Prehistorical archaeomagnetic directions from Hungary in comparison with those from south-eastern Europe

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Since the beginning of the modern archaeomagnetic investigations in Hungary in the nineteen seventies, some directional data of various prehistorical ages have also accumulated beside a larger body of the historical results. These are presented here and compared with 1) coeval directional results which are available from south-eastern Europe, as well as 2) the predictions of geomagnetic field directions for Hungary of the global geomagnetic field model, CALS7K.2. The comparison with the south-eastern European data has lead to new archaeomagnetic dates for one of the studied archaeological features which are thought to be an improvement to the presently accepted radiometric dates.
Key words: Archaeomagnetism, geomagnetic secular variation.

1. Introduction

For times prior to the advent of the direct measurements of the geomagnetic field a few centuries ago, the direction and intensity of the geomagnetic field can only be obtained in an indirect way by measuring the remanent magnetism of baked archaeological material, certain sediments and volcanic rocks. Archaeomagnetism studies are concerned with the measurement of the remanent magnetism of baked artifacts from archaeological excavations. Directional studies need undisplaced material, i.e. material which has not moved since the ultimate firing in antiquity. For intensity displaced material is suitable as well. These studies carried out in different regions of the world have led to a large body of directional and intensity data contributing to the GEOMAGIA50 database (Donadini *et al.*, 2006; Korhonen *et al.*, 2008).

Hungary is one of the regions where archaeomagnetic measurements have been pursued (since the beginning of the nineteen seventies), partly for determining the directional secular variation of the regional geomagnetic field, partly for estimating the ages of certain archaeological objects of "unknown" ages, during historical times. All studied objects were the excavated remnants of baked clay features which had not been moved after their ultimate firing in antiquity. At present, we have over 200 historical results of which the majority have been published (Márton and Ferencz, 2006), and a much smaller body of data obtained on prehistorical objects since the beginnings. The latter are presented here in two subsections of which the first comprises the results from a single Late Neolithic locality (Hódmezővásárhely-Gorzsa), and the second from Neolithic to Early Bronze age from various locations (Miscellaneous other localities).

As for the Neolithic, there are quite a number of archaeomagnetic data from south-eastern Europe, chiefly produced by Mary Kovacheva and co-workers (see http://geomagia.ucsd.edu/studies.php) and the data from Hungary offer an interesting comparison on the regional scale. For later prehistorical ages (Late Copper and Early Bronze), the data from the same region are much fewer and the Hungarian data constitute a useful contribution to the regional database. Also, thanks to the availability of CALS7K.2, a recent global geomagnetic field model for the last 7000 years (Korte and Constable, 2005), our data can be placed into a global perspective as well concerning the evolution of the geomagnetic field with time.

The organisation of the subsections is as follows. Short descriptions of the sampling sites/objects are followed by that of the archaeomagnetic procedures applied. The results are presented in tables (Tables 1 and 2) which are commented on and discussed briefly in comparison with the approximately coeval data from south-eastern Europe in a separate section. The sampling localities in Hungary referred to in the paper are shown in Fig. 1.

2. Hódmezővásárhely-Gorzsa

The description of the locality follows the works of Horváth (1982, 1987). Hódmezővásárhely-Gorzsa (Gorzsa for short) is one of the largest tell-like features of the Great Hungarian Plain (tell = mound in Arabic). It is a natural elevation near the confluence of the Tisza and Maros rivers which rises to a height of 4–5 metres above its surroundings and occupies an area of approximately 7 hectares of which hardly more than 2% has been excavated (!). The occupation deposits are of up to 3 metres thick and date back to the Late Neolithic through the Iron ages and the Sarmatian (Late Roman) period. Among these the most significant is the 1.8 to 2 metres thick Late Neolithic settlement layer which has been subdivided, on the basis of changes in the

Table 1. Archaeomagnetic results from Hódmezővásárhely-Gorzsa ($\varphi = 47.0°$N, $\lambda = 20.0°$E).

