

Early Neolithic settlement Yabalkovo (Maritsa valley, Bulgaria) in the context of archaeomagnetic studies

Maria Kostadinova-Avramova ^{a*}, Mary Kovacheva ^b, Neli Jordanova ^c

^a National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, bl.3 Acad. G. Bonchev Str., 1113 Sofia, Bulgaria; miki4740@abv.bg

^b National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, bl.3 Acad. G. Bonchev Str., 1113 Sofia, Bulgaria; marykov@abv.bg

^c National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences, bl.3 Acad. G. Bonchev Str., 1113 Sofia, Bulgaria; neli_jordanova@hotmail.com

* corresponding author

ABSTRACT

Five fired clay structures from the Northeast sector of the Early Neolithic settlement of Yabalkovo in the Maritsa valley, Bulgaria were a subject of an archaeomagnetic investigation. The results of the detailed rock-magnetic experiments carried out show that the collected materials are suitable for archaeomagnetic study and reliable determinations for past geomagnetic field elements can be obtained. According to the mean values calculated for the ancient geomagnetic field direction and intensity, two different periods of time can be undoubtedly distinguished for the investigated structures. This coincides exactly with the two chronological horizons suggested by the excavators. The archaeological observations point that the oven in sq. K36, the hearth in sq. F16 and the hearth in sq. H31 are related to Horizon II, while the hearths in sq. I31 and sq. F18 are connected with Horizon I.

Based on the Bulgarian reference curves (latest version), the following archaeomagnetic dating intervals are received: Yabalkovo – Horizon II – (5685–5489 BC) and Yabalkovo – Horizon I – (5472–5427 BC). These results agree well with the archaeological data that structures from Horizon II are older than structures from Horizon I. The existing ¹⁴C dates (for materials taken mainly from the Southwest sector of the settlement) show considerably older dating intervals but they are not able to differentiate chronologically the different structures. The obtained archaeomagnetic determinations for Yabalkovo are compared with these available for other archaeomagnetically studied Early Neolithic sites from Bulgaria and Northern Greece. This comparison indicates that Horizon II of Yabalkovo can be synchronised with the younger layers of Kovatchevo (Karanovo I), Stara Zagora (Karanovo II) and Dobriniste. Horizon I of Yabalkovo is chronologically comparable with Horizons VII+VIII of Samovodene and Avgi (Northern Greece).

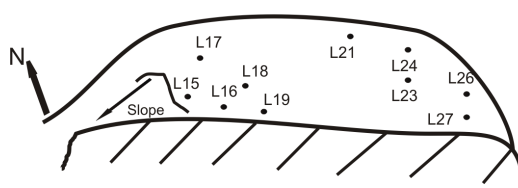
KEYWORDS

Archaeomagnetic dating, radiocarbon dating, synchronization, Early Neolithic, Yabalkovo

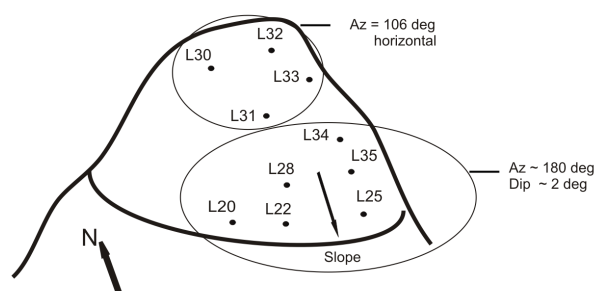
Introduction

Archaeomagnetism is a typical example of an interdisciplinary method, which has a wide application in both geophysics and archaeology. Archaeomagnetic investigations of different dated fired clay materials give invaluable information to geophysics about the behaviour of the geomagnetic field in the past. On the other hand, on the basis of large amount of materials well dated by other independent methods, it is possible to build the so called secular variation curves (SVCs) for a given territory. These reference curves can be

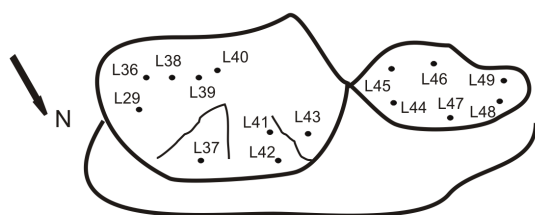
a) Structure 1 - (oven from Square K36, Horizon II)



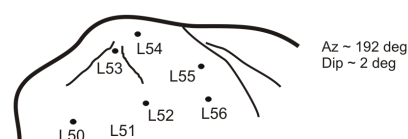
b) Structure 2 (hearth from Square I31, Horizon I)



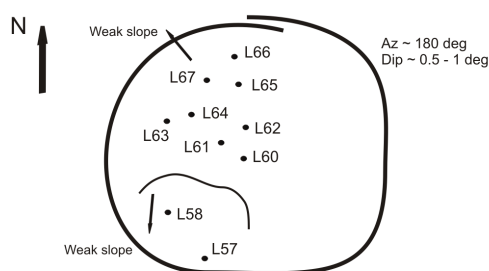
c) Structure 3 (hearth from Square F18, Horizon I)



d) Structure 4 (hearth from Square F16, Horizon II)



e) Structure 5 (hearth from Square H31, Horizon II)



f) General plan of the excavated squares in the Northeast sector and the sampled structures

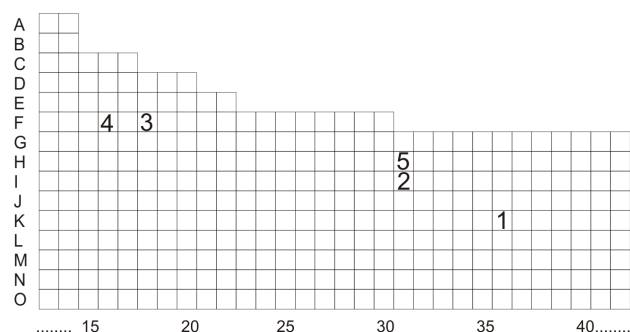


Fig. 1. Schematic drawing of the sampled structures (drawings by M. K.-Avramova)
Обр. 1. Схематично представяне на опробваните структури (чертежи М. К.-Аврамова)

used in archaeology for dating purposes (Kovacheva et al. 2004, 1563-1479; Kostadinova, Kovacheva 2008, 511-522; Ben-Yosef et al. 2010, 7-9; Aidona, Kondopoulou 2012, 839-842; Herve et al. 2011, 153-154; Prevosti et al. 2013, 2696-2700; Casas et al. 2014, 861-864; Kostadi-

nova-Avramova et al. 2014a, 44-47; Tema et al. 2015, 501 – 504; Ech-Chakrouni et al. 2015, 578 – 593).

The archaeomagnetic method is based on the fired clay ability to acquire a thermoremanent magnetization (TRM) during its last cooling in the Earth's magnetic field from temperatures around 600°C. The acquired in that way TRM retains information for the direction (inclination – I; declination – D) and the intensity (Fa) of the geomagnetic field existing at the time and place of the fired clay last cooling. All geomagnetic field elements (I, D and Fa) can be obtained only from oriented (found *in situ*) samples. It is considered that TRM is sufficiently stable to preserve information for the Earth's magnetic field elements. Nevertheless, over the time many factors affect the carried magnetization and the original mineralogy of the fired clay materials and this can influence the obtained archaeomagnetic results. That is why each archaeomagnetic study always includes detailed examination of rock-magnetic properties of the collected materials.

The subject of this study is an archaeomagnetic investigation of various fired clay structures of the Northeast sector of the site of Yabalkovo in order to: 1) determinate archaeomagnetically their last moment of use and 2) identify how these structures refer to each other.

Archaeological background and description of the studied collection

According to the archaeological data, three horizons can be distinguished in Yabalkovo (counted from top to bottom). The beginning of site occupation covers the Early Neolithic period in Bulgaria (Leshtakov et al. 2007, 185-234; Roodenberg et al. 2014). In the first publication the authors state that “Yabalkovo is the first excavated “flat” settlement located in the Maritsa River valley in Upper Trace” and “most probably, different parts of the gentle slopes of the Maritsa river valley were settled at different periods.” In such complicated circumstances, an archaeomagnetic study can reveal the differences in time of various studied structures with intention to help the site stratigraphy.

