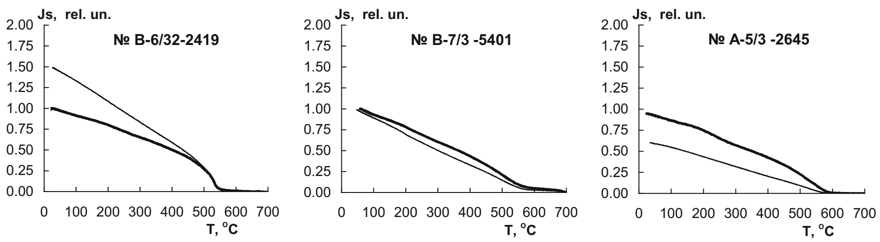


Fig. 8.4 Thermomagnetic analysis results. The bold line corresponds to the first heating, the thin line to the second heating

Table 8.2 Paleointensity of the geomagnetic field the ceramics from the Dmitrievskaya Sloboda II settlement

No. of the sample	$B_{an} \pm \sigma$ (μT)	Calculation temperature range (°C)
V7-57-1948	76.7 ± 0.9	250–450
B-6/2-2641	58.2 ± 0.8	200–450
A-5/3-2646	48.7 ± 3.6	250–450
B-6-2667	39.4 ± 1.3	250–450
B-6/6-2743	47.2 ± 0.7	400–550
G_2 8-3922	41.9 ± 1.3	250–500
G_2 8-3923	51.8 ± 5.1	250–450
VV 10/1-4259	54.8 ± 0.3	250–450
B-7/3-5401	67.9 ± 1.8	250–450

the time interval 5500–3500 B.C. The average level of the field intensity in this time interval is approximately two times less than the average level of the 8-thousand-year variation maximum. The variations of smaller periods are superimposed on the main variation. Figure 8.5 shows as an example a pattern of the change of the geomagnetic field intensity obtained from Iberian Peninsula archaeological monuments.

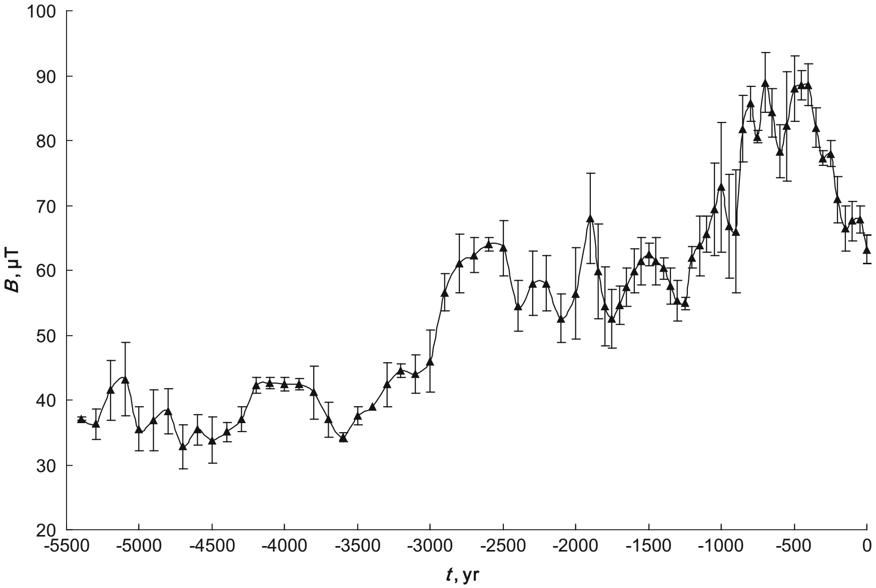


Fig. 8.5 The values of the intensity of the geomagnetic field B (μT), average for the time periods. The averaging interval is 200 year for the period from the sixth to third millennia B.C., 100 year for the period from the second millennium B.C. to the boundary between the eras

Variations of different periods show different drift direction, resulting in discrepancies in the detailed patterns of geomagnetic field intensity variations in regions from different longitude sectors. In this regard, a direct comparison of the obtained data on the geomagnetic field intensity makes sense if the territories for which the data are obtained are regions whose difference in longitude is <30°. The data on the geomagnetic field intensity obtained in the present study can thus be compared with the data obtained for the southeastern Europe.