	Structure	N/N_0	$D° \pm dD°$ $D_c° \pm dD_c°$	$I° \pm dI°$ $I_c° \pm dI_c°$ $I_r° \pm dI_r°$	K	Relative age/ Neolithic horizon- settlement phase/remark	Key ^{14}C ages BC* Archaeomagnetic ages BC
1	Oven floor	9/13	17.2±3.7 17.2±1.8	51.0±2.3 49.9±1.7	500 906	Oldest/ (D-12)	4860* ~4750
2	Oven floor	12/46	10.8±5.2 7.9±4.1	53.6±3.1 52.4±2.5 54.6±1.0	198 306	Oldest (younger)/ (D-10)	~4650–~4600
3	Burnt wall+4 oven floors	5/12	5.4±6.1	54.0±3.6	454	Older middle/ (C-10)	4650* ~4650–~4600
4	Oven floor	7/14	8.7±2.3 6.2±2.3	49.4±1.5 53.4±1.5	1609 1609	Younger/ (C-7)	~4400
5/a	3-layered oven, lowest layer	6/6	10.6±7.8 7.5±6.6	49.3±5.1 49.7±3.4	580 1332	Youngest/ (C-5)	
5/b	Middle layer	1/1	5.3 1.6	46.4 48.5		Youngest/ (C-4)	
5/c	Upper layer	3/6	13.1±5.0 7.4±5.0	40.9±3.8 49.2±3.9	1034 1025	Youngest/ (C-3)	
5	All 3 layers	7/13	11.0±5.6 6.7±2.8	45.3±3.9 49.4±1.8	238 1135	Youngest/ (C-5)–(C-3)	 ~4300
6/a	4-layered oven, lowermost layer	4/8				Youngest/ (C-7)/ No result	
6/b	Lower middle layer	8/14	11.0±6.9 3.2±4.9	42.5±5.1 49.5±3.2	118 305	Youngest/ (C-4)	
6/c	Upper middle layer	8/14	14.9±6.4 0.7±5.2	44.4±4.6 51.9±3.2	148 298	Youngest/ (C-3)	
6/d	Uppermost layer	3/5				Youngest/ (C-A) (?)/ No result	
6	2 middle layers together	16/28	12.9±4.4 2.0±3.4	43.5±3.2 50.7±2.2	132 292	Youngest/ (C-4)–(C-3)	4490* ~4300

Legend: $\varphi°$, $\lambda°$: approximate geographic latitude and longitude of sampling site; N/N_0: number of useful samples/specimens; $D° \pm dD°$: declination of the mean archaeomagnetic direction and its semi-angle of 95% confidence; $D_c° \pm dD_c°$: same after tilt correction; $I° \pm dI°$: inclination of the mean archaeomagnetic direction and its semi-angle of 95% confidence, $I_c° \pm dI_c°$: same after tilt correction; $I_r° \pm dI_r°$: same after tilt and refraction correction (Márton, 1989); K: precision of mean archaeomagnetic direction; Neolithic horizon and settlement phase are according to Horváth (1987) and Horváth (1988); Key ^{14}C ages are according to Hertelendi and Horváth (1992) and Hertelendi *et al.* (1995). Archaeomagnetic ages: this paper.

occupation patterns and the find material, into four phases as follows. Phase A is the uppermost (1st Neolithic level), overlying C which is the main phase (3rd to 10th levels) and D is the lowermost (11th to 16th levels) phase. Phase B (2nd level) is represented by graves dug in C.

According to traditional, comparative chronology, the Late Neolithic settlement at Gorzsa had been dated to the final phase of the early Tisza period, which corresponds to the B_2-C_1 transition of the Vinča culture to the South, the beginning of the Lengyel culture in Transdanubia and that of the Herpály culture in the northern part of the Great Hungarian Plain (Fig. 1). The settlement survived into the Vinča D_1 period which corresponds in the Tisza region to the final phase of the Tisza culture and the Proto-Tiszapolgár period.