In the summer of 2003, five fired clay structures from the Northeast sector of the settlement Yabalkovo were sampled and 53 pieces numbered from L15 to L67 were gathered for archaeomagnetic investigations (Fig. 1). According to the archaeological assumptions, all sampled structures are related to the Early Neolithic Horizons II and I (Horizon II assumed to be more ancient than Horizon I). The site's chronology is based on the conventional consideration about the colour type of ceramics discovered and radiocarbon dating (Leshtakov et al. 2007, 185-234; Roodenberg et al. 2014, 447).

All collected pieces were independently oriented with magnetic and sun compass (Fig. 2). Ten samples were taken from an oven situated in Square K36 and deriving from Horizon II (Fig. 1a – structure 1), ten samples – from a hearth in Square I31 – Horizon I (Fig. 1b – structure 2), fifteen – from a hearth in Square F18 – Horizon I (Fig. 1c – structure 3), seven – from a hearth in Square F16 – Horizon II (Fig. 1d – structure 4) and eleven from a hearth in Square H31 – Horizon II (Fig. 1e – structure 5). In all cases, the sampled clay plasters were thin, considerably cracked and some of them have a significant slope (Fig. 1, Fig. 3). If this slope has been acquired after the last burning of the plasters, the directional results would be affected. That is why the azimuth and the dip of each slope were carefully measured.

Most of the samples were impregnated with water glass to achieve better consolidation and to avoid their disintegration during cutting and laboratory procedures. After



Fig. 2. Orientation of the samples from oven in K36 (Structure 1) with sun compass
(photo by M. K.-Avramova)

Обр. 2. Ориентиране на образци от печ в квадрат K36 (структура 1) с помощта на слънчев компас (снимка М. К.-Аврамова)



Fig. 3. Sampling of hearth in Square F16 (Structure 4) (photo by M. K.-Avramova)

Обр. 3. Опробване на огнище в квадрат F16 (структура 4) (снимка М. К.-Аврамова)

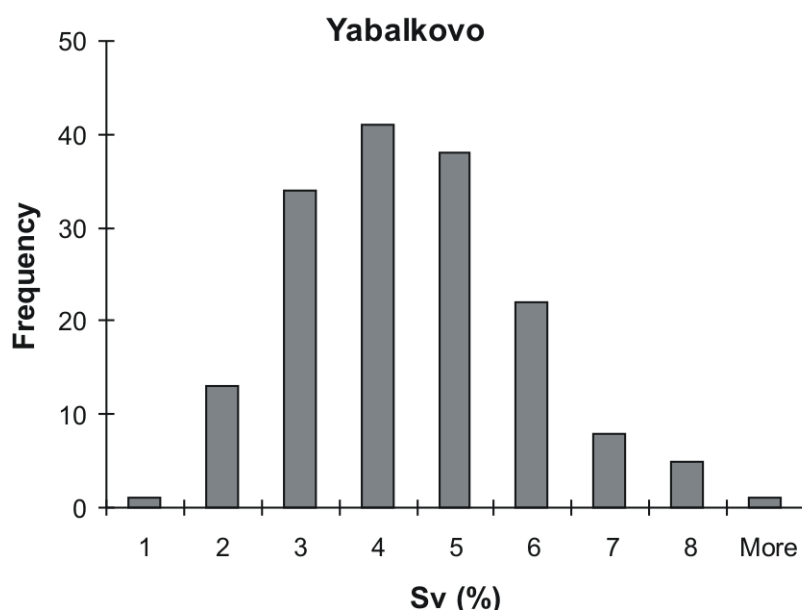


Fig. 4. Frequency distribution of the viscosity coefficient – Sv in percent

Обр. 4. Честотно разпределение на стойностите, получени за коефициента на вискозност – Sv в проценти

that, all independently oriented pieces were cut to cubes with 2 cm edge and thus 198 specimens (sub-samples) were obtained and studied. Despite the water glass impregnation, three hand samples from structure 3 (the hearth in Square F18) were lost during the cutting procedure.

Laboratory methods

Different laboratory experiments were carried out (Kovacheva, Jordanova 2001, 685-696) in order to establish the suitability of the collected materials for obtaining reliable archaeomagnetic determinations.

- **The method of viscous cleaning** was applied to all sub-samples to evaluate the stability of carried remanent magnetization (NRM) and the relative contribution of secondary viscous remanence (VRM). In our case, the calculated viscosity coefficient (Sv) values varied mainly between 2 and 6 percent (Fig. 4). A low viscosity is an evidence for stabilized magnetic capacity of the collected materials and the existence of enough stable thermoremanent magnetization.

- **Alternating field (AF) or thermal demagnetization** is another approach for secondary remanent magnetizations estimation and cleaning. Five sub-samples were demagnetized with alternating field up to 100 mT and ten were thermally step-wise demagnetized to 600°C. For all of them the behaviour of carried magnetic remanence is quite similar and two components of NRM are identified – one weak unstable viscous component, which is completely demagnetized at low AFs or temperatures and another stable primary component (Fig. 5). This is in good agreement with the results from viscous cleaning.

- **3IRM test** (Lowrie 1990, 159-162) – it allows the unblocking temperatures (Tb) of the three components of IRM to be determined which are representative for the main ferromagnetic minerals. Eight specimens were studied and the obtained results are compatible (Fig 6a). The observed unblocking temperatures are typical for magnetite and thitanomagnetite. Only in two specimens, the presence of high coercivity minerals (probably goethite) can be

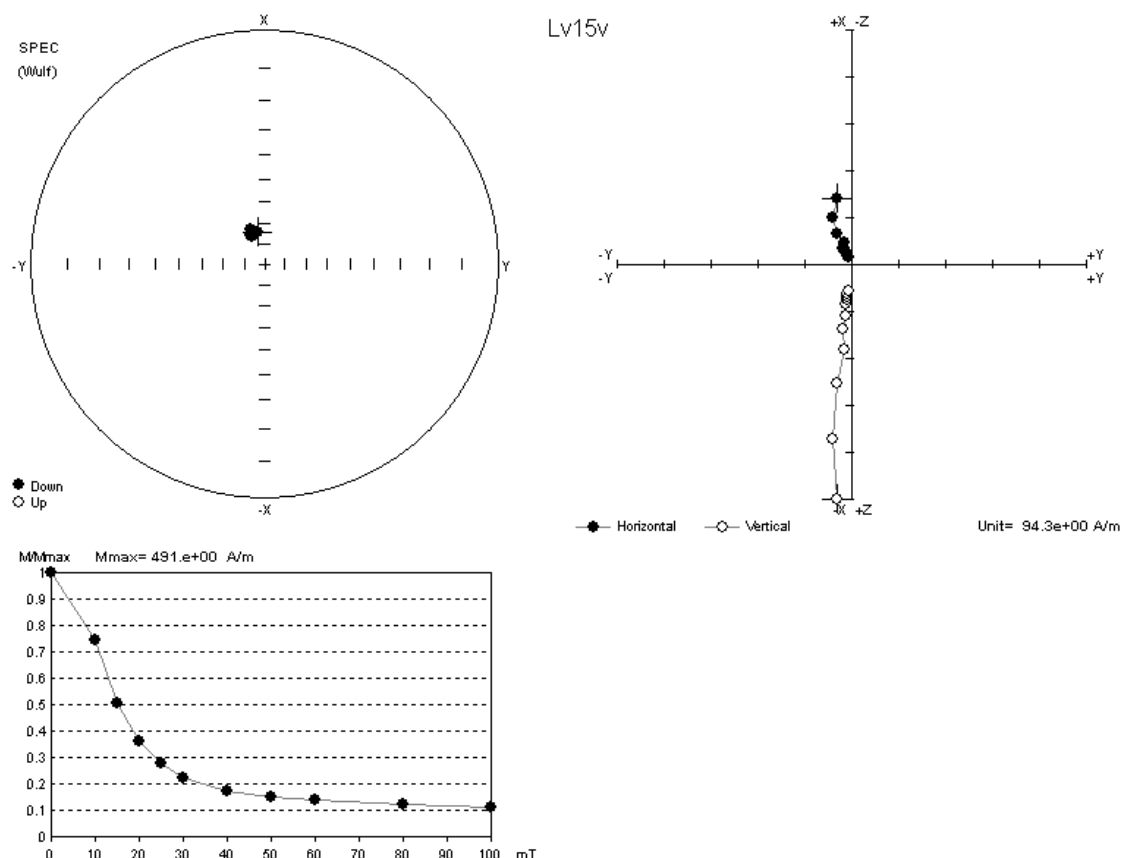


Fig. 5. Typical example of AF demagnetization
Обр. 5. Пример за AF размагнитване

assumed.