Previously obtained and new data of the geomagnetic field intensity in south-east Europe (in the longitude sector 26 ± 3°E) are compiled (Tema and Kondopoulou 2011). Despite the relatively small amount of data for the II millennium B.C., one can conclude that the average level of field intensity in the II millennium B.C. is noticeably higher than the level of field intensity in the III millennium B.C. A rapid change in the field intensity occurs in the middle of the II millennium B.C.

Data of the geomagnetic field intensity in the II millennium B.C. were also obtained for Egypt and western Asia (Aitken et al. 1984). One can note the rapid growth of the field intensity 1750–1500 year. B.C. and the change in the field intensity during the millennium by a factor of 2, although there are time intervals for which there are almost no data (XVII and XV centuries).

The picture of geomagnetic field intensity variations in the II millennium B.C. was also obtained on the material from Georgia archaeological monuments, having the longitude 44 ± 3°E (Nachasova and Burakov 1987). The main trend of geomagnetic field intensity variations in the II millennium B.C. is an increase in the field intensity by a factor of about 2. Against the background of this increase, variations of several centuries duration occur. In general, the patterns of the geomagnetic field intensity variations in the II millennium B.C. according to the data obtained in the cited works is very similar to that observed in Dmitrievskaya Sloboda II. In the time interval at which the Dmitrievskaya Sloboda II monument is dated, values of the field intensity from 45 to 96 μT were obtained on the material from Georgia (Nachasova and Burakov 1987). Average value (56.7 μT ± 8.3 μT) obtained on the material from Georgia, dated at XVII–XV centuries B.C., agrees well from the average value obtained at Dmitrievskaya Sloboda II (54.6 ± 5.1 μT). According to the data obtained from the material of Georgia, in the XX–XIX centuries B.C. the geomagnetic field intensity was relatively low (about 25 μT). Later in the XVIII–XVII centuries B.C. there is an increase in the geomagnetic field intensity. Such a change in the field intensity makes it possible to use the data obtained in this study to assign the time interval of the manufacture of the Dmitrievskaya Sloboda II ceramics as the XVIII–XV centuries B.C.

In a previous work, ceramic material of the Neolithic monument of Sakhtysh-I was studied. It is located in the same region as the Dmitrievskaya Sloboda II monument. Archaeointensity data were obtained for the time interval between V—III thousand years B.C. (Pilipenko et al. 2016; Nachasova et al. 2018). The geomagnetic field intensity varies mostly within a range of 30–60 μT. The average level of field intensity is about 50 μT in the second half of the V–beginning IV millennium B.C decreasing to about 35 μT in the IV—first half of the III millennium B.C. The limits of the change in the geomagnetic field intensity and the average value of the geomagnetic field intensity obtained for Dmitrievskaya Sloboda II are noticeably higher than for the Sakhtysh-I monument. This may indicate a tendency that the geomagnetic field intensity in the II millennium B.C. increased in comparison to the field level in the previous three millennia, being a manifestation of the 8-thousand-year variation of the field intensity.

In all, according to the data obtained for the different regions of Eurasia, in the II millennium B.C. the average level of field intensity appears much higher than the field level in the previous three millennia. The average value of the geomagnetic field intensity, obtained for Dmitrievskaya Sloboda II material in II millennium B.C., is also noticeably above the average level of geomagnetic field intensity in the IV–III millennium B.C. New data about the limits of variation and the average level of geomagnetic field intensity in Eastern Europe in the II millennium BC allow to improve the models of the geomagnetic field intensity variations in this time interval.

As a result of the performed research new data for the geomagnetic field intensity in the middle of the II millennium B.C are obtained. The geomagnetic field intensity varies within the limits of ~40–75 μT with an average value of about 55 μT.

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