ISSN 1069-3513, Izvestiya, Physics of the Solid Earth, 2020, Vol. 56, No. 2, pp. 238–248. © Pleiades Publishing, Ltd., 2020.
Russian Text © The Author(s), 2020, published in Fizika Zemli, 2020, No. 2, pp. 103–114.

The Geomagnetic Field Intensity in the Russian Plain in V–III Millennia B.C.

I. E. Nachasova[a], **O. V. Pilipenko**[a, *], **G. P. Markov**[a], **and N. G. Nedomolkina**[b, **]
[a] *Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, 123242 Russia*
[b] *Vologda State Historical, Cultural and Art Museum–Reserve, Vologda, 160035 Russia*
**e-mail: pilipenko@ifz.ru*
***e-mail: nedomolkiny_ljv@mail.ru*

Received December 12, 2018; revised February 11, 2019; accepted March 25, 2019

Abstract—The archaeomagnetic study of ceramic material from Veksa III archaeological site (φ = 59°17′ N, λ = 40°10′ E) yield the data on the intensity of geomagnetic field in the V–III millennia B.C. in the Russian Plain. The combined results from the material of the Veksa III and Sakhtysh I sites (φ = 56°48′ N, λ = 40°33′ E) suggest that in the studied time interval, the intensity of the geomagnetic field mainly varied within 30 to 50 μT. The gradual changes in the intensity are superimposed by a variation with a characteristic time of approximately 1000 years. The results on the intensity of the geomagnetic field determined for the Russian Plain for the time interval V–III millennia B.C. add substantially to the magnetic field data during this time interval, which promotes better understanding of the variations in the ancient geomagnetic field.

Keywords: intensity of the geomagnetic field, archaeomagnetic studies

DOI: 10.1134/S106935132002007X

1. INTRODUCTION

Most data on the intensity of geomagnetic field in the last millennia have been obtained for Eurasia, mainly for the regions concentrated in the latitudinal band 40°–45° N. The data are unevenly distributed across the timeline; most determinations of the intensity of geomagnetic field cover last two millennia. Therefore, it is highly relevant to expand the existing collection of archaeomagnetic data to the time interval B.C. With the growth of the data on the intensity of ancient geomagnetic field in the different regions and on the different time intervals, our understanding of regularities and peculiarities of magnetic variations becomes more adequate.

This work is part of the study aimed at obtaining information about the intensity of the main geomagnetic field in the European part of Russia on the time interval from V millennium B.C. to the beginning of the Common Era. Particular interest is attached to obtaining the data on the magnetic field in the time intervals of V–II millennia B.C. for which the intensity determinations are few compared to other time intervals (Nachasova, 1998; Gallet et al., 2015; Tema and Kondopoulou, 2011; Tema et al., 2012). This work is devoted to obtaining the data on the intensity of the geomagnetic field in V–III millennia B.C. in the Russian (East European) Plain.

2. STUDY OBJECT AND DATING

The complex of multilayered Neolithic settlements Veksa is located in the basin of the Verkhnyaya Sukhona River (Vologda Oblast, ~17 km northeast of the city of Vologda) (Nedomolkina, 2000b). Archaeological sites are located along the left bank of the Vologda River at the confluence of a small tributary of the Veksa River into Vologda River (Fig. 1). Neolithic site Veksa III is situated in the lower part of the complex east of the Veksa River mouth (φ = 59°17′, λ = 40°10′). The clearly stratified sequence of the archaeological layers reaching a total thickness of three meters and spanning all the periods from the Early Neolithic to the Middle Ages determine the exceptional importance of the Veksa III site (Nedomolkina, 2000a; 2000b). Nine stratigraphic cultural layers with five of them correlated to the Neolithic and Eneolithic periods are identified in the Veksa III site (Fig. 2). Ceramic artifacts for the study were picked from these cultural layers.

According to the archaeological data, cultural development in the basin of the Upper Sukhona River began in the early Neolithic, in the VI millennium B.C. when favorable conditions for settling appeared in this territory which was flooded before that time.

Dating of ancient ceramics that was fired in the time interval B.C. is challenging. Archaeological dating determines the age of the remains according to the appearance of artifacts typical of the different stages of

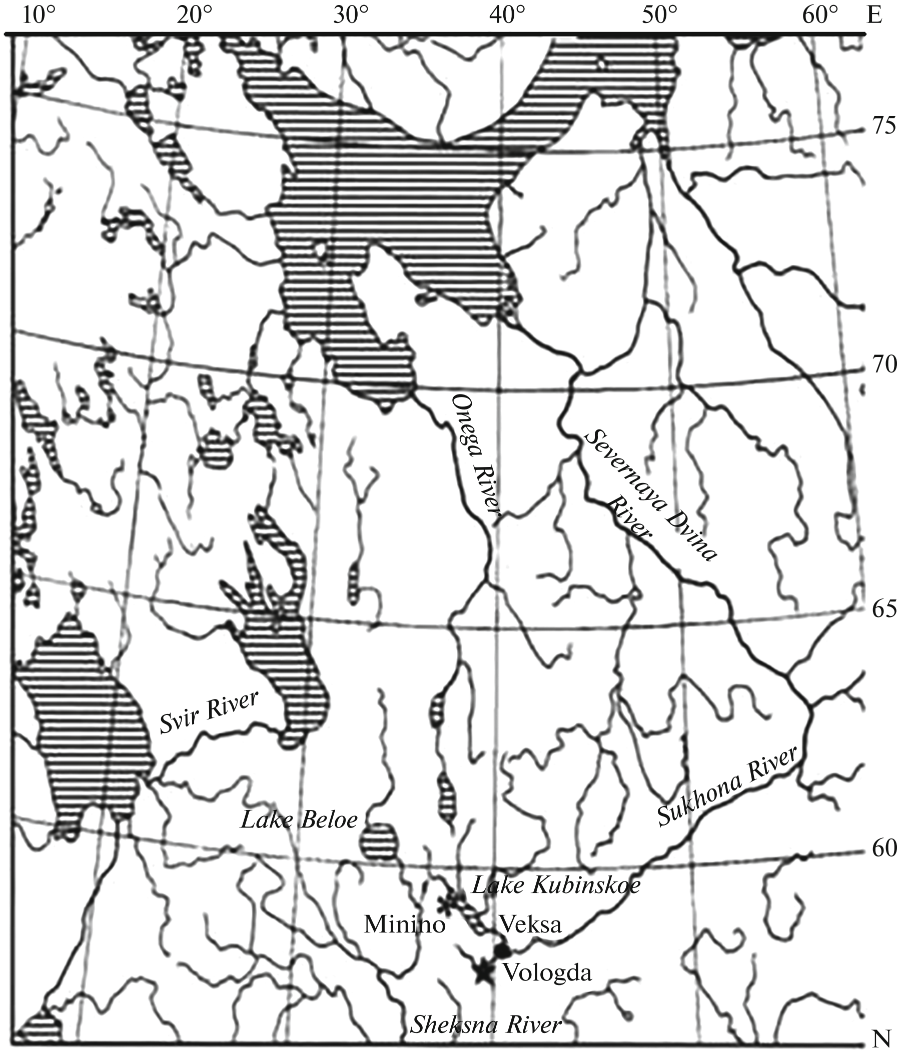

Fig. 1. Geographic location of Neolithic settlement complex Veksa.