The behaviour of magnetic susceptibility (K) was monitored at each heating step because all changes in magnetic mineralogy reflect in K . For the most of the studied samples, magnetic susceptibility variations are less than 10 percent, evidence for insignificant mineralogical alterations during heating. The stable magnetic mineralogy is another important condition for reliable archaeointensity results.

- **High temperature dependence of magnetic susceptibility (thermomagnetic analysis)** – it enables a determination of the Curie temperatures (T_c) of the main ferromagnetic minerals and the degree of mineralogical changes. The results show Curie temperatures in the range of 450°C and 580°C (Fig. 6c) and minor mineralogical transformations. This confirms the results from 3IRM test that the magnetic remanence carriers are magnetite/thitanomagnetite grains.

- **SIRM test** (Van Velzen, Zijdeveld 1992, 79-90; Jordanova et al. 2003, 146-158) – it is an additional test for mineralogical changes monitoring of the studied material. The results (seven specimens) agree well with the previous conclusions for insignificant mineralogical transformations (Fig. 6e).

- **Lowrie and Fuller test** (Lowrie, Fuller 1971, 6339-6349) – five specimens. This test can partially identify the type of dominant domain state of magnetic carriers. According to the results obtained, the materials contain a mixture of grains with multi-domain and single-domain size. This can be explained by the fact that archaeological fired clay materials are often a mixture of various inclusions in contrast to the well-selected fine clays used for

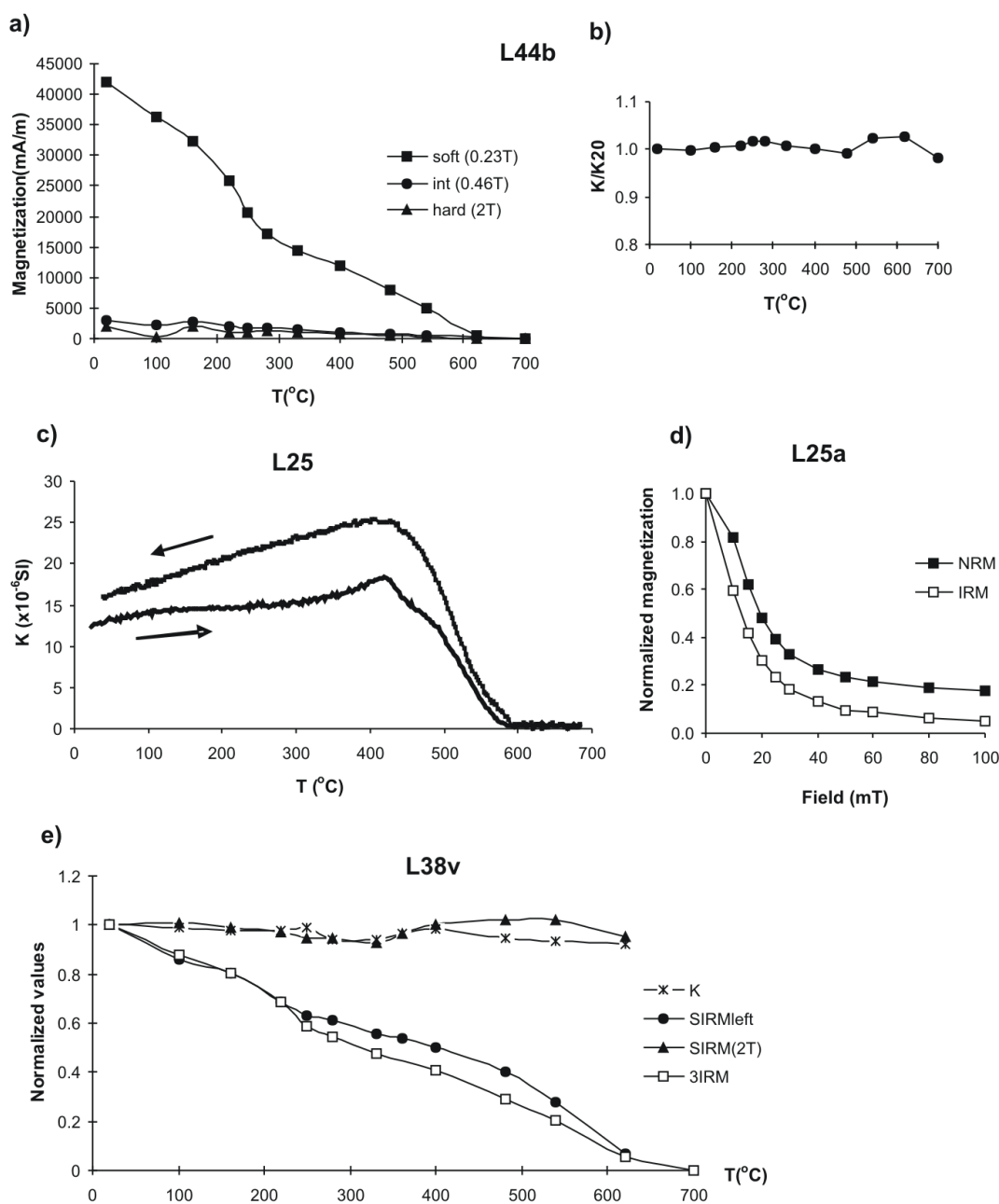


Fig. 6. Typical examples of (rock-magnetic experiments carried out): a) 3IRM test b) variations in K during the 3IRM test c) thermomagnetic analyses d) SIRM test and e) Lowrie and Fuller test
 Обр. 6. Примери за направените магнитно диагностични експерименти: а) 3IRM тест б) изменение на магнитната възприемчивост по време на 3IRM теста в) термомагнитен анализ д) SIRM тест и е) тест на Lowrie & Fuller

the pottery production (Kovacheva et al. 1998, 431-460).

Based on the results of the different rock-magnetic experiments described above, 36 specimens were chosen for archaeointensity (Fa) determination. Two different methods for Fa determination were used. A classical Thellier (Thellier, Thellier 1959, 285-376) experiment was applied to 13 specimens, the remaining 23 specimens were treated according to the Coe protocol (Coe 1978, 3247-3262). It should be noted that the classical Thellier experiment was performed in the observatory situated on Vitosha Mountain using two home-

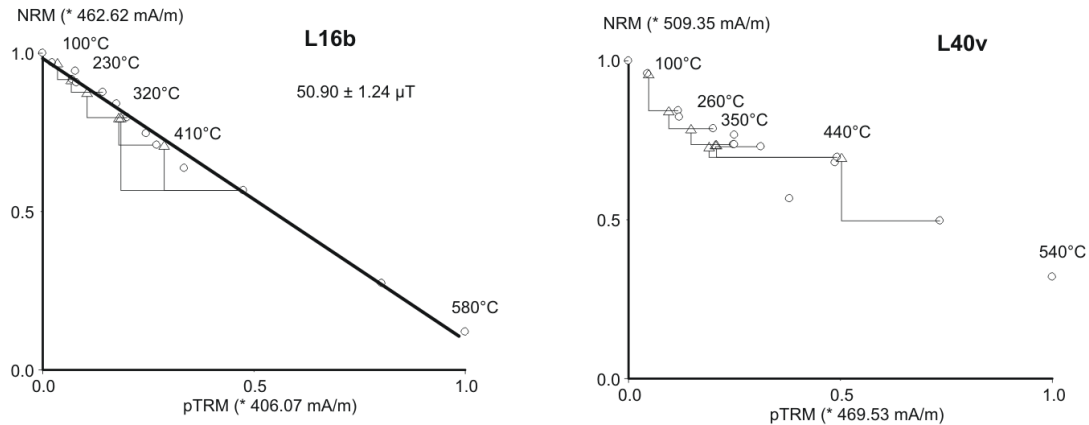


Fig. 7. Two examples of Coe experiment with the corresponding pTRM tests: a) successful and b) failed.