On the radiocarbon chronology of the Late Neolithic settlements in the Tisza-Maros region established by Hertelendi and Horváth (1992), Gorzsa and Csőszhalom are placed between 6050 BP and 5450 BP (4860–4270 cal BC), i.e. covering the final phase of the Tisza culture between 6050 BP and 5570 BP (4860–4490 cal BC) and the Proto-Tiszapolgár period between 5570 BP and 5450 BP (4570–4270 cal BC) (Hertelendi *et al.*, 1998). For the regional chronologies of the Neolithic cultures in Hungary and their relationships see the paper of Hertelendi *et al.* (1998), and Hertelendi and Horváth (1992) for the correlations between the Hungarian and South-East European Neolithic cultures.

Undisplaced ("in situ") structures made available for archaeomagnetic sampling (courtesy F. Horváth) were excavated from the D and C-(A?) phases (cf. Table 1) in 1980, 1987 and 1988.

In 1980, the sampling was made only to check the suitability of the then available remnants for archaeomagnetism studies. Thus, 7 independently oriented samples were taken from 6 different remnants from level C-10. From the 5 useful samples, one represented a burnt wall and the others were floor samples from three ovens.

Table 2. Archaeomagnetic directions from miscellaneous prehistorical sites in Hungary.

	Locality (φ°N, λ°E)	Sampled structure	Archaeo-logical age	N/N_0	$D^\circ \pm dD^\circ$ $D^\circ_c \pm dD^\circ_c$	$I^\circ \pm dI^\circ$ $I^\circ_c \pm dI^\circ_c$	K	Cleaning/ remark
1	Óbuda-Ürömi út (47.5, 19.1)	Oven, wall	Early Neolithic (∼5500 BC)	10/10	−10.3±10.2	69.9±3.5	192	AF
2	Győr-Ménfőcsanak (47.7, 17.7)	Oven, floor	Early Neolithic	8/11 8/10	7.6±6.8 7.7±7.6	63.0±3.1 60.9±3.7	317 221	TH (130–250)°C (250–520)°C
3	Mezőkeresztes (47.8, 20.7)	Oven, floor	Late Copper (∼2000 BC)	5/10	−3.4±6.2 −1.8±6.2	64.0±2.7 67.6±2.7	675	AF and TH/ (2 sets of measurement)
4	Kiszombor (46.2, 20.4)	Oven, floor	Bronze (∼1900 BC)	12/12	−0.7±5.0 1.4±5.0	60.1±2.5 61.4±2.4	292 333	AF
5	Százhalombatta (47.3, 18.9)	Unidentified burnt object, rim	Bronze (∼1800 BC)	7/8	−21.2±5.1	63.3±2.3	666	TH
6	Százhalombatta (as above)	Oven, floor fragment	Bronze (∼1500 BC)	2/9	8.2	65.3		TH/ See text
7	Mezőkeresztes (as above)	Cylindrical “cauldron”, wall	Uncertain (Sarmatian?)	6/15	−4.4±7.1	69.3±2.5	705	AF and TH/ (2 sets of measurement)
8	Mezőkeresztes (as above)	Cylindrical “cauldron”, wall	Uncertain (Sarmatian?)	4/12	−12.8±22.2	64.9±9.4	68 (!)	AF and TH/ (2 sets of measurement)

Legend: φ°, λ°: approximate geographic latitude and longitude of sampling site. Cleaning: AF: Alternating field demagnetisation, TH: Thermal demagnetisation. Other symbols are as in Table 1.