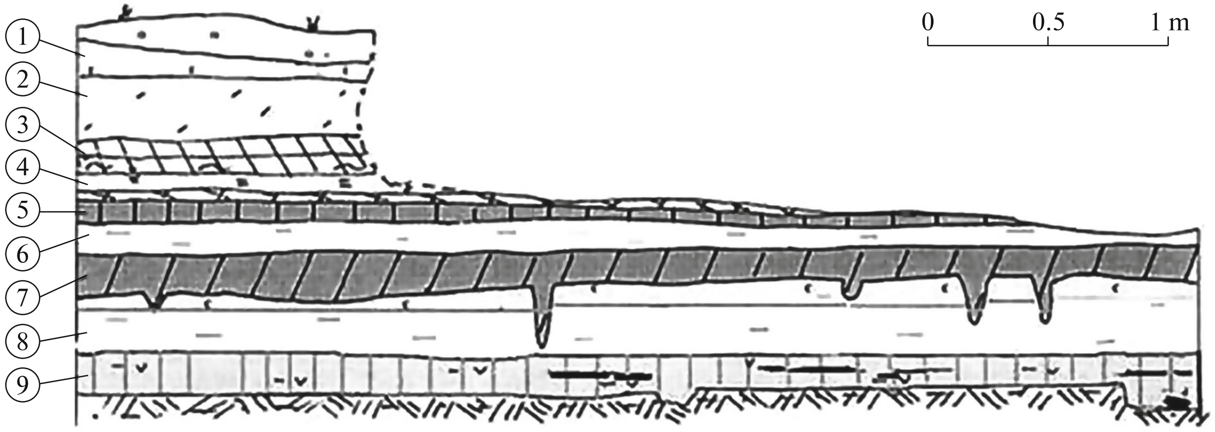

Fig. 2. Stratigraphy of eastern wall of excavation pit of 2005 of Veksa III site with numbers of cultural layers.

human cultures in a particular region. Various ceramic complexes allow the researchers to identify and track the development of archaeological cultures over time. Radiocarbon analysis of the material from layers of cultural deposits at archaeological sites provides independent estimates of the age of cultural layers of the archaeological sites which increases the reliability of archaeological dating of accumulation of cultural deposits at a monument under study. The time correlation of the obtained data on the intensity of the geomagnetic field is based on the dating of the studied ceramic material by the archaeologists who explore the archaeological site.

The dating of the ceramic material investigated in this paper for obtaining the data on the intensity of the geomagnetic field is based on the results of the prolonged studies of the material from the multilayer neolithic settlements Veksa (Nedomolkina, 2000a; 2000b; 2004; Nedomolkina and Piezonka, 2016).

The most ancient cultural layer 9 of Veksa III settlement is located at a depth of ~1.9–3 m from the surface and contains the material belonging to the Early Neolithic era (Fig. 2). This is confirmed by radiocarbon datings from charcoal and soil ~6950 ± 150 BP (Le-5866), 6730 ± 150 BP (Le-5864) (Nedomolkina and Piezonka, 2016). At that time, ceramics of the Upper Volga culture became widespread in this region.

The overlying layer 8 is located at a depth of ~1.6–1.9 m from the surface. The bottom part of layer 8 contains pottery material of the "second comb ware complex" for which a narrow range of ages—from 6220 ± 150 BP (Le-5868) to ~6200 ± 170 BP (Le-5856)—was obtained from charcoals (Nedomolkina and Piezonka, 2016). On another segment of the site, within the same layer at a depth of 1.6–1.8 m, a bed was revealed with the material whose age was determined from the charred remains on the ceramics at 5843 ± 80 BP (SPb-1691) (Nedomolkina and Piezonka, 2016). Layer 8 is weakly pronounced morphologically and severely violated by the overlying cultural layer 7.

Layer 7 is located at a depth of ~1.4–1.6 m and relates to the period of the fully developed Neolithic cultures. The Neolithic complex is represented by comb-pitted wares similar to the so-called northern-type ceramics from the stations in the Upper Volga region (Fig. 3). The most probable datings of layer 7 with "northern" ceramics determined from the charred crust on the ceramic material are 5650 ± 150 BP (GIN-10182) and 5700 ± 700 BP (Le-5857) (Nedomolkina and Piezonka, 2016).

Layer 6 is located at a depth of 1.3–1.4 m. The material of this Neolithic layer is pitted ware of Kargopol type. The radiocarbon age for the Kargopol type artifacts complex was determined from soil with charcoals at ~5220 ± 320 BP (GIN-10180) (Nedomolkina and Piezonka, 2016).

Layer 5 is located at a depth of 1.2–1.3 m and dated to the Eneolithic period with Modlona–II type of porous ceramic whose age is determined by radiocarbon method from wooden piles at 4410 ± 35 BP (Poz-51486) to 4155 ± 35 BP (Poz-51484) and from charred remains adhering on pottery at ~5425 ± 30 BP (KIA-33926) (Nedomolkina and Piezonka, 2016). We studied the ceramic material from layers 5–9 of the Veksa III archaeological site. The results are presented in Table 1 and illustrated in Fig. 7.

3. METHODS OF ROCK MAGNETIC AND ARCHAEOMAGNETIC STUDY

Rock magnetic and archaeomagnetic studies were conducted for 58 fragments of fired ceramics from which cubic specimens with a size of ~1 cm^3 were sawed (one or two cubes for a selected ceramic fragment depending on fragment's size). Overall, 88 samples were examined. All experiments were carried out in the laboratory of Main geomagnetic field and rock magnetism of the Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences.

Samples of pilot collection composed of 31 ceramic artifacts were subjected to thermomagnetic analysis (TMA) in air using Curie magnetic balance (ORION, Russia) with measuring the temperature dependence of magnetic moment $M(T)$ in a constant magnetic field of ~0.4 T. TMA consisted of a series of cycles of step-by-step heating (with a step of 100°C) and cooling of samples in the magnetic field for identifying the ceramic fragments in which the composition of ferromagnetic fraction changes as a result of heating and for determining the Curie points of the samples. The Curie point of the samples was determined from the curve of the last heating to 600°C (Fig. 4).