Обр. 7. Два примера за експеримента на Коу със съответните pTRM тестове: а) успешен и б) неуспешен

made furnaces for heating (no fan was used, thus assuming relatively low cooling rate) and JR4 spinner magnetometer (AGICO, Brno) used for magnetic remanence measurements. Laboratory TRM was induced in the existing Earth's magnetic field, that was measured several time per day. The Coe protocol was performed in Sofia palaeomagnetic laboratory using mu-metal shielded oven MMTD (Magnetic measurements Ltd. UK) equipped with a fan for cooling cycles and skytronic power supply for the laboratory TRM acquisition. The thermoremanences were measured on Molspin magnetometer (Molspin Ltd., UK). Two examples of the Coe experiments (successful and failed) can be seen on Fig. 7. During the experiments, the magnetic susceptibility was measured with a Kappabridge KLY-2 (AGICO, Brno) at each heating step to follow the changes in magnetic capacity of the materials. With few exceptions, this parameter was considerably constant, suggesting negligible transformations in the initial magnetic mineralogy (less than 10 percent change).

Archaeomagnetic results and discussion

The results obtained for the three geomagnetic field elements: inclination (I), declination (D) and intensity (Fa) are summarized in Table 1. All directional analyses were done by Palaeomag-Tools, V.4.2 software. The mean direction for each sample is calculated as an average of the values measured of the cut specimens after the corresponding cleaning. Sun compass corrections were applied to the declination avoiding the influence of possible local magnetic anomalies (Table 1, third column). The final direction for each structure is obtained by Fisher statistics (Fisher 1953, 295) over the averaged directional values for all samples included in the corresponding structure (given in bold in Table 1). In the first column of Table 1, after the corresponding field number, the numbers of accepted/all measured specimens are given. The directional results for some specimens are rejected in order to improve the dispersion between specimens cut from the same sample (Table 1 – first column). It is obvious, from Table 1, that for the structure 2, 3 and 4 a significant scatter between the directional results for samples collected from the same structure exists. It should be noted that this scatter is only between the samples, not between the sub-samples (specimens cut from one piece). The most probable reason for the observed dispersion is the fact that the structures had many cracks (Fig. 3). Thus, the position of some samples could not have been precisely *in situ* during the sampling. The existence of significant slopes (Fig. 3)

probably secondarily formed additionally complicated the situation. The slope corrections applied do not improve the observed scatter and they are not used in the calculation of the final directions for the different structures. The aberrant directional results are marked with italic and asterisks in Table 1.

The F_a obtained values with their relevant standard errors are given in columns seven and eight in Table 1, respectively. The mean F_a results with corresponding standard deviation of the weighted average archaeointensity (Kovacheva, Kanarchev 1986, 1297-1310) for each structure are given in bold. Only three from the 36 experiments (specimens L40v, L44d and L54b) carried out for F_a determination were unsuccessful. For sub-samples L40v and L44d, the F_a results were rejected because of linearity lack on the Arai diagrams (Fig. 7b). For specimen L54b significant variations in magnetic susceptibility were observed suggesting more than 10 percent mineralogical transformations during the experiment and unreliable F_a result.

The temperature intervals (Table 1, column 6) used for F_a determination are with T_{max} in the range of around 500°C for the structures 1 (oven in K36), 3 (hearth in F18) and 5 (hearth in H31) and 400 – 450°C for the structures 2 (hearth in I31) and 4 (hearth in F16). Therefore, we can conclude that the first three structures have been probably heated to the relatively higher temperatures in antiquity than the other two.

It should be underlined that there is an excellent agreement between the obtained archaeointensity results independently of the applied methodology (classical Thellier method or its Coe version) using sister specimens. Moreover, the internal consistency between the results is remarkable (Table 1). Therefore, the present study shows that both protocols, performed under completely different experimental conditions and using different equipment are equally appropriate for archaeointensity determination. The next inference from this comparison is that for the collections of thin prehistoric materials the cooling rate correction is not as important. The same is valid for the influence of magnetic anisotropy correction (Kovacheva et al. 2009).

Based on the obtained archaeomagnetic results (D , I and F_a values - Table 2) the studied structures can be obviously combined in two groups. The first group includes structures 1, 4 and 5, which show higher mean inclination and intensity values and slightly western declination (Table 1, Table 2). In contrast, the structures in the second group – structures 2 and 3 – have lower mean inclination and intensity and eastern declination (Table 1, Table 2). The most important result is that all the structures archaeomagnetically distinguished as first group are from Horizon II and respectively all structures belonging to the second group are from Horizon I (Table 1, Table 2). Thus, this independently archaeomagnetic grouping confirms the archaeological conceptions about the site's stratigraphy. This is an essential interdisciplinary involvement in archaeological investigations. Moreover, knowing that the site in question is of a "flat" type, the identification of its stratigraphy is quite difficult. In fact, structures in close proximity have significant chronological differences (Fig 1f – the hearths in squares I31 / H31 and those in F16 / F18).

Archaeomagnetic dating and synchronizations

Archaeomagnetic dating is possible only when well-established reference curves are available for a given territory. It is a great advantage that Bulgarian reference curves follow the variations of the three geomagnetic field elements – inclination, declination and intensity (I , D and F_a) and this is a precondition for more precise dating (Kovacheva et al. 2014).

No	D (°)	Dcorr (°)	I (°)	Sv (%)	$T_{min} - T_{max}$ (°C)	Fa (μT)	σ (μT)	Method	Horizon/Structure Square/Depth
L20 (3/3)	13.8	22.5*	47.1*	5.2					
L22 (3/3)	8.6	5.7	46.0	2.6	20 - 460	35.11	1.41	Threllier	
					100 - 410	38.39	3.79	Coe	Horizon I
L25 (3/5)	6.9	1.6	58.2	3.0	20 - 580	33.36	1.12	Coe	Structure 2 - hearth
L28 (4/4)	5.0	8.0	48.8	3.0	150 - 500	34.61	0.72	Tellier	Square I31
					200 - 470	37.54	1.97	Coe	0.55m
L30 (1/1)	24.9	31.1*	64.2*	2.3					
L31 (3/3)	4.8	9.8	53.4	2.3					
L32 (2/2)	358.3	0.5*	69.8*						
L33 (2/3)	5.5	13.4*	77.3*						
L34 (5/5)	345.4	345.4*	53.7*	1.8					
L35 (4/4)	357.4	357.1	54.2	1.7	200 - 410	36.41	2.47	Coe	
Average (5/10)		4.6	52.2	$\alpha_{95}=5.4$	N=6/6	34.76	1.16		
L29 (4/4)	359.4	4.2	65.0	3.5	200 - 500	34.11	1.18	Thellier	
					100 - 540	32.86	1.64	Coe	
L38 (5/5)	353.3	357.1	56.3	4.6					Horizon I
L39 (5/6)	348.9	353.9	57.5		200 - 500	35.96	0.73	Thellier	Structure 3 - hearth
L40 (4/4)	4.9	8.9	51.0	4.7		rejected		Coe	Square F18
L41 (4/4)	14.9	20.9*	52.6*	5.9					(1.78 - 1.85)m
L42 (2/2)	17.9	24.8*	62.2*	3.2					
L43 (3/3)	0.1	5.1	56.3	5.1					
L44 (5/5)	16.4	20.6*	68.1*	6.1		rejected		Coe	
L45 (3/3)	5.1	10.3*	65.0*	5.1					
L46 (3/4)	359.6	3.8	67.9	3.7	150 - 500	34.15	0.76	Thellier	
					200 - 500	34.84	2.11	Coe	
L47 (4/4)	12.5	17.9*	70.6*	4.3					
L49 (4/5)	16.4	19.8*	64.2*	6.3					
Average (6/12)		2.2	59.1	$\alpha_{95}=5.8$	N=5/7	34.77	1.01		
L15 (4/6)	340.2	349.8	72.4	5.2	20 - 500	45.24	1.79	Thellier	
					200 - 580	47.17	3.05	Coe	
L16 (3/3)	343.5	350.1	66.2	2.8	20 - 550	48.02	1.26	Tellier	Horizon II
					20 - 580	50.90	1.24	Coe	Structure 1 - oven
L17 (3/3)	348.0	354.9	69.2	2.6	20 - 500	47.45	2.71	Thellier	Square K36
					20 - 440	46.75	2.70	Coe	(1.06 - 1.12)m
L18 (4/4)	357.6	1.5	60.1		20 - 580	50.19	1.20	Coe	
L19 (4/4)	349.9	355.8	62.0	3.4	20 - 580	46.29	1.42	Coe	
L21 (4/4)	342.6	348.8	64.6	3.6					
L23 (3/3)	353.2	355.1	61.1	3.2					
L24 (3/6)	349.5	355.0	61.3	4.0					
L26 (3/5)	349.4	347.0	60.8	3.6					
L27 (3/3)	348.2	356.0	59.1	4.3					
Average N=10/10		353.6	63.7	$\alpha_{95}=2.9$	N=8/8	48.43	1.98		
L50 (3/3)	2.1	8.3*	73.2*	3.9					
L51 (2/2)	4.9	3.1	62.7	2.9	120 - 460	40.44	0.72	Thellier	
					0 - 410	44.52	1.90	Coe	Horizon II
L52 (2/2)	349.8	354.9	64.0	3.9					Structure 4 - hearth
L53 (4/4)	16.6	16.8*	58.6*	5.1	100 - 410	44.02	2.94	Coe	Square F16
L54 (2/3)	326.6	332*	68.4*	7.3		rejected		Thellier	2.15m