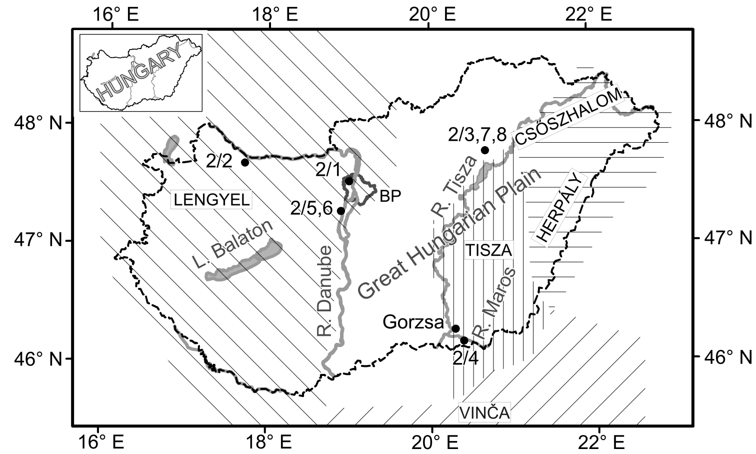

Fig. 1. Locality map of the sampling sites in Hungary with other relevant information. Legend: BP stands for Budapest. Hachured areas show the distribution of Late Neolithic cultures (Lengyel, Vinča, Tisza, Herpály and Csőszhalom) mentioned in the text. Dots are the locations of the sampling localities. Hódmezővásárhely-Gorzsa is marked as Gorzsa and the others are numbered as in Table 2, i.e. 2/1–2/8.

In 1987, the floors of two big ovens were sampled from levels D-10 and 12. The older of the two had a thin (∼1 cm) tessellated floor, so that the magnetometric specimens were prepared by gluing 2 sisters from the same sample together. The younger oven had a 10 cm thick, hard floor with widely varying remanence which enabled an analysis to be made of the relationship between the magnetic inclination and intensity (Márton, 1989).

Collection of samples at Gorzsa was completed in 1988 by sampling the floor remnants of 3 ovens from the youngest levels. The floor from C-7 consisted of a single burnt layer, while the floors of the younger ovens comprised 3 and 4 layers from C-3–5 and C-7–A?), respectively.

In the field, hand samples (“blocks”) were taken after orientation usually both by sun and magnetic compasses. Then the blocks were cut into small cubic specimens (2×2×2 cm) for magnetometric measurements retaining the orientation. The magnetic measurements were carried out on these specimens with a Jr-4 (Jelinek) magnetometer. For magnetic cleaning a Schonstedt TSD-1 thermal demagnetiser was used and the resulting demagnetisation (Zijderveld-) curves were processed for the “primary” magnetic data by searching for linear segments using a statistically based algorithm of Kent *et al.* (1983). Computations of the mean archaeomagnetic directions and statistical parameters were based on the number of the independently

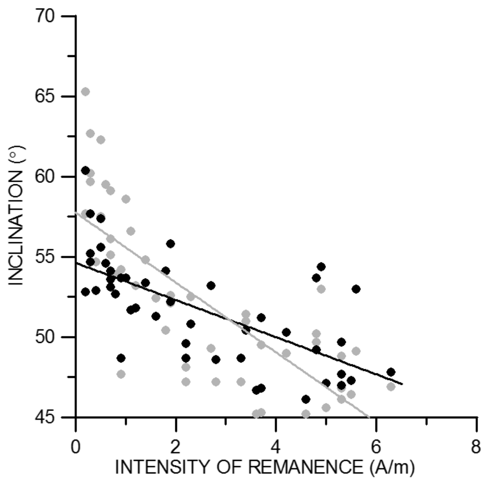

Fig. 2. Inclination vs. remanence intensity after thermal demagnetisation at 460°C. Entry 2 in Table 1. Legend: Grey: inclinations before tilt correction (dots) with straight line fit; Black: inclinations after tilt correction (dots) with straight line fit. The black regression line intersects the inclination axis at 54.6°.

oriented samples according to Fisher (1953).

Allowance for the differences in tilt of the floor samples within one structure were made by tilt correction only if the precision of the mean direction improved after the correction or when the overall tilt of the floor was judged to have taken place after use.

Table 1 contains all archaeomagnetic directional results obtained for the Gorzsa locality from the beginning to the end of the archaeomagnetic campaign. Stratigraphic information and key radiometric ages are from Horváth (1988). For each entry the final archaeomagnetic direction is the (tilt) corrected one except the third where no correction was deemed necessary.