The remanent magnetization of the samples was measured on JR-6 magnetometer (AGICO, Czech Republic) in three orthogonal positions of sample's rotation. The sensitivity of the instrument is ~2.4 × 10^{-6} A/m. Before beginning the heating cycle, we measured natural remanent magnetization (NRM) of the samples. The whole experiment was conducted according to the modified Thellier procedure (Thellier and Thellier, 1959; Coe, 1967) with the use of the criteria developed in (Coe et al., 1978). The samples were heated in a nonmagnetic furnace MMTD80 (Magnetic Measurements, UK) with internal residual field of at most 10 nT. During cooling of the samples, a constant magnetic field $B_{lab} = 50$ μT was created in the furnace. The cycles of heating–cooling without the field and heating–cooling in the field were carried out from 150 to 550°C with a step of 50°C on all ceramic samples. For reducing the effect of magnetic anisotropy, the samples were laid out in the furnace in such a way that the maximum NRM component was parallel to the direction of the magnetic field in the furnace. The samples in the furnace were cooled at a natural rate with cooling fan turned off, which excluded the influence of the cooling rate on the acquisition of

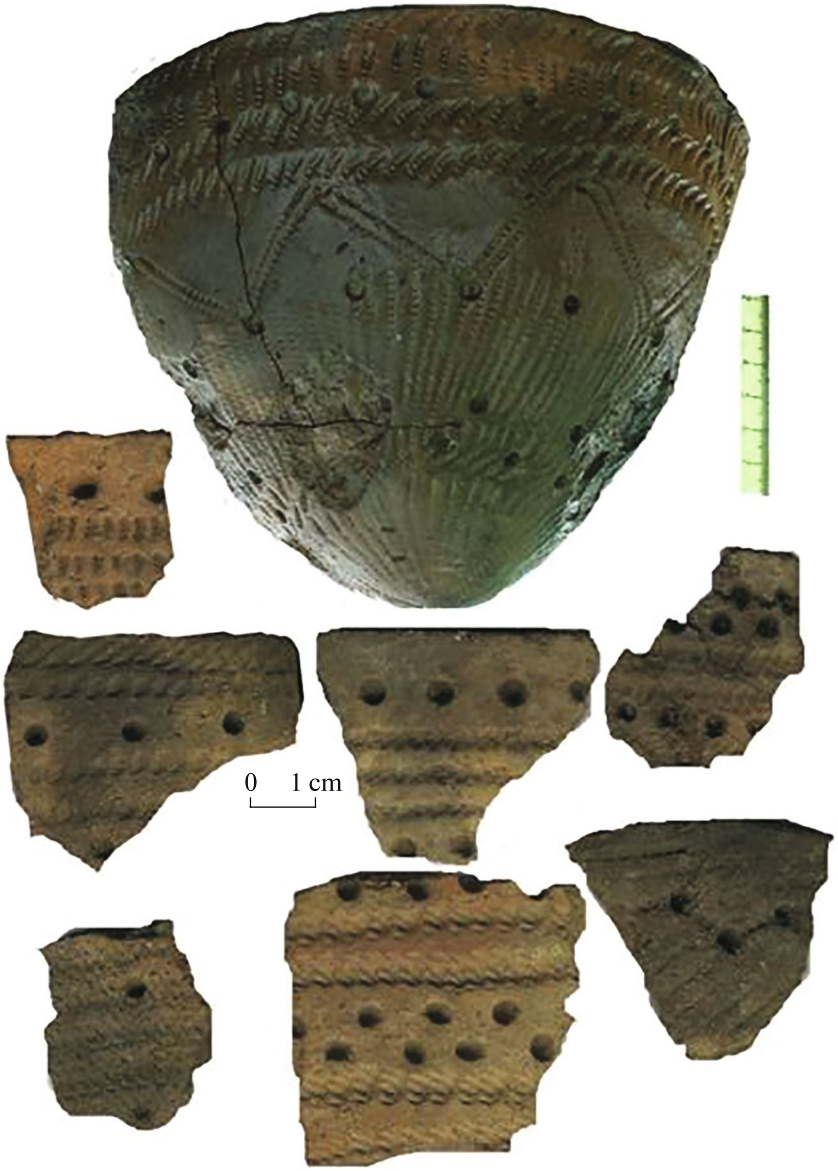

Fig. 3. Artifacts from layer 7 of Veksa III site.

thermal remanent magnetization (TRM). Based on the measurement results, the Arai-Nagata diagram was constructed for each sample (Nagata et al., 1963) (Fig. 5).

With the criteria developed in (Coe et al., 1978) taken into account, the paleointensity of the ancient geomagnetic field was calculated on a linear segment of the Arai-Nagata diagram, which consisted of at least 4 points typically lying in the temperature interval of 200–450°C, with a heating step 50°C. In accordance with the recommendations presented in (Coe et al., 1978), the low temperature interval containing a probable viscous magnetization component and the high temperature interval were cut off.

The probable changes in the ability of a sample to acquire TRM at the checking temperatures that are below the blocking temperature were controlled by recreating and measuring the so-called pTRM check points at the temperatures 200, 300, 400, and 500°C (Paterson et al., 2014). The samples in which the deviations of the pTRM check points were higher than 10% of the partial thermoremanent magnetization pTRM at this temperature step were excluded from the further analysis.

Besides, in order to exclude probable changes in the magnetic content of magnetization carriers at temperatures below the blocking temperature, we conducted the repeated heating of the collection samples

Table 1. Results of geomagnetic field determination from ceramic fragments of Veksa III archaeological site