No	D (°)	Dcorr (°)	I (°)	Sv (%)	T _{min} – T _{max} (°C)	Fa (μT)	σ (μT)	Method	Horizon/Structure Square/Depth
L55 (4/4)	354.9	2.3	70.0	3.9	0 - 410	48.15	1.79	Coe	
L56 (4/5)	20.9	29.3*	76.1*		0 - 410	43.61	2.76	Coe	
Average	(3/7)	0.0	65.6	α₉₅ = 6.6	N=5/6	42.02	2.63		
L57 (3/3)	5.4	9.8	55.1						
L58 (4/4)	16.8	21.2*	56.8*						
L59 (4/4)	3.9	8.3	51.2	5					
L60 (6/6)	3.7	8.1	54.9	3	120 - 460	40.51	0.91	Thellier	Horizon II
					230 - 500	38.41	3.44	Coe	Structure 5 - hearth
L61 (4/4)	4.8	9.2	59.0	4.4					Square H31
L62 (6/6)	358.4	2.8	57.4	3.5	200 - 460	43.91	1.03	Thellier	0.90m
					230 - 500	44.84	3.11	Coe	
					230 - 500	43.01	2.57	Coe	
L63 (0/4)	rejected		rejected	4.7					
L64 (6/6)	356.9	1.3	68.8	3.4					
L65 (5/5)	356.3	0.7	61.4	3.9					
L66 (6/6)	358.4	2.8	66.1	3.8	200 - 500	40.13	1.07	Thellier	
					200 - 500	44.06	3.25	Coe	
					230 - 500	40.80	1.66	Coe	
L67 (5/5/)	10.5	14.9*	65.3	3.6*	200 - 550	37.44	1.08	Coe	
Average	(8/10)	5.8	59.3	α₉₅ = 4.1	N=9/9	40.79	2.23		

Table 1. Summarized archaeomagnetic determinations of the different structures. No – sample's number; D and Dcorr – magnetic declination before and after sun compass correction (in degree); I – magnetic inclination (in degree); Sv – calculated viscosity coefficient; T_{min} – T_{max} – temperature interval used for Fa determination; Fa and σ – the obtained archaeointensity value and its corresponding error (in microtesla)

Таблица 1. Археоманитни определения за различните структури. No – номер на образаца; D и Dcorr – магнитна деклинация преди и след корекция (в градуси); I – магнитна инклинация (в градуси); Sv – коефициент на вискозност в проценти; T_{min} – T_{max} – температурен интервал, използван при определянето на Fa; Fa и σ – стойност, получена за археоинтензитета и съответната му грешка (в микротесли)

79-94). Several factors affect the precision of each archaeomagnetic dating: the accuracy of the experimental archaeomagnetic determinations obtained; the accuracy of the reference curves used and the sharpness of the geomagnetic field variations in the considered period.

The final mean I, D and Fa values determined for Horizon I and Horizon II (Table 2) are compared to the Bulgarian reference curves updated in 2014 (Kovacheva et al. 2014, 79-94) for the age interval of 6000 BC to 5000 BC. The dating is performed with REN-DATE Model, version: 5.0.0.4 (Lanos 2004, 43-82) on 95 percent probability level (2σ). The following possible archaeomagnetic dating intervals are obtained by combined analysis of the three geomagnetic field elements for the studied horizons (Fig. 8a and b):

Horizon II (structures 1, 4, 5) – (5685–5489 BC) with 95.1 percent probability density.

Horizon I (structures 2, 3): – (5472–5427 BC) or (5376–5297 BC) with 22.6 percent and 72.6 percent probability density correspondingly. From both dating alternatives, the first one is closer to the archaeological conceptions.

Horizon / Structure	I (°)	D (°)	N _{DIR}	α_{95} (°)	k	Fa (μT)	σ (μT)	N _{Fa}
I / 2	52.2	5.4	5/10	5.4	203	34.76	1.16	6/6
I / 3	59.1	2.2	6/12	5.8	135	34.77	1.01	5/7
mean values	56.0	3.4	11	4.0	130	34.77	1.08	11
II / 1	63.7	353.6	10/10	2.9	287	48.43	1.98	8/8
II / 4	65.6	0.0	3/7	6.6	349	42.02	2.63	5/6
II / 5	59.3	5.8	8/10	4.1	183	40.79	2.23	9/9
mean values	62.4	359.5	21	2.4	184	43.39	4.03	22

Table 2. Mean directional and archaeointensity results for the five studied structures. α_{95} and k – parameters for accuracy evaluation; NDIR – number of the accepted/all directional results; NFa – number of the accepted/all archaeointensity evaluations

Таблица 2. Средни стойности за посоката и археоинтензитета за петте изследвани структури. α_{95} и k – параметри за оценка на грешката; NDIR – номер на приетите/всички резултати за посоката; NFa – брой на приетите/всички резултати за археоинтензитета

These dating intervals are close to the end of Early Neolithic and beginning of the Middle Neolithic period (Bojadziev 1995, 161-165). The discovered ceramic features are related mainly to the Early Neolithic period (Leshtakov et al. 2007, 185-234). It should be noted that materials from the oldest Horizon III have not been archaeomagnetically studied and in fact, the obtained archaeomagnetic dating intervals marked the end of the corresponding horizon existence.

Recently a new technique (based on the spherical cap harmonic analysis) for archaeomagnetic dating has been developed for Europe (Pavon-Carrasco 2010). In Pavon-Carrasco model besides the European archaeomagnetic results, the data from lake sediments are also included. The time intervals determined for Horizon II – (5671 – 5408 BC) and Horizon I – (5491 – 5245 BC) by applying the second software, are comparable with these obtained by REN-DATE Model (Fig. 8; Fig. 9).

The obvious confirmation of the archaeomagnetic dating intervals received by two different dating methods (Lanos 2004, 43-82; Pavon-Carrasco 2010) underlines the reliability of the proposed dating bearing in mind that the Pavon-Carrasco method uses also palaeomagnetic data from lake sediments. The available radiocarbon determinations from Yabulkovo are explained in detail in Roodenberg et al. (2014; 449). They are older in comparison to the archaeomagnetic ones (fig. 10). It should be noted that the existing ^{14}C dates are derived from different sectors of the site. They vary within a wide range (more than 300 years) and in general are inconclusive according to the site` stratigraphy. Moreover, the greatest difference is observed for ^{14}C dates of grain samples OxA-23558 and OxA-23559 taken from the same pit and level of the Southwest sector (fig. 10; Roodenberg et al. 2014, 447-448). Both dating methods (^{14}C and archaeomagnetic) applied on samples coming from non-coincident areas indicate a large span of time for the site existence. The observed discrepancy between the archaeomagnetic and ^{14}C dating intervals necessitates a further investigation of the Early Neolithic chronology of the region.