Commenting on the results in Table 1, first it is noted that in general the inclinations are unusually small for the site latitude (the geocentric axial dipole value is 64.5°), despite the tilt corrections which have increased their values significantly for the structures of the lowest inclinations (4, 5b, 5c, 6b and 6c). Given that all structures sampled at Gorzsa were burnt layers (oven floors) the underlying effect of the inclination shallowing might be thought to have been caused by magnetic refraction of which the presence had already been demonstrated in the case of one oven floor (Table 1, entry 2) by Márton (1989) as follows. The specimens cut from this structure exhibited a wide variation of magnetic intensity and a noisy (linear) relationship was indicated between intensity and inclination, i.e. in general, the inclination increased with the decrease of the intensity giving an inclination of 54.6° at zero intensity after tilt correction (Fig. 2). This value is only 2.2° steeper than the corresponding average (52.4°) but is better constrained statistically (Table 1, entry 2). However, the intensity and its variation were sufficient in none of the other sample groups for the effect of the intensity dependent refraction to be recognized. Thus, in the following all results in Table 1 will be considered as the archaeomagnetic reproductions of the directions of the local geomagnetic field at the time of the last firing of the respective objects in antiquity.

3. Miscellaneous Other Localities

At some earlier excavations of historical sites remnants of older structures had also been found and some of them were sampled and measured but the results have never been published. The structures made available for sampling were excavated by I. Poroszlai at Százhalombatta in 1990 and 1991, A. Figler at Győr-Ménfőcsanak in 1991, M. Wolf at Mezőkeresztes in 1994 and Z. Kárpáti at Óbuda-Ürömi út, respectively B. Kürti at Kiszombor in 2000. The age estimates were provided by the excavating archaeologists and are based on archaeological evidences. The descriptions of the sites/sampled objects are inevitably short as most of them came to light as secondary material not associated with the main objects for which the excavation was planned to be carried out. The samples were treated magnetically as outlined in the preceding section, except that some sample groups were treated by AF demagnetisation alone (using a Schonstedt GSD-1 demagnetiser) or both by AF and thermal demagnetisations as will be described below.

3.1 Óbuda-Ürömi út (∼5500 BC)

The remnant of this cylindrically shaped oven with a mantle was sampled using the upper 10 cm of the hard-baked wall. The 10 samples collected were azimuthally distributed between 143 and 328 degrees. The mean direction of magnetisation was computed after AF- cleaning. No relationship was detected between remanence direction and wall azimuth.

3.2 Győr-Ménfőcsanak (Early Neolithic)

This domestic oven had a baked floor and a mantle as well. Both were sampled, and after elimination of a low temperature (<250°C) partial TRM, the primary magnetisation direction was defined as that of the high temperature component removed between 250 (300)°C and 520°C. Statistically, however, the primary and the overprinting remanences are of the same direction.

3.3 Mezőkeresztes (∼2000 BC)

The sampled feature was the remnant of a baked layer, probably an oven floor. Five handsamples could be taken. Each sample was cut into two from which one was treated by AF-, another by thermal demagnetisation. Both treatments gave statistically identical results, so the final mean direction of magnetisation was computed by combining them into one. Allowance for the tilt of the feature as a whole was preferred because it resulted in a little better statistics (though the same mean direction) than the correction using the samples' individual tilts.

3.4 Kiszombor (∼1900 BC)

Part of the floor of this domestic oven was tilted relative to the major "in situ" segment. Both areas were sampled and after treatment by AF demagnetisation the mean direction of magnetisation was computed from the linear segments of the demagnetisation curves between 13 (20) mT and 55 mT before and after tilt correction as well.

3.5 Százhalombatta (∼1800 BC)

The sampled feature was the remnant of a cast bronze mould of which only the samples from the hard-baked rim lent themselves for magnetic treatment. All these samples possessed a stable, single component remanence which was isolated after cleaning at 150°C.

3.6 Százhalombatta (∼1500 BC)

At this excavation, a small hard-baked patch surrounded by burnt earth was recognized as part of an oven floor. 2 + 3 handsamples could be taken, subsampled and measured. On measurement only the 2 samples (7, respectively 2 subsamples) from the hard part gave coherent results. After the removal of a low temperature partial TRM by thermal demagnetisation, the mean direction computed as the average of 7 plus 2 tightly grouping directions was $D = 8.2°$, $I = 65.3°$ ($K = 944$, $\alpha_{95} = 1.7°$).