Ceramics description	Sample no.	Date *t* B.C., years	$\pm\Delta t$, years	*B*, μT	$\pm\sigma$, μT
Most ancient Neolithic pit-comb ceramics of Upper Volga culture, layer 9	35, 44	–4800	100	40.4	1.1
Earliest Comb-Pitted ware Neolithic ceramics, layer 9	77,81, 83, 85, 86	–4600	100	37.7	4.2
Comb ceramics with admixture of clastic material, layer 9	36, 40, 46, 66, 70	–4400	100	38.0	4.4
Thick-wall ceramics, layer 9	41, 42, 43	–4100	100	41.8	12.2
Comb ceramics, layer 8	$9_{1,2}$, 9a, $32_{1,2}$	–4000	150	34.4	3.9
Northern type pit-comb ceramics, layer 7	95, 100, 101, 102, 104, 106, 107, 109	–3800	200	41.5	6.6
Comb ceramics of Kargopol culture, layer 6	$8_{1,2}$, $11_{1,2}$	–3300	100	47.7	3.8
Porous ceramics of Modlona-II type, layer 6	$16_{1,2}$	–3250		39.9	3.4
Pitted ceramics of Kargopol culture, layer 6	$29_{1,2}$, 132, 133	–3220	320	31.4	3.3
Eneolithic ceramics, layer 5	$10_{1,2}$	–3000		36.3	3.2
Porous ceramics of Modlona-II type, layer 5	$119_{1,2}$, $120_{1,2}$, $121_{1,2}$, $122_{1,2}$, $123_{1,2}$, $124_{1,2}$, $125_{1,2}$, $126_{1,2}$, 127, 130,131	–2283	163	31.0	1.4
Asbestos ceramics, layer 5	$6_{1,2}$	–2000		42.8	0.3

in the absence of the field, the so-called pTRM tail checks (Bolshakov and Shcherbakova, 1979; Riisager and Riisager, 2001; Shcherbakov and Shcherbakova, 2002) at temperatures of 150, 250, 350, 450, and 550°C. The samples for which the deviations of pTRM tail checks exceeded 10% of residual NRM at this temperature step were also excluded from the subsequent analysis.

As a rule, the thermomagnetic *M*(*T*) curves of the samples of ceramics that were excluded from the further examination were not reversible after ~200°C because of the chemical changes taking place in these samples. The example of the Arai–Nagata diagram for the sample demonstrating high deviations of the pTRM check points and pTRM tail checks as well as the TMA diagram *M*(*T*) of this sample are shown in Fig. 6. As can be seen, during heating, the *M* value significantly decreases due to the magnetic mineral changes that occur in the sample at heating; therefore, this ceramic fragment was not used in paleointensity determination.

4. RESULTS OF ROCK MAGNETIC AND ARCHAEOMAGNETIC STUDIES

As a rule, the *M*(*T*) curves have the form shown in Fig. 4. Usually, viscous component of magnetization was removed the temperature below 200°C. After heating to 200°C, the *M* (*T*) curves were reversible. On the last-heating curve of the samples there is a single Curie point *T*c ~550–580°C, apparently corresponding to magnetite. The Curie points of the studied samples preserve their pre-heating positions after heating, which indicates the stability of the samples to thermal treatment.

The conducted studies yielded new data on paleointensity of the geomagnetic field recorded in 88 samples of ceramic artifacts found in the archaeological site Veksa III which us dated to V–III millennium B.C. After applying the pTRM check-point and pTRM tail check criteria and excluding the samples failing these tests, 61 paleointensity determinations were taken retained for the subsequent analysis (Table 1). The obtained determinations of the intensity of the geomagnetic field are in the range of ~30–50 μT. The average intensity is ~40 μT.

5. DISCUSSION OF RESULTS

The scatter in the individual determinations sharply increases in the fourth quarter of V Millennium B.C., indicating a rapid change in the intensity of the geomagnetic field in this time interval. Separate high paleointensity values reaching 65 μT appear (Fig. 7). The increase of the intensity of the geomagnetic field in V Millennium B.C. and the decrease in IV Millennium BC determine the general pattern of changes in paleointensity in the V–III Millennium B.C. The value obtained for the second half of III millennium B.C. is also low. Based on material dated to 2000 B.C., a

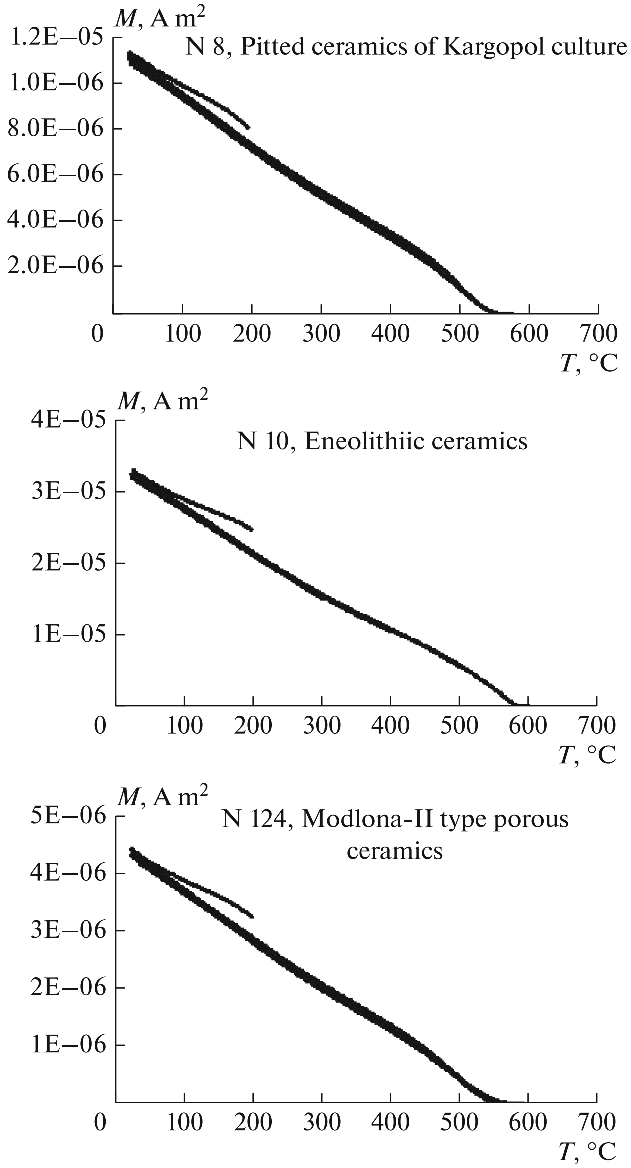

Fig. 4. TMA results on temperature dependence of magnetic moment in the presence of magnetic field.

higher paleointensity value is obtained. The smooth changes in the intensity of the field are superimposed by the variations whose characteristic duration can be estimated at about 1000 years.

The analysis of the combined set of paleointensity determinations in the Russian Plain obtained by the study of ceramic material from the Veksa III site and the Sakhtysh I site ($\varphi = 56°48'$ N, $\lambda = 40°33'$ E) (Nachasova et al., 2018) located on the same longitude but ~250 km south of Veksa III has shown good consistency of intensity variations with time (Fig. 7). Thus, the data on the intensity of the geomagnetic field obtained for two regions of the Russian Plain located at almost the same longitude and close in latitude indicate the presence of a smooth change in the intensity in the interval V–III Millennium B.C. which is superimposed by the variation with a characteristic time of ~1000 years. Variations of this duration are noted in the changes of paleointensity during the last eight millennia in all regions of Eurasia (Nachasova, 1998).