Fundamental principle in archaeomagnetism is the fact that materials last burned in close moments of time should have similar geomagnetic characteristics. Therefore, based on archaeomagnetic determinations only, it is possible to compare and synchronize different archaeological sites of the same age and area (Kostadinova-Avramova et al. 2014b, 227-238). That is why, the obtained I, D and Fa values for the investigated horizons in Yabalkovo

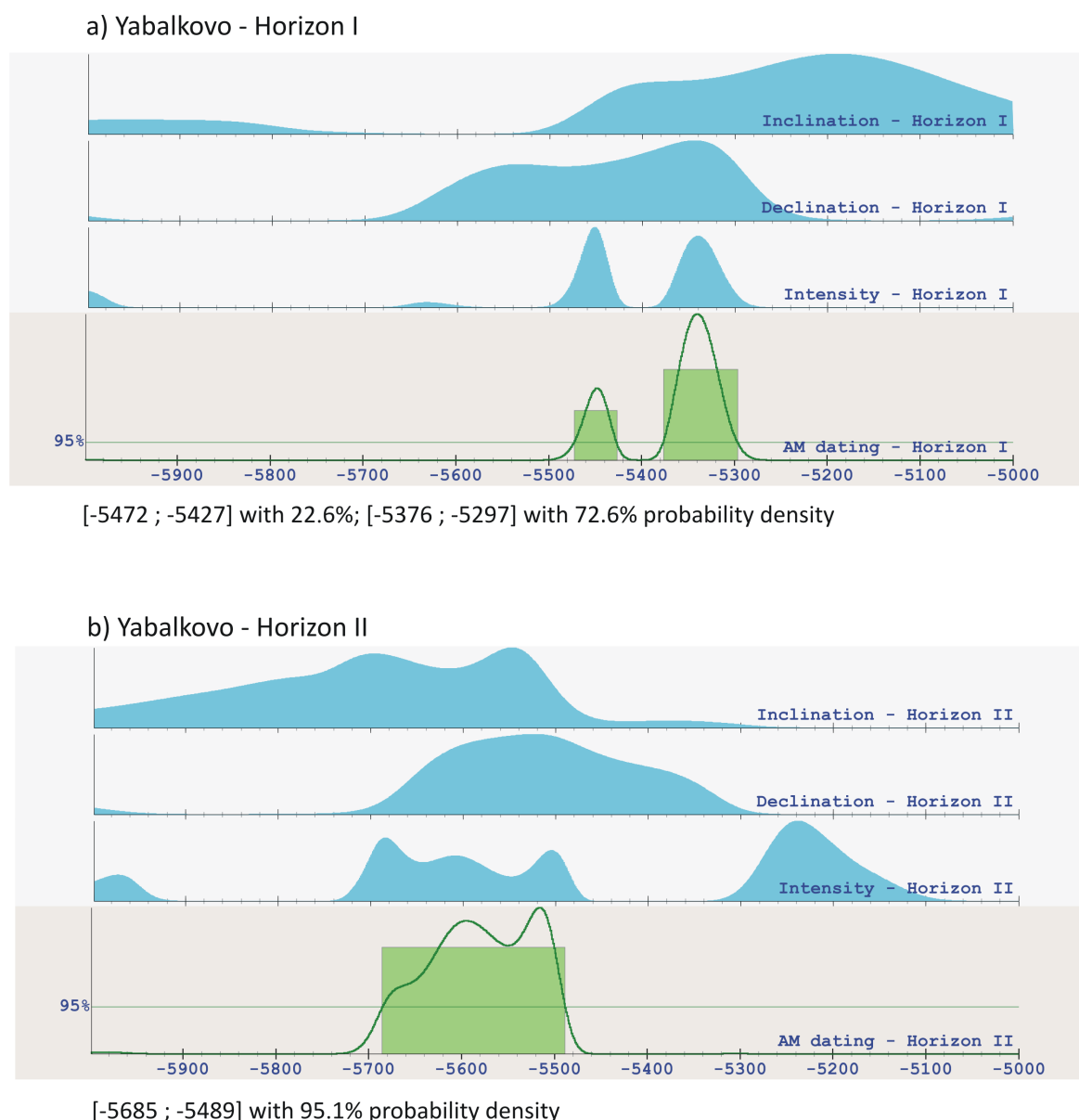


Fig. 8. Archaeomagnetic dating of Yabalkovo site based on local reference curves using the three geomagnetic field elements: a) Horizon I and b) Horizon II

Обр. 8. Археоманитно датиране на обекта Ябълково въз основа на локалните реперни криви за вариациите на трите геомагнитни елемента (инклинация, деклинация и интензитет): а) хоризонт I и б) хоризонт II

were compared with these available from other (previously archaeomagnetically studied) Early Neolithic sites in Bulgaria (Kovacheva et al. 2014, 86-87) and Northern Greece (Aidona, Kondopoulou 2012, 838-839). It can be assumed that Yabalkovo Horizon II has been probably simultaneous with the younger layers of Kovatchevo (Karanovo I), Stara Zagora (Karanovo II) and Dobriniste. Furthermore, the dating intervals corresponding to these sites are based on series of ^{14}C dates and agree very well with the determined archaeomagnetic dating interval for Yabalkovo Horizon II (Table 3). Yabalkovo Horizon I can be synchronized with Samovodene (Horizons VII+VIII) and Avgi (Northern Greece) dated independently by relative chronology and ^{14}C respectively (Table 3). Again, there is a good agreement between the dating intervals related to the synchronized sites (Table 3).

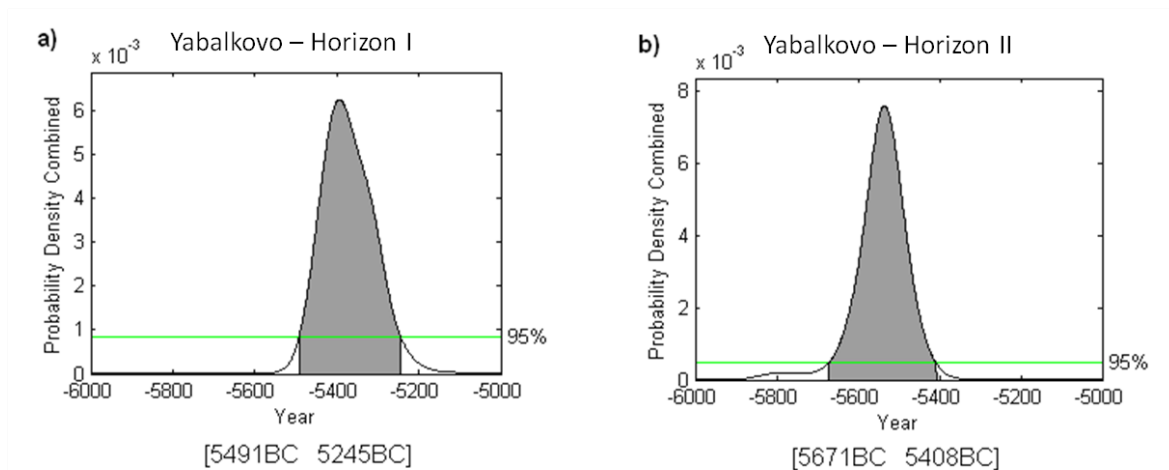


Fig. 9. Archaeomagnetic dating using European geomagnetic model: a) Horizon I and b) Horizon II
Обр. 9. Археоманитно датиране според геомагнитния модел за Европа а) хоризонт I и б) хоризонт II