3.7 Mezőkeresztes (uncertain, Sarmatian?)

During this excavation, several baked (burnt) features of upright cylindrical shape came to light. They were about half a metre both in diameter and depth without a burnt floor. (Both their function and age are uncertain. The latter may not even be prehistorical. In fact, the quoted Sarmatian(?) merely refers to the ancient inhabitants who lived in the region between the Danube and Tisza rivers during Roman times.) Two of such remnants were sampled taking handsamples around the circumference of the upper rims. Two series of magnetic measurement were carried out one with AF, another with thermal demagnetisation giving statistically identical mean directions after sufficient cleaning. The end results were obtained by combining the two into one for each of the two features.

All data relevant to the above described localities are presented in Table 2. The final archaeomagnetic results (the uncorrected ones for entries 1, 2 and 5–7, and the tilt-corrected ones for entries 3 and 4) are assumed to represent local geomagnetic field directions at the times indicated.

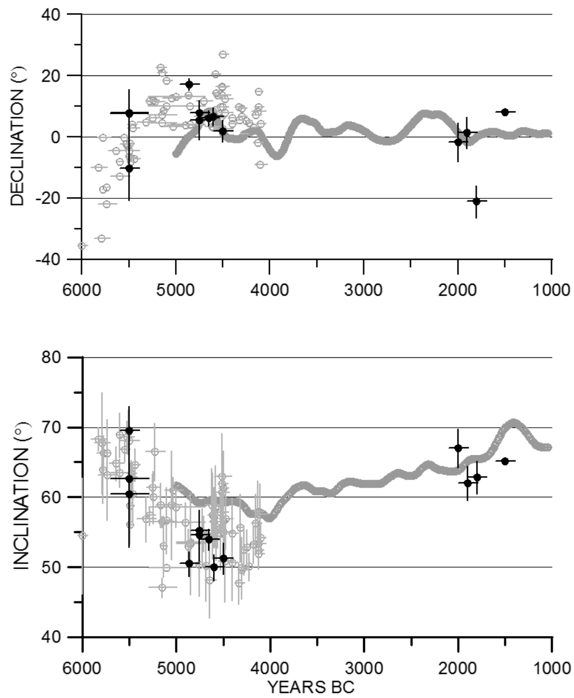

Fig. 3. Archaeomagnetic directional data from Hungary in comparison with those from south-eastern Europe (40°N ≤ φ ≤ 50°N, 15°E ≤ λ ≤ 30°E) transferred to Hungary (φ = 47.0°N, λ = 20.0°E) for the Neolithic and some later prehistorical ages (Late Copper and Early Bronze), as well as a continuous directional secular variation curve for Hungary from 5000 BC to 1000 BC as predicted by CALS7K.2. Legend: Black dots with error bars: present results from Hungary; Small grey dots with error bars: results from south-eastern Europe; Grey curve: model secular variation for Hungary from CALS7K.2. Upper figure: declination data; Lower figure: inclination data.

4. Discussion

The results in Tables 1 and 2 are displayed in Fig. 3. The grey background of this figure comprises the archaeomagnetic directional data of the GEOMAGIA50 database from south-eastern Europe (40°N ≤ φ ≤ 50°N, 15°E ≤ λ ≤ 30°E) transferred via their respective VGPs to Hungary (φ = 47.0°N, λ = 20.0°E) for the Neolithic and some later prehistorical ages (Late Copper and Early Bronze), as well as a continuous directional secular variation curve for Hungary from 5000 BC to 1000 BC as predicted by CALS7K.2 for comparison. The agreement between all declinations (except one) displayed is excellent but, in general, the inclinations in south-eastern Europe (including Hungary) are a few degrees shallower for the entire period of time for which predictions exist. Thus, concerning the evolution of the geomagnetic field with time this inclination "anomaly" over south-eastern Europe could have been a longstanding feature unless it (or at least part of it) is the result of a general shallowing of inclination not uncommon in archaeomagnetic material.