The obtained intensity data of the geomagnetic field can be used for refining the time correlation of the ceramic material whose archaeological dating is pretty loose. For example, all the individual determinations based on the ceramics from Veksa III site which is dated to 3200 ± 300 B.C. are below 40 μT and the average intensity value is 31.4 ± 3.3 μT. All the intensity determinations obtained from the material dated to 3300 ± 100 B.C. are above 40 μT. Based on

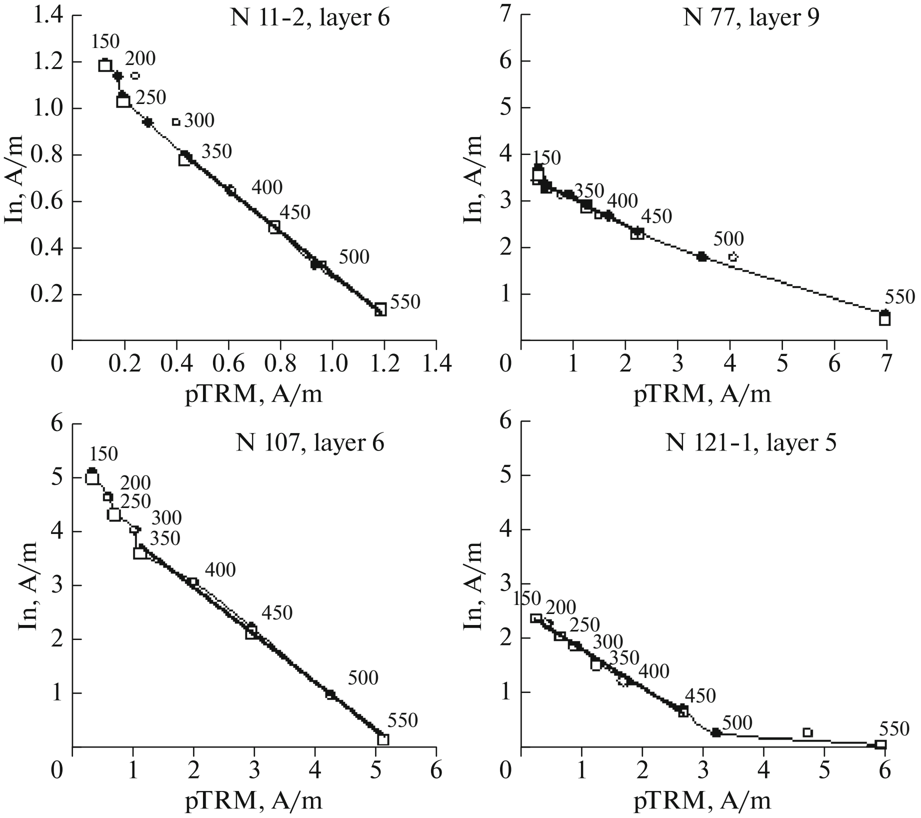

Fig. 5. Arai–Nagata diagrams. Black circle indicates results obtained by modified Thellier method. Open circle is pTRM check point, filled square is pTRM check tail. The numbers near symbols indicate heating temperatures.

this, it can be concluded that such a wide dating does not reflect the actual time interval of firing of the studied material but, rather, is associated with dating error. The average value obtained from the loosely dated material is close to 33.5 ± 10.6 μT estimated from the pit-comb ceramics of the Sakhtysh I site dated to the time interval 3050 ± 100 B.C.; however, the determination error is in this case is noticeably lower. This suggests that the time span of manufacturing of the pottery from Veksa III site which has a loose archaeological dating may even be narrower than 200 years old and, in accordance with the pattern of intensity variations, can be attributed to 3050 ± 50 B.C. (Fig. 7).

The world data on the variations of the intensity of geomagnetic field in the last eight millennia obtained for Eurasia (Nachasova, 1998; Nachasova and Akimova, 2015; Nachasova et al., 2015; Gallet et al., 2015; Kovacheva, 1980; Kovacheva et al., 2009) have shown that the picture of changes in the intensity has largely similar features. The "main" oscillation has a characteristic time of about eight millennia. The minimum of the "main" fluctuation falls in the time interval of V–III Millennium B.C. The maximum intensity is observed on the time interval of I Millennium B.C. to the boundary of eras. The "main" oscillation is superimposed by the variations of different durations.

The analysis of the time series of intensity data has shown that the change in the intensity of the geomagnetic field can be approximated by the superposition of a number of drifting waves having different periods and different drift directions (western and eastern) (Nachasova, 1998). This suggests that the overall picture of changes in the intensity of the geomagnetic field changes with longitude. As of now, direct comparison of paleointensity data for the epochs that are fairly distant from the present, obtained for the regions located at different longitudes does not allow a reliable conclusion about the factors of probable discrepancies in the pattern of changes of paleointensity. This is associated with the specific character of the changes in the pattern of paleointensity variations and with insufficient amount of the material which leads to the nonuniform distribution of the studied material (and, consequently, the paleointensity data) across the timeline. Insufficient dating accuracy is yet another factor. At the current stage, it is necessary to increase the data obtained for the time interval B.C.

Figure 8 presents the results determined from the material of the monuments in the Russian Plain and the Caucasus (Burakov and Nachasova, 1988). The dating limits of the obtained data are not shown to make the picture of the changes in the geomagnetic