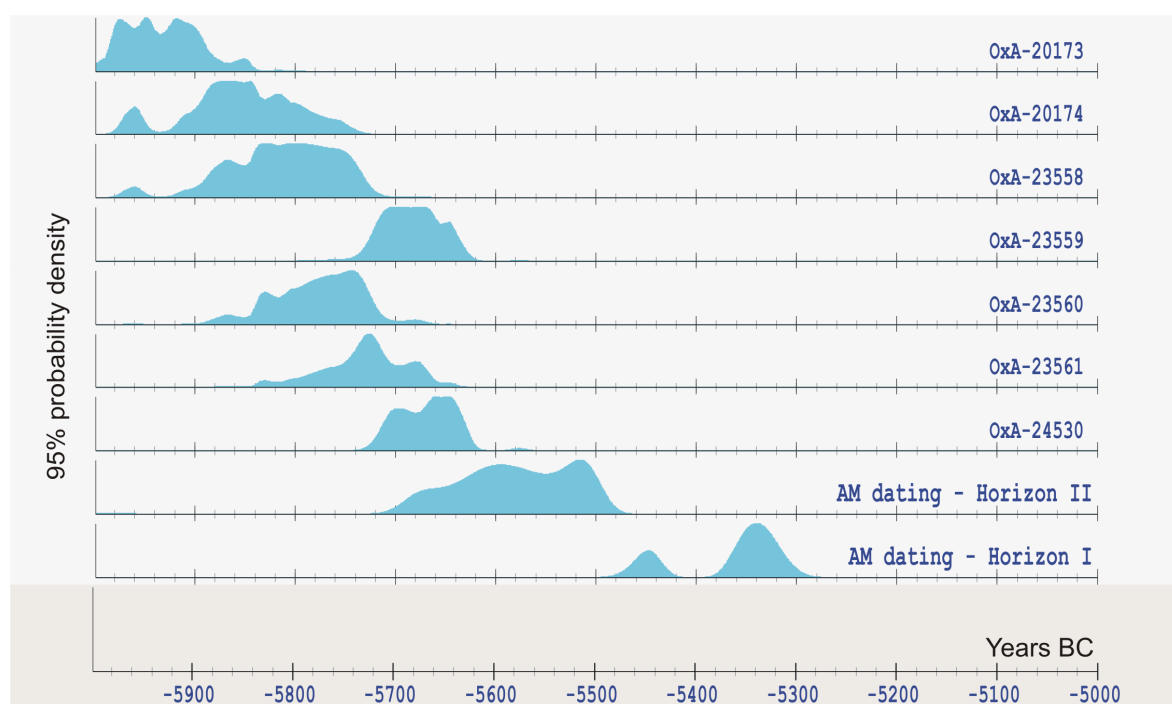


Fig. 10. The available radiocarbon (after Roodenberg, 2014, Table 1, 447) and archaeomagnetic (this study) dating intervals for Yabalkovo site

Обр. 10. Налични радиоуглеродни (по Roodenberg, 2014, Table 1, 447) и археоманитни (настоящото изследване) датируеми интервали за обекта Ябълково

The biggest problem of the chronological distribution of archaeomagnetically studied Bulgarian prehistoric sites is the lack of reliable independent dates, obtained by different scientific method (Kostadinova-Avramova et al. 2014b, 227-228). The archaeological evidence from many prehistoric sites are related to specific cultural-temporal frames, some lasting several hundreds of years. Besides, sometimes the appearance of different Neolithic stages at Bulgarian sites can be questioned (Boyadziev 1995, 161-178). A better understanding of the spatial distribution and development of the white- and dark-painted pottery (Boyadziev 2000, 327-333) is required. The mutual efforts of archaeologists and interdis-

Site (Horizon) / Labno	D (°)	I (°)	α_{95} (°)	k	N _{DIR}	Fa (μT)	σ (μT)	N _{pl}	Ages / Method
Yabalkovo (I) / 355	3.4	56.0	4.0	130	11	34.77	1.08	11	-5449.5 ± 22.5; -5336.5 ± 39.5 / AM
Samovodene (VII+VIII) / 326	7.4	59.3	2.6	301	11	30.91	2.83	5	-5450 ± 70 / Rel. Chr.
Avgi (Greece)	10.1	53.4	4.2	47	26	*	*	*	-5300 ± 340 / ¹⁴ C
Yabalkovo (II) / 139	359.5	62.4	2.5	167	21	43.39	4.03	22	-5587 ± 98 / AM
Dobrinishte / 8	356.8	65.5	3.1	187	12	41.41	1.49	7	-5558 ± 68 / ¹⁴ C
Stara Zagora / 7	351.9	65.2	3.1	72	30	48.63	4.12	13	-5680 ± 62 / ¹⁴ C
Kovachevo / 261	355.5	63.8	3.3	205	10	37.69	4.32	6	-5724 ± 155 / ¹⁴ C

Table 3. The obtained archaeomagnetic determinations for both horizons of Yabalkovo site and their comparison with other archaeomagnetically studied Neolithic sites (from Bulgaria and Northern Greece). AM – dating by archaeomagnetic methodology; Rel Chr. – relative chronology
Таблица 3. Сравнение на получените археомагнитни определения за двата хоризонта на Ябълково с други археомагнитно изследвани неолитни обекта (от България и Северна Гърция). AM – археомагнитно датиране; Rel Chr. – относителна хронология

plinary specialists can solve similar problems in archaeology. All newly studied archaeological sites contribute to the refinement of the Bulgarian dataset and increase the precision of the Bulgarian reference curves.

Conclusions

1. The results from the performed rock-magnetic analyses indicate that the materials collected from the Neolithic settlement of Yabalkovo have suitable magnetic properties for archaeomagnetic study and reliable geomagnetic field determinations can be received.

2. According to the obtained archaeomagnetic results, the sampled structures can be divided into two groups corresponding to different periods. The independent archaeomagnetic discrimination coincides with the archaeological conception for two different horizons – Horizon II and Horizon I.

3. The archaeomagnetic dating on 95 percent probability level (2σ) gives following archaeomagnetic dating intervals for Yabalkovo site: Horizon II – (5685 - 5489 BC) and Horizon I – (5472 - 5427 BC). These dating intervals are confirmed by the second available archaeomagnetic dating methodology. Having in mind the chronology of the Bulgarian Neolithic period (Bojadziev, 1995) both dating intervals correspond to the end of the Early Neolithic and beginning of the Middle Neolithic period.

4. There are several possible synchronizations of the two archaeomagnetically studied Yabalkovo horizons with previously investigated Early Neolithic sites. Yabalkovo Horizon II is probably simultaneous with the younger layers of Kovatchevo (Karanovo I), Stara Zagora (Karanovo II) and Dobriniste. Yabalkovo Horizon I is synchronized with Samovodene (Horizon VII+VIII) and Avgi (Northern Greece).

Acknowledgement

The authors are grateful to the archaeologist Dr Leshtakov and his collaborators for the possibility to sample the discovered structures. The remarks made by Prof. Chapman help considerably to improve the text.