Whatever the case may be, the archaeomagnetic directional data from Hungary are directly comparable with those from south-eastern Europe and in order to better see the evolution of inclination with time we have produced a model curve of directional secular variation for Hungary from the south-eastern European directional results between 5800 BC and 4100 BC. The model reproduced in Fig. 4 consists of the directional averages over 100 year wide windows (with 50% overlaps) of the relocated directional data from south-eastern Europe (grey in Fig. 3). Figure 4 also contains the cubic regressions of the directional elements which emphasize the smooth variation of declination and the oscillatory character of inclination, both with time. On the whole, our results for the Neolithic agree with this picture but those for Gorzsa need some more consideration.

In our interpretation, the differences shown between the oldest (Table 1, entry 1) and "medium old" (Table 1, entries 2, 3 and 4) archaeomagnetic directions, as well as those between the medium old and the youngest ones (Table 1, entries 5 and 6) are manifestations of the secular variation of the local geomagnetic field. The change of inclination with time from low to higher and to low again, however, is in disagreement with that of the model of Fig. 4, at least within the time span limited with the radiometric ages of Table 1 (i.e. 4860 BC–4490 BC). But considering that these ages had not been measured directly, but merely assigned to the respective archaeological objects on stratigraphical grounds we may use the model curves of Fig. 4 to find the right ages, i.e. to date the archaeomagnetically studied objects directly by archaeomagnetic means. This would result in younger ages in general but still within the time span of the Gorzsa "culture" (see above). Particularly, the age of the oldest object should be shifted to about 4750 BC, the two youngest to about 4300 BC, whilst two of the medium old objects could be dated between 4650 BC and 4600 BC and the third

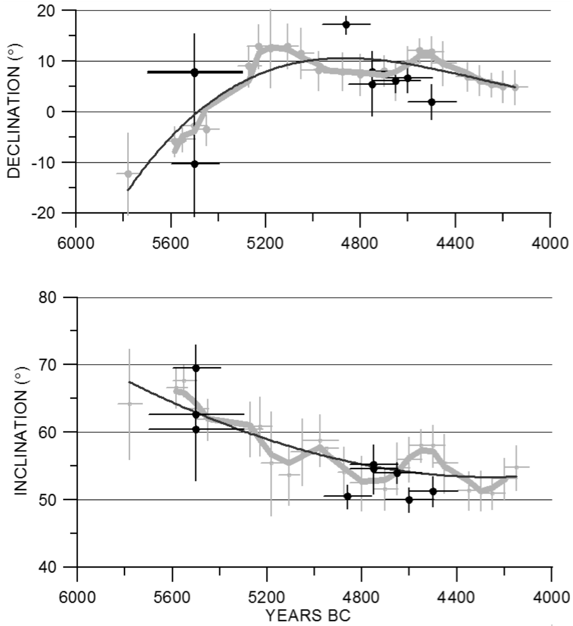

Fig. 4. Late Neolithic archaeomagnetic results for Hungary (same as in Fig. 3) and the secular variations of the archaeomagnetic declination and inclination for Hungary during the Late Neolithic as derived from the archaeomagnetic results from south-eastern Europe (see text). Legend: Black dots with error bars: present results from Hungary at ($\varphi = 47.0°$N, $\lambda = 20.0°$E); Grey dots with error bars: 100 year averages of south-eastern European data; Thick grey line: the secular variation curve; Thin black line: cubic polynomial fit to the secular variation; Upper figure: declination variation; Lower figure: inclination variation.

to 4400 BC (Fig. 4 and Table 1). Thus, the archaeomagnetic ages for Neolithic Gorzsa would cover a longer period of time than the radiometric ages imply and would extend upwards into the period of the Proto-Tiszapolgár culture in accordance with the archaeological observations.

5. Concluding Remarks

The archaeomagnetic directional results reported here constitute a new contribution to the south-eastern European as well as the global dataset hitherto collected together in the GEOMAGIA50 database. They are in general agreement with the regional data, so that the latter can be employed to directly date by archaeomagnetic means certain archaeological objects with stratigraphically assigned radiometric ages as exemplified by the dating of the objects of Neolithic Gorzsa which were studied archaeomagnetically.

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