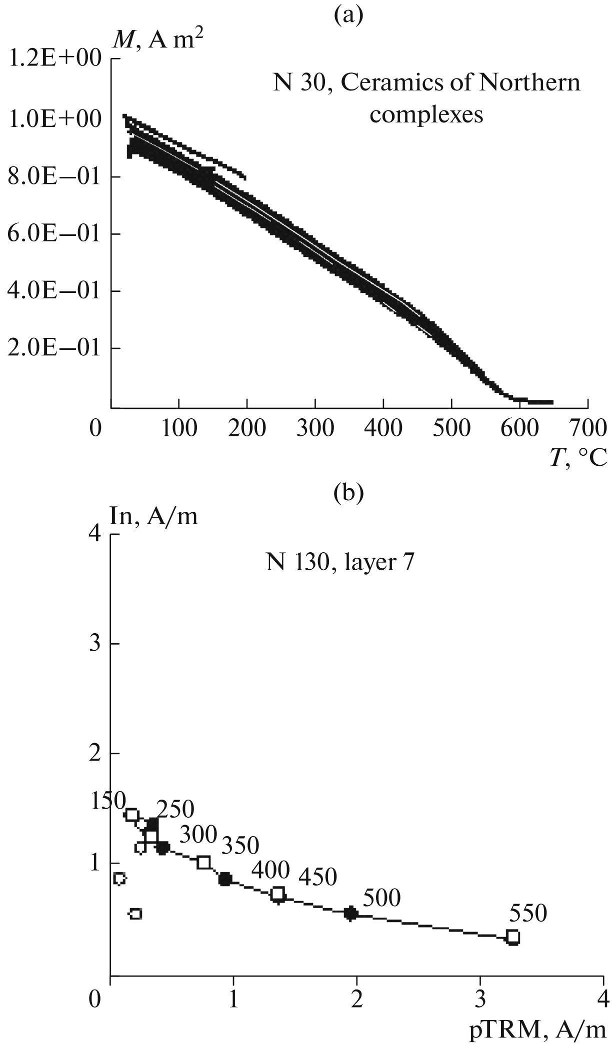

Fig. 6. (a) Arai–Nagata diagram and TMS diagram for sample of ceramic fragment not used paleointensity estimation. Designations correspond to Fig. 5.

field intensity fairly transparent and not obscured by the details. Dating errors for the material from the Georgian sites range from ±50 to ±300 years. The comparison of the pattern of changes in the geomagnetic field intensity obtained for the Russian Plain with the data for the Caucasus shows good agreement in the interval from IV Millennium to the beginning of III Millennium B.C. Certain discrepancy at the beginning of V Millennium B.C. is most likely to be due to the fact that the determination based on the material dated to 5000 ± 100 B.C. obtained for the Caucasus may relate to a somewhat earlier period when the intensity of the geomagnetic field was higher (Nachasova, 1998; Gallet et al., 2015) (Fig. 8). According to data obtained for the Caucasus, in III Millennium B.C., the geomagnetic field intensity experiences rapid changes which are sharpest in the middle of the millennium. In the fourth quarter of III Millennium, the intensity of the geomagnetic field increases significantly. The change in the intensity of the field according to all the obtained data is approximately within the same range; the intensity increases approximately around the end of V, end of IV, and end of III Millennium B.C. On the time interval from IV to the middle of III millennium B.C., the average level of the geomagnetic field intensity varies little.

The longitudinal sector of archaeological sites Veksa III and Sakhtysh I also covers Syria. The study of the ceramic material from the Halula archaeological site (φ=36°25′ N, λ=38°10′ E, Syria) provided the data on the geomagnetic field intensity in VII–VI Millennium B.C. (Gallet et al., 2015). The data on the intensity of the geomagnetic field in V Millennium B.C. for the Middle East are absent. Very few determinations are obtained for IV Millennium B.C. Using the paleointensity data for Syria and the Russian Plain, we may construct a picture of the behavior of the geomagnetic field intensity in VII–IV Millennium B.C. Figure 9 shows the values of the virtual axial dipole moment (VADM) calculated from the data on the geomagnetic field intensity obtained from the material of the Halula archaeological site in Syria (open circles) averaged over the time intervals indicated by horizontal lines and the values for the Russian Plain (filled circles) obtained by averaging the determinations based on material of archaeological sites of the Russian Plain (Veksa III and Sakhtysh I) over 200-year time intervals for which the determinations from the both monuments exist. The vertical lines show standard errors of determinations.

The character of changes in the geomagnetic field intensity is almost identical throughout four millennia. The main smooth oscillation is superimposed by the variations with the characteristic time of about 1000 years, which is consistent with the results of the previous studies for a more recent period, indicating the stability of variations with this characteristic time (Nachasova, 1998). Around the boundary of VI and V millennia B.C., the direction of the main paleointensity oscillation changes. The main trend in VII–VI millennia is the decrease in the intensity, whereas in V–IV millennia, the average paleointensity level varies little.

The data on the geomagnetic field intensity obtained for the territory of the Russian Plain for the time interval V–III millennium BC substantially expands the existing intensity data for this time interval and, thus, provides the possibility to confirm the stability of the variations at all stages of the long-period (“main”) oscillation, to determine the time interval of the change in the trend of the variations of the geomagnetic field intensity, and to increase the reliability of the assessments concerning the amplitude of the “main” fluctuation of the intensity. The average level of the intensity of the geomagnetic field in the considered time interval is approximately half the average level at the maximum of the 8-thousand-year oscillation.

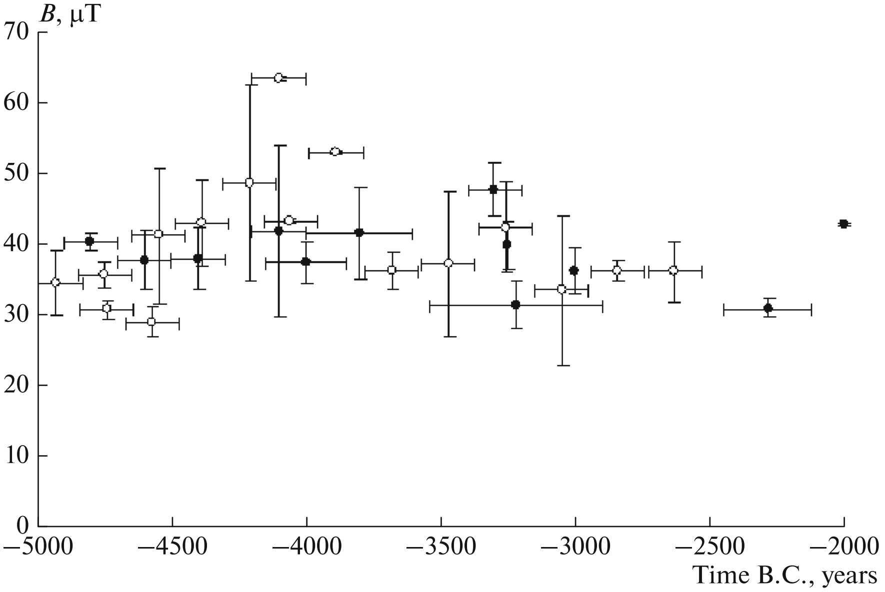

Fig. 7. Values of geomagnetic field intensity, vertical lines are rms errors of intensity determinations, horizontal lines are age determination errors. Black circles indicate data obtained from Veksa III ceramics, open circles indicate data determined from Sakhtysh I artifacts (Nachasova et al., 2018).