References

- Aidona, E., Kondopoulou, D. 2012. First archaeomagnetic results and dating of Neolithic structures in northern Greece. *Studia Geophysica et Geodaetica*, 56, 827-844, doi: 10.1007/s11200-011-9006-8.
- Ben-Yosef, E., Tauxe, L., Levy T. E. 2010. Archaeomagnetic dating of copper smelting site F2 in the Timna Valley (Israel) and its implications for the modeling of ancient technological developments. *Archaeometry*, doi: 10.1111/j.1475-4754.2010.00528.
- Boyadziev, Y. 1995. Chronology of Prehistoric Cultures in Bulgaria. In Bailey, D and Panayotov, I. (eds) *Prehistoric Bulgaria*. Monographs in World Archaeology No 22, Madison, Wisconsin: Prehistory Press, 149-192.
- Boyadziev, Y. 2000. The absolute chronology of the Neolithic and Eneolithic cultures in the valley of Struma. In Todorova, H., Stefanovich, M, and Ivanov, G. (eds.) *The Struma/Strymon River Valley in Prehistory*. Sofia: Gerda Henkel Stiftung and Museum of History, Kyustendil, 309-316.
- Casas, L., Prevosti, M., Fouzai, B., Álvarez, A. 2014. Archaeomagnetic study and dating at five sites from Catalonia (NE Spain). *Journal of Archaeological Science*, 41, 856-867.
- Coe, P. C., Gromme, C. S., Mankinen, E. A., 1978. Geomagnetic paleointensities from radiocarbon-dated lava flows on Hawaii and the question of the Pacific non-dipole low, *Journal of Geophysical Research*, 83, 1740-1756.
- Dunlop, D., 1983. Determination of domain structure in igneous rocks by alternating field and other methods. *Earth and Planetary Science Letters*, 63, 353-367.
- Ech-Chakrouni, S. Hus, J., Marchal, J-Ph. 2015. Comparison of archaeomagnetic and ¹⁴C datings of ovens in a cremation necropolis of funerary urns in Belgium. *Studia Geophysica et Geodaetica* 59/4, 578-593.
- Fisher, R. A., 1953. Dispersion on a Sphere. *Proceeding of the Royal Society of London, Series A*, no 217, 295-305.
- Herve, G., Schnepf, E., Chauvin, A., Lanos, Ph. Nowaczyk, N., 2011. Archaeomagnetic results on three Early Iron Age salt-kilns from Moyenvic (France). *Geophysical Journal International*, 185/1, 144-156. DOI:10.1111/j.1365-246X.2011.04933.
- Jordanova, N., Kovacheva, M., Hedley, I. and Kostadinova, M., 2003. On the suitability of fired clay for archaeomagnetic studies as deduced from detailed rock-magnetic studies. *Geophysical Journal International*, 153, 146-158.
- Kostadinova, M., Kovacheva, M. 2008. Case study of the Bulgarian Neolithic Archaeological Site of Piperkov Chiflik and its archaeomagnetic dating. *Physics and Chemistry of the Earth*, 33, 511-522.
- Kostadinova-Avramova, M., Lesigyski, D., M., Kovacheva, M. 2014a. Archaeomagnetic study of two medieval ovens discovered in the Pliska Palace, North-eastern Bulgaria. *Bulgarian e-Journal of Archaeology*, 4/1, 35-50.
- Kostadinova_Avramova, M., Kovacheva, M., Boyadzhiev, Y., 2014b. Contribution of stratigraphic constraints of Bulgarian multilevel tells in the prehistory and comparison with archaeomagnetic observations. *Journal of Archaeological Science*, 43, 227-238.
- Kovacheva, M., Kanarchev, M., 1986. Revised archaeointensity data from Bulgaria. *Journal of Geomagnetism and Geoelectricity*, 38/12, 1297-1310.
- Kovacheva, M., Jordanova, N., Karloukovski, V., 1998. Geomagnetic field variation as de-

- terminated from Bulgarian archaeomagnetic data. Part II: the last 8000 years. *Surveys in Geophysics*, 19/5, 413-460.
- Kovacheva, M., Jordanova, N. 2001. Bulgarian archaeomagnetic studies: a review of methodological progress and applications in archaeology. Proceed. of Workshop "Archaeometry in archaeology: new trends", Rhodes, 3-6.11.1999. *Journal of Radioanalytical and Nuclear Chemistry*, 247/ 3, 685-696.
- Kovacheva, M., Hedley, I., Jordanova, N., Kostadinova, M., Gigov, V., 2004. Archaeomagnetic dating of archaeological sites from Switzerland and Bulgaria. *Journal of Archaeological Science*, 31, 1463-1479.
- Kovacheva, M., Chauvin, A., Jordanova, N., Lanos, Ph., Karloukovski, V., 2009. Remanence anisotropy effect on the palaeointensity results obtained from various archaeological materials, excluding pottery. *Earth Planets Space*, 61, 711-732.
- Kovacheva, M., Kostadinova-Avramova, M., Jordanova N., Lanos, Ph., Boyadzhiev, Y., 2014. Extended and Revised Archaeomagnetic Database and Secular Variation Curves from Bulgaria for the Last Eight Millennia. *Physics of the Earth and Planetary Interiors*, 23, 79-94.
- Lanos Ph. 2004. Bayesian inference of calibration curves, application to archaeomagnetism (Chapter 3). In Buck C.E., Millard A.R. (eds.) *Tools for Constructing Chronologies, Crossing Disciplinary Boundaries* (Lecture Notes in Statistics, 177), London: Springer, 43-82.
- Leshtakov, K., Todorova, N., Petrova, V., Zlateva-Uzunova, R., Ozbek, O., Popova, Tz., Spassov, N., Iliev N. 2007. Preliminary Report on the Salvage Archaeological Excavations at the Early Neolithic Site Yabalkovo in the Maritsa Valley 2000-2005 Field Seasons. *Anatolica XXXIII*, 185-234.
- Lowrie, W., Fuller, M. 1971. On the alternating field demagnetization characteristics of multidomain thermoremanent magnetization in magnetite. *Journal of Geophysical Research*, 76, No 26, 6339-6349.
- Lowrie, W., 1990. Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. *Geophysical Research Letters*, 17, No 2, 159-162.
- Pavón-Carrasco, F.J., Osete, M.L., Torta, J.M. 2010. Regional modeling of the geomagnetic field in Europe from 6000 to 1000 B.C. *Geochemistry, Geophysics, Geosystems* Vol. 11, No. 11, 11: 20. doi: 10.1029/2010GC00031.
- Prevosti, M., Casas, L., Francesc R.P., Fouzai, B., Álvarez, A., Pitarch, À. 2013. Archaeological and archaeomagnetic dating at a site from the ager Terraconensis (Tarragona, Spain): El Vila-sec Roman pottery. *Journal of Archaeological Science* 41, 856-867.
- Roodenberg, J., Leshtakov, K., Petrova, V. (eds) 2014. *Yabalkovo*, vol 1, Sofia: ATE – Ars et Technica Explicatus.
- Tema, E., Polymeris, G., Morales, J., Goguitchaichvili, A., Tsaknaki, V. 2015. Dating of ancient kilns: A combined archaeomagnetic and thermoluminescence analysis applied to a brick workshop at Kato Achaia, Greece. *Journal of Cultural Heritage* 16, 496-507.
- Thellier, E., Thellier, O. 1959. Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique. *Annales de Geophysique*, 15, 285-376.
- Van Velzen, A. J., Zijderveld, J. D. A. 1992. A method to study alterations of magnetic minerals during thermal demagnetization applied to fine-grained marine marl (Trubi formation, Sicily). *Geophysical Journal International*. 110, 79-90.

Раннонеолитното селище Ябълково (долината на Марица) в контекста на археомагнитно проучване

Мария Костадинова-Аврамова, Мери Ковачева, Нели Йорданова

(резюме)

От североизточния сектор на раннонеолитното селище Ябълково, разположено в долината на р. Марица, са опробвани и археомагнитно изследвани 5 структури от изпечена глина. Направените детайлни магнитно-диагностични лабораторни експерименти показват, че събраните материали са подходящи за получаването на достоверни археомагнитни резултати. Според определените средни стойности за посоката и големината на древното геомагнитно поле, безспорно се разграничават два различни периода, през които изследваните структури са били използвани в древността. Това археомагнитно разграничаване напълно потвърждава (по независим път) предположението на археолозите за стратиграфията на обекта. По техни наблюдения пещта в кв. К36, огнището в кв. F16 и огнището в кв. H31 са свързани с хоризонт II, докато огнището в кв. I31 и огнището в кв. F18 са отнесени към хоризонт I.

Археомагнитното датиране е направено с последната версия на българските реперни криви. Получени са следните датируеми интервали: Ябълково – хоризонт II (5685 – 5489 BC) и Ябълково – хоризонт I – (5472 – 5427 BC). Тези резултати се съгласуват много добре с археологическите сведения, че структурите от хоризонт II предхождат структурите от хоризонт I. Наличните радиовъглеродни дати (от материали взети основно от югозападния сектор на обекта) са значително по-ранни от археомагнитните, но те не могат да разграничат хронологически различните структури. Археомагнитните определения за Ябълково са сравнени с други археомагнитно изследвани раннонеолитни обекти от България и Северна Гърция. В резултат на това може да се предполага, че Ябълково, хоризонт II вероятно е синхронен с по-късните хоризонти на Ковачево (култура Караново I), Стара Загора (култура Караново II) и Добринище. Хоризонт I на Ябълково е хронологически съпоставим (според археомагнитните си характеристики) с хоризонти VII и VIII на Самоводене и Avgi (Северна Гърция).