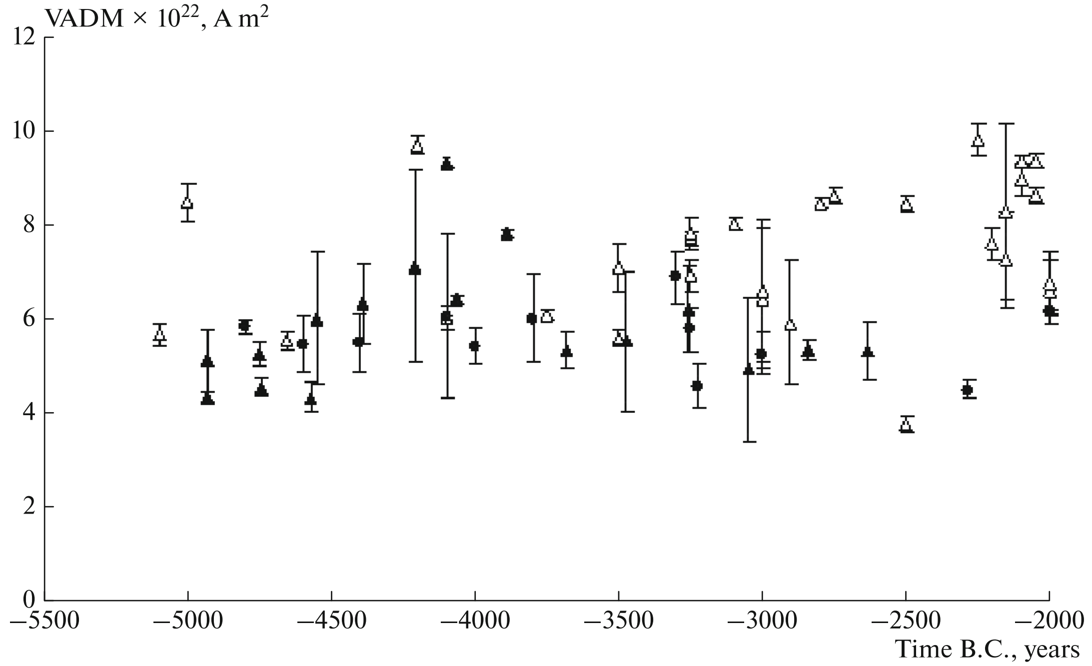

Fig. 8. Values of virtual axial dipole moment (VADM), vertical lines are rms errors of VADM determination. Black circles, black triangles, and open triangles indicate data obtained from Veksa III ceramics, Sakhtysh I ceramics (Nachasova et al., 2018), and Georgia monuments (Burakov and Nachasova, 1988), respectively.

CONCLUSIONS

As a result of the study of ceramic material from the archaeological site Veksa III, the data on the geomagnetic field intensity in the Russian Plain in V–III millennium B.C. are obtained. The analysis of the combined data obtained from the sites Veksa III and Sakhtysh I of the Russian Plain has shown that in the studied time interval, the geomagnetic field intensity mainly varied within 30–50 μT, and the variations occurred against the background of the relatively low

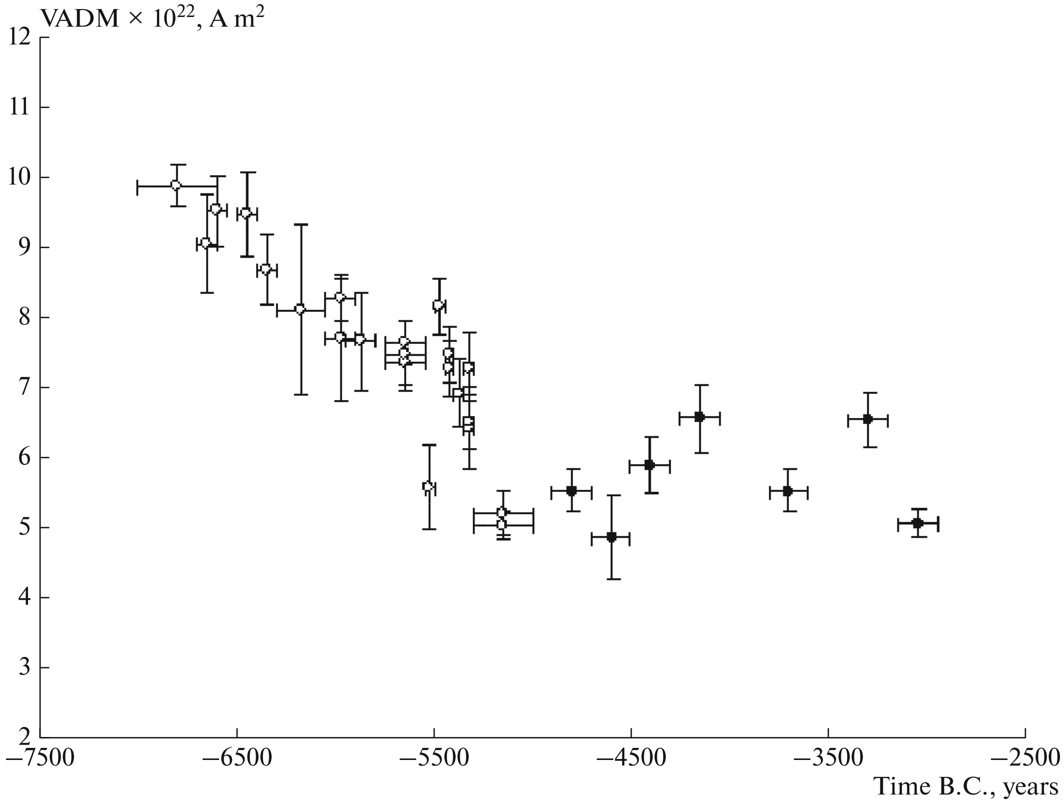

Fig. 9. VADM values with age determination error and rms error of VADM determination. Black circles are VADM values obtained by averaging the determinations based on ceramics from archaeological sites of Russian Plain (Veksa III and Sakhtysh I) dated to the same 200-year time intervals; open circles are VADM values obtained from material of Halula monument, Syria (Gallet et al., 2015).

average level of the field. The data on the geomagnetic field intensity obtained for two regions with close coordinates testify to the presence of a smooth change in the field intensity in the interval V–III millennium B.C., which is superimposed by the variation with a characteristic time of about 1000 years. Variations of this duration are noted in the changes of the geomagnetic field intensity throughout the last eight millennia in all regions of Eurasia.

The data on the geomagnetic field intensity obtained for the territory of the Russian Plain for the time interval V–III millennium B.C. substantially add to the data on the field intensity for this time interval, thus making it possible to refine the time interval accommodating the minimum of the "main" oscillation in the intensity of the geomagnetic field.

FUNDING

This work was supported by the Russian Foundation for Basic Research (project no. 16-05-00378) and carried out in partial fulfillment of state contract of IPE RAS.

REFERENCES

Bol'shakov, A.S. and Shcherbakova, V.V., Thermomagnetic criterion for determining the domain tructure of ferromagnetics, *Izv. Akad. Nauk SSSR, Fiz. Zemli,* 1979, no. 2, pp. 38–47.

Burakov, K.S. and Nachasova, I.E., The change in the intensity of the geomagnetic field in Georgia in the V–III millennia B.C., *Geomagn. Aeron.*, 1988, no.6, pp. 1033–1035.

Coe, R.S., Paleointensities of the Earth's magnetic field determined from tertiary and quaternary rocks, *J. Geophys. Res.*, 1967, vol. 72, pp. 3247–3262.

Coe, R.S., Gromme, S., and Mankinen, E.A., Geomagnetic paleointensity from radiocarbon-dated flows on Hawaii and the question of the Pacific nondipole low, *J. Geophys. Res.*, 1978, vol. 83, no. B4, pp. 1740–1756.

Gallet, Y., Molist, M., Genevey, A., Garcia, X.C., Thebault, E., Gomez, A., Le Goff, M., Robert, B., and Nachasova, I., New Late Neolithic (c. 7000–5000 BC) archeointensity data from Syria. Reconstructing 9000 years of archeomagnetic field intensity variations in the Middle East, *Phys. Earth Planet. Inter.*, 2015, vol. 238, pp. 89–103.

Kovacheva, M., Summarized results of the archaeomagnetic investigations of the geomagnetic field variation for the last 8000 yr in south-eastern Europe, *Geophys. J. R. Astron. Soc.*, 1980, vol. 61. pp. 57–64.

Kovacheva, M., Boyadziev, Y., Kostadinova-Avramova, M., Jordanova, N., and Donadini, F., Updated archaeomagnetic data set of the past 8 millenia from the Sofia laboratory, Bulgaria, *Geochem. Geophys. Geosyst.,* 2009, vol. 10. https://doi.org/10.1029/2008GC002347

Nachasova, I.E., Characteristics of variations in the intensity of the geomagnetic field according to archaeomagnetic data, *Extended Abstract of Doctoral (Phys.-Math.) Dissertation,* IPE RAS, 1998.

Nachasova, I.E. and Akimova, S.V., The geomagnetic field intensity variations in the Iberian Peninsula during the last Millennium, *Izv., Phys. Solid Earth,* 2015, vol. 51, no. 5, pp. 709–715.

Nachasova, I.E., Burakov, K.S., and Pilipenko, O.V., Variations in the intensity of the geomagnetic field in Siberia during the last 13 000 years, *Izv., Phys. Solid Earth,* 2015, vol. 51, no. 1. pp. 44–50.

Nachasova, I.E., Pilipenko, O.V., Markov, G.P., Gribov, S.K., and Tsetlin, Yu.B., Geomagnetic field intensity during the Neolith in the Central East European Plain, *Geomagn. Aeron.*, 2018, vol. 58, no. 3, pp. 438–447.

Nagata, T., Arai, Y., and Momose, K., Secular variation of the geomagnetic total force during the last 5000 years, *J. Geophys. Res.*, 1963, vol. 68, no. 18, pp. 5277–5281.

Nedomolkina, N.G., Veksa III settlement (Ust-Vologda III), in *Traditsii v kontekste russkoy kul'tury* (Traditions in the Context of Russian Culture), vol. 4, Cherepovets: CHGPI, 2000a, pp. 3–5.

Nedomolkina, N.G., The multilayer settlement of Veksa, in *Tverskoi arkheologicheskii sbornik* (Tver Archaeological Paper Collection), series 4, vol. 1, Tver': Tverskoi ob"edinennyi gos. muzei, 2000b, pp. 277–283.

Nedomolkina, N.G., Neolithic complexes of Veksa and Veksa III sites of the Upper Sukhona basin and their chronology, in *Problemy khronologii i etnokul'turnykh vzaimodeystviy v neolite Yevrazii (khronologiya neolita, osobennosti kul'tur i neolitizatsiya regionov, vzaimodeystviya neoliticheskikh kul'tur v Vostochnoy i Sredney Evrope)* (Problems of Chronology and Ethnocultural Interactions in the Neolithic Eurasia (Neolithic Chronology, Features of Cultures and Neolithicization of Regions, Interaction of Neolithic Cultures in Eastern and Central Europe)), Timofeev, V.I. and Zaitseva, G.I., Eds., St. Petersburg: IIMK RAN, 2004, pp. 265–279.

Nedomolkina, N. and Piezonka, H., The Upper Sukhona region in the Early and Middle Neolithic according to the results of radiocarbon dating (case study of Veksa I, Veksa III settlements), in *Radiouglerodnaya khronologiya epokhi neolita Vostochnoy Evropy VII–III tysyacheletiya do n. e.* (Radiocarbon Chronology of the Neolithic of Eastern Europe VII–III Millennia B.C.), Zaitseva, G.I., Lozovskaya, O.V., Vybornov, A.A., and Mazurkevich, A.N., Eds., Smolensk: Svitok, 2016, pp. 425–443.

Paterson, G.A., Tauxe, L., Biggin, A.J., Shaar, R., and Jonestrask, L.C., *Stand. Paleointensity Definitions*, 2014, V. 1.0. https://earthref.org/PmagPy/SPD/DL/SPD_v1.0.pdf.

Riisager, P. and Riisager, J., Detecting multidomain magnetic grains in Thellier palaeointensity experiments, *Phys. Earth Planet. Inter.,* 2001, vol. 125, pp. 111–117.

Shcherbakov, V.P. and Shcherbakova, V.V., The paleomagnetic direction determination: implications of the domain structure of ferromagnetic grains in rocks, *Izv., Phys. Solid Earth*, 2002, vol. 38, no. 5. pp. 404–411.

Tema, E. and Kondopoulou, D., Secular variation of the Earth's magnetic field in the Balkan region during the last 8 millennia based on archaeomagnetic data, *Geophys. J. Int.*, 2011, vol. 186, pp. 603–614. https://doi.org/10.1111/j.1365-246X.2011.05088x

Tema, E., Gomez-Paccard, M., Kondopoulou, D., and Almar,Y., Intensity of the Earth's magnetic field in Greece during the last five millennia: New data from Greek pottery, *Phys. Earth Planet. Inter.*, 2012, vol. 202–203, pp. 14–26.

Thellier, E. and Thellier, O., Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique, *Ann. Geophys.*, 1959, vol. 15, pp. 285–378.

Translated by M. Nazarenko